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Healthy Building: An Energy Efficient Air Conditioned Office With Good Indoor Air Quality.

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Healthy Building: An energy efficient air conditioned office with good indoor air quality.

Synopsis

The NORWEB Headquarters in Manchester, UK, is an air conditioned energy efficient office building of unusual design, completed in 1988. It has three stories with overhanging canopies providing solar shading and 21% solar control glazing. The open plan interior is ventilated by a displacement system with three twist outlets in the floor to each desk position.

A detailed questionnaire survey showed this to be one of the 'healthiest' buildings tested so far, with a very low 'building sickness symptom score'.

Air temperature, humidity, air speed, fresh air, noise, dust and lighting were monitored and found to lie within accepted guidelines. Fine dust levels were lower than outside.

Energy costs monitored over three years proved to be low for a building of this type.

The achievement of good indoor air quality combined with energy efficiency is attributed to good passive design features, the displacement ventilation system, a limited smoking policy and active participation of the end user at all stages of the design, construction and management of the building.

1 Introduction

1.1 Building design

The NORWEB Headquarters in Manchester is a purpose built office building which was completed in 1988. The plan, Figure 1, comprises a central core with two wings per floor which are mainly open plan. The three floors progressively decrease in area providing balconies and walkways which give solar shading, access for maintenance and a striking external appearance.

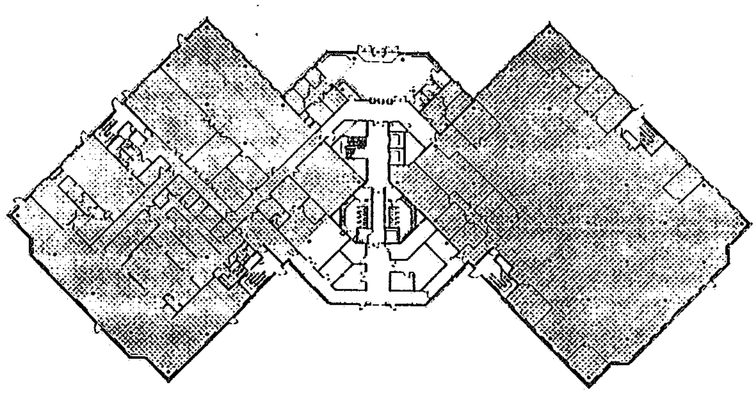

Figure 1 Norweb HQ floor plan.

The design brief was for an all electric building which would provide the best possible working conditions combined with operational flexibility, ease of maintenance and energy efficiency. The plan had to accommodate present and future information technology requirements

The original brief also included an instruction to include energy conservation features which had a payback period of three years or less.

1.2 Passive design features

The main structure is of reinforced concrete providing a long thermal time constant. 21% of the wall area is glazed with solar control double glazing (U-value 1.6 W/m^2K). This moderate window area provides a useful degree of contact with the outside without causing problems for the heating and ventilating system. Solar shading is provided by overhanging canopies to all floors, while balconies provide access for maintenance, as shown in Figure 2.

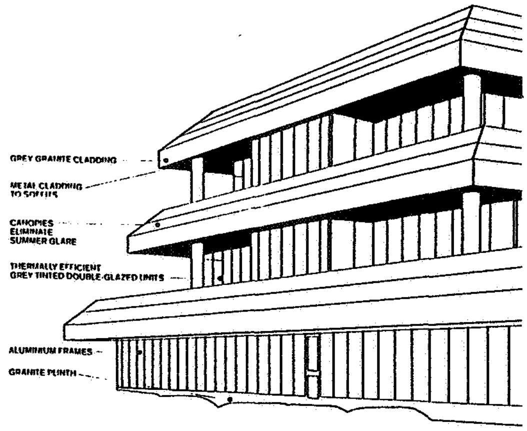

Figure2 Overhanging canopies and balconies.

1.3 Thermal Performance

Walls, floor and roof are insulated to U-values of 0.48, 0.12, and 0.28 W/m^2 K respectively. The design day (-4 C) heat loss is 443 kW equivalent to 45.5 Watts/square metre of floor area.

The number of occupants is 540, equivalent to a thermal contribution of about 65 kW. The net usable space allocation overall is about 9.75 square metres per person and in the open plan areas the space per person, is about 6.5 square metres.

2. Heating and ventilating system

2.1 Air conditioning

The open plan areas are provided with air at a fixed flow rate. Nominally 25% of this is fresh outside air, the rest being recycled. The total air flow rate is nominally 8 air changes/hour. Tracer decay tests showed that the actual fresh air ventilation rate in the open plan areas was 1 air change/ hour. This is equivalent to 10-14 litre/second per person, which is generous compared to the CIBSE and ASHRAE guidelines of 8-10 litres/second per person.

Exhaust air passes through heat recovery coils with heat pumps transferring heat to the low pressure hot water system as preheat for the building hot water services. The chillers for the air conditioning plant reject heat which cannot be used for heating other parts of the building to an open cooling tower on the roof. To reduce running costs, the chilled water temperature is controlled between 10 and 20°C depending on the cooling load requirements.

2.2 Heating

The heating system consists of two water to water heat pumps each electrically loaded at 135 kW, incorporating double bundle condensers. Heat is extracted from the cooling coils within each extract plant in sequence.

Heat to the main heater batteries and volume control box reheat coils is supplied in sequence from the heating condenser and hot water storage vessels with a total stored volume of 35000 litres at a temperature of 135 C. The two megatherm boilers, each rated at 234 kW, are supplied with night electricity using the cheapest 14 half hour periods between 2200 and 0630 daily.

2.3 Air distribution

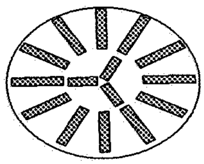

Figure 3 Twist outlet.

The air is supplied via an under floor plenum to 'twist' outlet grilles Figure 3, nominally three per desk which provide a rapidly decaying spiral of air at low speed . The air speed in the vicinity of the grilles has dropped to the low ambient level of 0.1 m/s within a radius of 0.25m and a height of 0.6m. Air return is through the light fittings.

The underfloor plenum also acts as an easily accessible services distribution duct; the floor is in easily removable sections 600x600mm. This also makes it easy to reposition the twist outlets when desks have been moved.

With cool air being supplied at low speed at floor level, and ceiling extract, the system acts in a displacement ventilation mode.

2.4 Control system

Each open plan office area is controlled in 2 central zones (east and west) plus a perimeter, and control is by two averaging thermostats operating the individual heater or cooler batteries. Overall control is through a computer energy management system which monitors and controls all the main plant, flow and return temperatures. The plant is switched off, to minimise energy usage, when:

(a) the building is unoccupied,
or (b) when predetermined conditions are reached.

The preheat/building response time is automatically adjusted by optimisers in the energy management system. The longest pre-heat period occurred in the worst of the four winters, on a Monday morning after being switched off all weekend, when the system switched on at 0100 for an 0800 occupancy.

3 Lighting

3.1 Design

In general, the lighting installation in the offices was designed to use fluorescent luminaires of the air handling type incorporating high frequency low-loss electronic ballast equipment, and low brightness diffusers complying with TM6, the CIBSE Lighting Guide for Visual Display Units (now LG3).

The design encompassed the three main human working requirements of comfort, satisfaction and performance. The office complex supports a diverse operation including all aspects of office work such as reading/writing reports, drawing office, transferring information from documents at computer terminals, full time word processing at VDU screens, desk top publishing, electricity utilisation/environmental design work and planning the electricity supply network.

Task lighting is supplied where needed.

3.2 Operation

The lighting load is 136 kW, i.e 14 Watts/square metre, with 7 kW of emergency lighting. Control is by localised manual switching and also by the computer energy management system.

The illumination levels in the office areas are between 500 and 600 lux at desk level with a mean of 525 lux and a standard deviation of 100 lux. Subjectively, a questionnaire survey showed that over 90% of all the office staff were satisfied with their lighting scheme.

4 Water heating

Hot water to the kitchen and toilets is heated electrically by day and night (cheap rate) immersion heaters, after the cold water feed has been pre-heated by a loop off the low pressure hot water heat recovery coils.

5 Environmental assessment

5.1 Subjective survey

A self completion questionnaire survey of the occupants was carried out in two open plan wings of the building . The questionnaire was one developed for studies in offices by Building Use Studies Ltd, who also carried out the survey for EA Technology. The questions covered type of work, smoking habits, VDU usage, environmental comfort, and the various symptoms which have come to be associated with sick building syndrome. 166 questionnaires were distributed and 147 returned.

Respondents were presented with a list of eight symptoms associated with Sick Building Syndrome; the most common symptom experienced was lethargy, followed in turn by headache, stuffy nose, dry throat, dry eyes, itching eyes, flu-like symptoms and runny nose. A symptom was counted if experienced on more than two occasions in the past year and improved on leaving the building. The 'building sickness score' is the average number of symptoms per person, i.e. the lower the score the 'healthier' the building. A survey [1] of over 4000 workers in 47 buildings carried out on 1985/86 found building sickness scores between 1.25 and 5.25 depending mainly on the type of building; mean values were as follows:

2.18 in mechanically ventilated buildings
2.49 in naturally ventilated buildings
3.41 in centrally air conditioned
3.81 in those with local air conditioning.

The building sickness score for this building was 1.68 making it the best air conditioned building found by ourselves so far. 38% of the sample reported no symptoms at all; in common with other buildings those who did suffer did so frequently, on most days

The most common response on environmental comfort factors (i.e. thermal comfort, ventilation, noise and lighting) was the neutral point of a seven point scale, except for noise. Most people found the conditions satisfactory:

%	1 2 3 satisfsactory	4 neutral	5 6 7 unsatisfactory
thermal comfort	56	31	13
ventilation	49	31	20
noise level	40	24	36
lighting	53	31	16

Satisfaction with the noise level was lower than for other comfort factors and, in reply to a supplementary question, 56% of respondents judged the noise level to be loud and intrusive.

Two thirds of the sample were to some degree dissatisfied with the privacy at their desks, most people felt that they had little or no control over their environmental conditions and found their job fairly stressful. These factors did not relate to number of symptoms reported.

The number of symptoms was significantly related to dissatisfaction with environmental comfort factors. Women clerical workers experienced more symptoms than other categories of workers.

The sample consisted of mainly professional males (47%) and clerical females(25%) with 59% of them under 40 years old. Only 13% were current smokers, compared with 22% in the Office Environment Survey. The office has a no-smoking policy at desks so that there is virtually no passive smoking in the building. Most people use a VDU regularly, but usually less than 3 hours per day.

5.2 Physical survey

A measurement survey of environmental factors was carried out at the same time as the subjective survey.

Air temperature was found to be very uniform in space and time. During a week in September, when the outside temperature was 12 C, the temperature at sitting head height (1.2m) was 23$\pm$0.5 C falling to 22 C over the weekend and rising to 24 C on some afternoons. Ankle temperatures were generally 0.5 C cooler; ceiling temperatures up to 1 C warmer. Relative humidity was 50$\pm$5%.

Air speeds were generally about 0.1m/s, and always less than 0.2m/s.

At the occupancy found during the survey (carried out on a normal working day in september), the fresh air rate as measured by tracer decay was of the order 14 l/s per person. This generous fresh air rate was reflected in the relatively low carbon dioxide concentration, which showed a peak of 560 ppm mid-morning and mid-afternoon.

The equivalent continuous sound level Leq was nearly 60 dBA which would generally be considered too noisy for sedentary workers. The CIBSE Guide [2] recommends NR45 (eqivalent to about 51dBA) for a landscaped office.

The indoor dust level in the particle size range 0.25 to 8 microns was less than outside, particularly in the range 1 to 2 microns where the ratio of indoor to outdoor dust was 1:20. However the dust level for particles larger than 8 microns was greater than outside.

5.3 Microbiological survey

Samples of water were taken from the mains tap in the kitchen, cold water storage tanks, humidifiers, calorifiers, cooling tower distribution troughs. All systems were free of legionellae. All water systems were found to be in excellent condition and very clean, although the bacteria counts in the calorifiers and cooling towers were higher than elsewhere.

Air sampling inside the building showed a yeast and mould count lower than outside.

6 Energy analysis

The building is all-electric with a sub-station on site serving two 800kVA transformers. The high voltage input is metered, with low voltage submetering on each transformer, chiller and megatherm boiler, and also the plant room, sports/social club and kitchen. Lighting and general power are deduced as the difference between total and submetered loads.

The monthly energy consumption has been monitored over the three years since the building was commissioned. The sports and social club is in a separate building and the kitchen is excluded as not being part of the office for the purpose of this paper.

To allow for different month lengths, and variations in date of meter readings, the monthly kWh figures have been converted into daily mean power data in Watts/m^2 by dividing by (number of days x 24 x floor area). Figure 4 shows the itemised figures together with the appropriate monthly degree day data to base 15.5 C for Manchester.

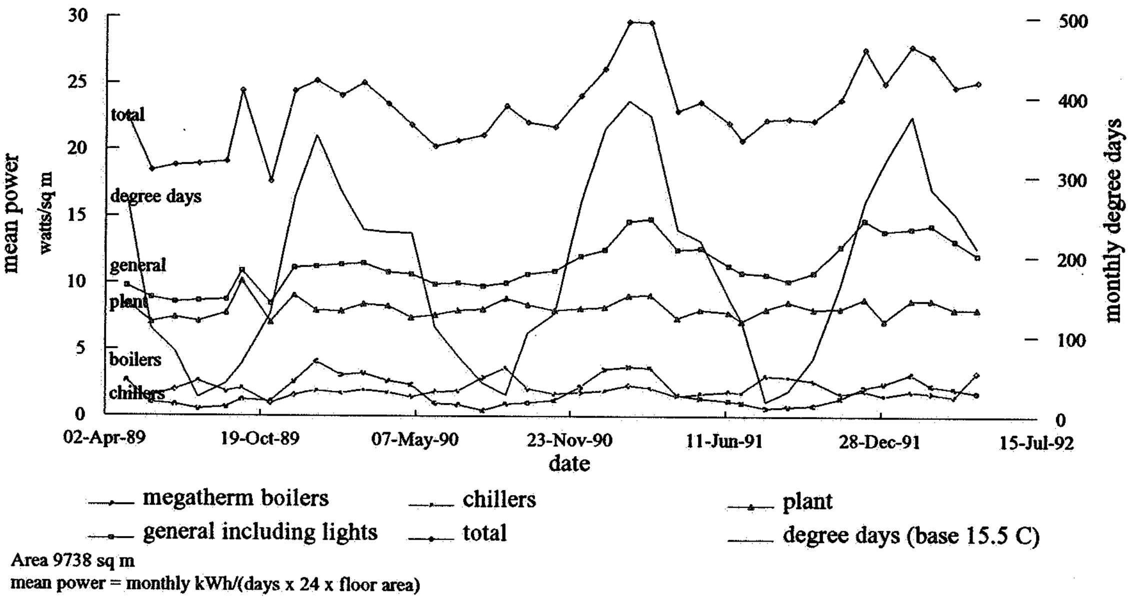

Figure 4 Monthly mean power data

The corresponding annual (1st April to 31st March) energy consumptions in kWh/m2 are:

year	boilers	chillers	plant	general and lighting	total energy	corrected total energy
1989/90	17.1	15.7	69.7	86.9	189.4	**172**
1990/91	16.3	18.3	71.4	100.6	206.6	**188**
1991/92	14.2	17.7	71.1	109.3	212.3	**193**

For comparison with other offices, allowance must be made for the length of the working day. Since moving into this new building, owing to changes brought about by privatisation of the Electricity Supply Industry in the UK, staff office hours have been longer than normal office hours and the building has been in use for 12 to 14 hours per day (for 5 days pr week) rather than the usual commercial working day of 10 hours. A factor of 1.1 has been applied to the energy figures to allow for this. The degree days for the three yearly periods are 2089, 2044 and 2045 respectively.

Figures collected by the UK Energy Efficiency Office [3] show that energy consumption in offices varies from 100 to 1000 kWh per year per square metre of treated floor area. A typical prestige 'good practice' air conditioned office runs at about 400 kWh/m^2. The figures for the Norweb office are seen to be about half this value.

7 Indoor air quality and energy efficiency

By all the normal measures of indoor air quality, and by subjective assessment the environment inside this air conditioned building , the conditions are very acceptable. The general impression of a comfortable pleasant office is reflected in the low incidence of 'building sickness' symptoms. If there were any complaints it was that it was sometimes slightly too warm, dry rather than humid and perhaps somewhat noisy. However the majority were comfortable. The no-smoking policy assists in achieving good indoor air quality.

Energy efficiency has been achieved by attention to detail at all stages of the design construction and operation. The occupiers were intimately involved throughout. Passive design features are mainly modest glazing and solar shading. Aesthetically the building is interesting both inside and out. Design decisions which contribute to the success are the underfloor plenum and associated displacement ventilation system; this provides efficient ventilation and a services duct which is easily accessible. The building and its systems are well managed by staff who understand them.

8 Conclusions

In a deep plan air conditioned office it is possible to achieve good indoor air quality and energy efficiency. Approriate design decisions for the building shell (glazing and shading) plus wise choice of heating and ventilating plant (displacement ventilation) combined with good management, and involvement of the end users at all stages of the project explain the success of this building.

9 References

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2. CIBSE Guide Volume A. The Chartered Institution of Building Service Engineers.

3 Energy Efficiency Office (UK). Energy consumption guide 19:
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