ELECTRICITY COUNCIL RESEARCH

AN INVESTIGATION INTO THE AIR QUALITY OF THREE WORKING MEN'S CLUBS

by

G. W. Brundrett and R. Barker

SUMMARY

Packaged air conditioning is being introduced into Working Men's Clubs to provide air recirculation and cleaning when the buildings are occupied. Air cooling and dehumidification is also available. In general this innovation is welcomed by club members but one particular club, designated club A, was dissatisfied. The actual installation was apparently similar to the successful clubs and therefore an investigation was started to identify the difference. Measurements showed that the unsatisfactory installation was unusual in two ways. First the fresh air supply rate was lower than design due to the airtightness of the building and the number of air-locks to the outside. Second the cigarette consumption was particularly high. These two factors reinforced each other to create an undesirable atmosphere.

August, 1977.

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1. BACKGROUND

Working Men's Clubs are commercially thriving organisations catering for a wide range of social activities. The tend to be large in size, holding 300-400 people in a single room and particularly active with family parties in the evening. Smoking is permitted. Traditionally such places are heated and ventilated in a simple way. An air conditioning firm, E.L. Etherington, is improving the indoor climate in such clubs by providing electrostatic precipitators and cooling and together with a reduction in excess ventilation. Etheringtons manufacture a wall mounted air conditioner with remote condenser to meet this need. This unit, based on conventional proprietary components, recycles the room air over an electrostatic precipitator and a cooling coil and can also introduce a proportion of fresh air if needed. Table 1, Figure 1.

At least four clubs have these units in one area. The first at Club B was highly successful but the last at Club A had resulted in complaints from the users, complaints of smell and running eyes. ECRC were invited to trace the origin of the dissatisfaction and identify solutions.

This note describes the investigation.

2. PROCEDURE

Since the air conditioners had success in some clubs but not others, the procedure was to concentrate attention on the worst club Club A and also undertake spot checks in two other clubs at Club C and Club B. This was done during Saturday night the 5th March, 1977.

The main gas samples at Club A were collected over the evening and stored for laboratory analysis. Spot checks at each building included carbon dioxide concentration, dry bulb temperature and humidity.

50 were dancing.

All four units were switched on 'fan only' all evening.

(b) Club B

This club held its normal maximum of about 220 people at 9.0 p.m. Spot checks showed the indoor conditions to be 22.5^{o}C at 44% relative humidity. The carbon dioxide level was 0.32% by volume. The evening was much more of a dance than the concert at Club A. About a third of the floor area was cleared of tables and chairs and some 50 people were actively dancing. There was a higher proportion of younger people here than at Club A, though this may simply be due to the 21st celebrations in progress which may not be typical. The atmosphere was pleasant and there was a distinct air movement out of the room through the bar servery area. Cigarette consumption for the evening was 868.

The two conditioning units with fresh air supply were switched to 'fan only'. The other two were operating in their cooling mode.

(c) Club C

At 9.40 p.m. the club contained approximately 375 people, compared with a normal maximum of 450. Spot checks showed the temperature to be 25^{o}C at 45% relative humidity. The carbon dioxide level was also high at 0.35% by volume. The musical concert was in progress with about ten people dancing in a small cleared space. Our eyes smarted slightly during the measurements.

The four air conditioners were in operation on 'fan only'.

4. ANALYSIS OF RESULTS

(a) Thermal conditions

The thermal conditions were comfortably warm in all the clubs (23^{o}C or 73^{o}F). Club A was becoming hot at the end of the evening (25^{o}C or 77^{o}F) though not sufficient to require cooling. The

Cigarette consumption was obtained from co-operative managements who agreed to collect the evening's cigarette ends from the main concert hall of the allegedly worst environment at Club A and the best at Club B. Due to an accidental error the cigarette ends from Club A were lost for the measurement night. A collection was repeated and counted on the following Saturday night.

3. RESULTS

(a) Club A

The club was almost full at 8.15 p.m. in time for the musical concert at 8.30 p.m. Spot checks showed the temperature and humidity to be as designed (23^{o}C 55% r.h.). The carbon dioxide level was surprisingly high at 0.44%. There was an antiseptic-like odour and our eyes watered. One of the air conditioners was cracking loudly. This was the result of incorporating coarse low pressure filters into the unit to replace the conventional ones. This change had been introduced to permit a higher air flow through the unit but it also meant that more fibrous material was entering the electrostatic precipitators and causing discharges.

The gas samples, when subsequently analysed, contained:

carbon dioxide 0.4 at 8.25 p.m. to 1.0% at the end of the evening
carbon monoxide 4 - 8 ppm by volume at 8.35 p.m.
ammonia 2-3 ppm by volume at 9.35 p.m.
hydrocarbons 5 ppm of which 0.5 to 0.8 ppm was acrolein
no ozone or nitrogen dioxide or hydrogen sulphide was detected.

Subsequent measurements showed the fresh air supply to be 2.3-2.8m^3/min. per unit (80-100 cfm), and the cigarette consumption 2413 for a Saturday evening.

Spot checks made at the end of the evening (10.30 p.m.) showed the indoor temperature was 25^{o}C at 52% r.h. and the carbon dioxide level was approximately 1%. The population was down to 200 of which about

The air conditioning units provide coarse filtering followed by electrostatic precipitation and then cooling when required. Fresh air is introduced into the unit. The actual fresh air drawn in at Club A is less than half the designer's intended value. This is attributed to the tightness of modern building construction and the provision of a multiple air lock from the concert hall to the outside doors. With no air exhaust grille the room will become pressurised and the fresh air supply decline.

The electrostatic filters will extract the particulate matter from the cigarette smoke but the gases will recirculate unchanged and build up concentration over the evening. It is these gases which are creating the distress.

The two routes available are extra ventilation or charcoal absorbers or a combination of both. If ventilation is chosen then the fresh air rate for Club A will need to be changed from the present ½ air change/hour to 3 air changes/hour. This can be achieved by additional fans and the provision of extract grilles.

Current IHVE proposals for this number of people are a minimum of 12 air changes/hour with a recommended value of 24 air changes/hour.

6. CONCLUSIONS

The unacceptability of the Club A atmosphere is related to two factors which reinforce each other. The first is that the ventilation is insufficient and below the design value. This is due to the airtightness of the new building construction and the provision of several air locks between the main concert hall and the entrance hall. The second factor is the high incidence of cigarette smoking per person which is twice that of the more acceptable atmosphere in Club B.

Acrolein is the major lacrimator in cigarette smoke and can be removed by charcoal absorbers placed after the electrostatic units. A design study is recommended to assess the possibilities of providing more fresh air and a planned air exhaust in conjunction with charcoal absorbers.

relative humidity was in the comfort band at all clubs (44-55% r.h.).

(b) Carbon dioxide (see Appendix 1)

Carbon dioxide is a by-product of breathing which is proportional to activity level (Table 4). For a given activity its concentration level gives a good guide to the amount of fresh air. In Club A the conditioners were giving less than half their design air of $680m^3/h$ per unit. The high carbon dioxide concentration confirms this. Similar calculations for Club B based on the two conditioners supplying their design air flow suggests that much more air is entering the room. This is also true for Club C.

(c) Cigarette smoke (see Appendix 2)

Cigarette smoke contains small particles of ash and tar and a range of pungent gases. The electrostatic pricipitators will remove some of these particles but the gases continue to recirculate, building up in concentration over the evening. The most powerful of these gases is an unsaturated aldehyde called acrolein, which irritate the eyes and lungs.

At Club A the cigarette consumption was 1000/h and the highest acrolein concentration should have been 0.5 ppm. It was higher than this which supports the argument that the fresh air flow is low or that the cigarettes smoked are particularly high in acrolein release. The theoretical concentration of acrolein, based on the design air flow values, would be one third of the ClubA estimate. The actual cigarette consumption per head was 1½/h at Club B and twice that, 3/h at Club A. This may be partly attributed to the more widespread dancing activity at Club B which acts as a limit on smoking.

5. DISCUSSION

The measurements show that the Club A differs from Club B in two important ways. The ventilation rate is less at Club A and the cigarette consumption per person is twice that of Club B.

TABLE 2 Details of the three concert halls

Club	A	B	C
Approx. length m	22	20	27.4
" width m	12.5	12.5	12.5
" height m	3.7	3.5	3.7
" volume m^3	1028	890	1254
Design capacity	450	280	550
Working capacity	350	280	450
Number at time of survey	330 at 8.15p.m.*	220 at 9.00p.m.	375 at 9.40
Actual space/person at survey m^3	3.1	4.0	3.3
No. of Elecair units	4	4	4
No. with fresh air	4	2	4
Operating mode during survey	All on fan	2 Fans + fresh air 2 cool	All on fan
Indoor temperature at time	23°C	22.5°C	25°C
Indoor relative humidity	55% r.h.	44% r.h.	45% r.h.
Indoor carbon dioxide concentration by volume	0.44%	0.32%	0.35%
Outdoor carbon dioxide concentration by volume	0.04%		
Cigarettes over the Saturday evening	2413	868	not recorde
Approx. rate per hour cigs/hour	1000	350	" "
Dancing	No space until end of evening	Large space ~ 25 couples	Very littl space ~ 5 couples

*returning at 10.30 p.m. about 1/3 had left; dry bulb was 25°C 52% r.h. carbon dioxide concentration was off scale, i.e. well above 0.5%

TABLE 1 E.L. Eitherington's 'Elecair' air conditioner

Size (wall mounted) 1m wide x 0.85m high x 0.5m deep	
Nominal recycle air flow	1270m^3/h
Nominal fresh air supply (when provided)	340m^3/h
Operating (preset) temperature	22^{o}C
Cooling load	9 kW
Pre-filters	Washable coarse filter
Electrostatic filter (Honeywell)	ionises at 8150v
	collector plates 4150v
Outdoor unit 0.8m x 0.7m x 0.7m	

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TABLE 4 Fresh air needed for carbon dioxide dilution

Activity level	Metabolism watts	Carbon dioxide generation m^3/h	Fresh air needed/person	
			for 0.1% CO_2 m^3/h	for 0.5% CO m^3/h
Sleep	75	0.011	15.7	2.34
Sedentary work	140	0.021	30.0	4.5
Light factory work	235	0.035	50.0	7.45
Dancing	265	0.040	57.0	8.5
Heavy factory work	440	0.065	92.5	13.8

TABLE 5 Sidestream combustion products of cigarettes*

Contaminant	Range
Carbon monoxide	22 - 100 mg/cig
Carbon dioxide	57 - 98 mg/cig
Acrolein	0.4 - 0.7 mg/cig
Total particulate matter	400 - 500 mg/cig

Brundrett ECRC/M870 1975.

*Sidestream smoke drifts directly into the room from the tip of the cigarette; mainstream smoke is inhaled.

TABLE 3 Sensory response to acrolein vapour

(Maximum allowable vapour concentration for 8 hour exposure is 0.1 ppm by volume)

Concentration ppm by volume	Exposure time	Response
0.25	5 min	Moderate irritation of sensory organs
1.0	1 min	Slight nasal irritation
	2-3 min	Slight nasal and moderate eye irritation
	4-5 min	Moderate nasal and practically intolerable eye irritation
1.8	30 s	Odour of acrolein
	1 min	Slight eye irritation
	3-4 min	Profuse lachrymation: practically intolerable

From Smith, C.W. Acrolein, Wiley, 1962.

APPENDIX 1

Theoretical carbon dioxide concentration

The concentration is $\frac{Cq_1 + q_2}{C} \left(1 - e^{-\frac{C.t}{v}}\right)$

where C = fresh air quantity

q_1 = concentration of carbon dioxide in fresh air (0.04%)

q_2 = generation rate of carbon dioxide in the hall

v = volume of hall

t = elapsed time in hours

For Club A C = $612m^3$/h fresh air measured, Cq_1 = $0.245m^3$/h, v = $1020m^3$

q_2 = 300 people at $0.02m^3 CO_2$/h = $6.6m^3$/h

equilibrium value for $CO_2 = \frac{Cq_1 + q_2}{C} = \frac{6.85}{612} = 1.12\%$

Time h	$\frac{C.t}{v}$	$e^{-\frac{C.t}{v}}$	CO_2 conc.	% CO_2 by volume
½	.3	.74	26% max.	0.29%
1	.6	.55	45% max.	0.5%
2	1.2	.30	70% max.	0.78%
4	2.4	.09	91% max.	1.02%

For Club B C = $680m^3$/h design fresh air; Cq_1 = $0.27m^3$/h; v = $890m^3$

q_2 = 170 people x $0.020m^3$/h CO_2 + 50 people dancing x $0.040m^3$/h

= $54m^3$/h

equilibrium value for $CO_2 = \frac{Cq_1 + q_2}{C} = \frac{5.7}{680} = 0.84\%$.

Time h	$\frac{C.t}{v}$	$e^{-\frac{C.t}{v}}$	CO_2 conc.	% CO_2 by volume
½	.38	.684	32% max.	0.27%
1	.76	.47	53% max.	0.44%
2	1.58	.21	79% max.	0.66%
4	3.2	.04	96% max.	0.81%

APPENDIX 2

Cigarette smoke and gases: theoretical assessment

Each cigarette relases 0.4 - 0.7 mg of acrolein into the room. 1mg of acrolein is $4 \times 10^{-7} m^3$ in volume under room conditions. The equilibrium concentration of acrolein is therefore

$$\text{acrolein concentration } C_a = \frac{\text{No. of cigs/h} \times 0.7 \times 4 \times 10^{-7} m^3 \times 10^6}{\text{Fresh air flow } m^3/h} \text{ ppm by volume}$$

$$= \frac{N/h \times 0.28}{Cm^3/h} \text{ ppm by volume}$$

For Club A:

$$\text{theoretical acrolein concentration } C_a = \frac{1000 \times 0.28}{612} = 0.46 \text{ ppm}$$

For Club B

$$\text{theoretical acrolein concentration } C_a = \frac{350 \times 0.28}{680} = 0.14 \text{ ppm}$$

<u>For Club C</u>

C = $1260 m^3/h$ design fresh air; $Cq_1 = 0.54 m^3/h$ carbon dioxide;

v = $1254 m^3$

q_2 = 375 people x $0.020 m^3/h$ CO_2 = $7.5 m^3/h$

equilibrium value for $CO_2 = \frac{Cq_1 + q_2}{C} = \frac{7.5}{1360} = 0.55\%$

Time h	$\frac{C.t}{V}$	$e^{-\frac{C.t}{V}}$	CO_2 conc.	% CO_2 by volume
½	.54	.58	42% max.	0.23%
1	1.08	.34	66% max.	0.36%
2	2.16	.11	89% max.	0.49%
4	4.32	.01	99% max.	0.54%

E.L. ETHERINGTON LIMITED

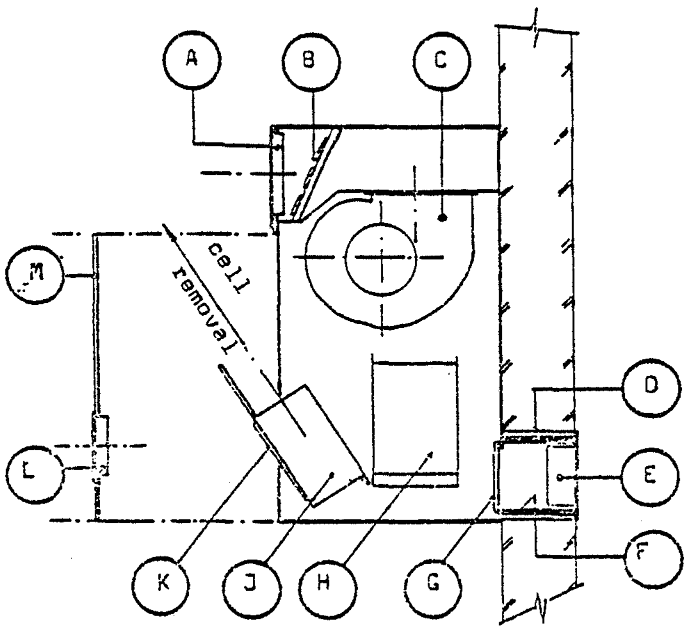
Air conditioning, Industrial cooling and dehumidification

POTTERNEWTON MOUNT, LEEDS LS7 2DR

Telephone: Leeds 621112/3

OPERATING INSTRUCTIONS FOR ELECAIR SYSTEM

ELECAIR(IN-DOOR UNIT)



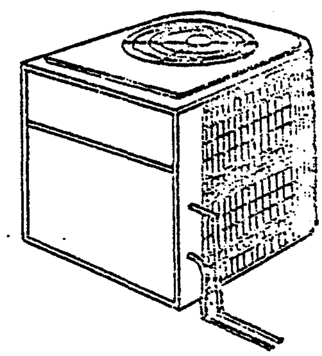
A - Supply air diffuser
B - Heating elements (optional)
C - Fan Blower
D - Timber lined opening by builder
E - Fresh air in let louvre
F - Accoustic lining (as required)
G - Fresh air inlet filter
H - Cooling coil
J - Electrostatic cell pack
K - Pre-filter
L - Return air grille
M - Removable front panel

Dimensions

Depth		Width		Height	
ins	mm	ins	mm	ins	mm
20	508	40	1016	36	915

OUTDOOR UNIT

To suit either single or 3 phase supply



Dimensions

Depth		Width		Height		Net weight	
ins	mm	ins	mm	ins	mm	lb.	kg.
30	760	26	660	28	700	210	96

Fig. 1 The Elecair air conditioner

ECRC/N1078

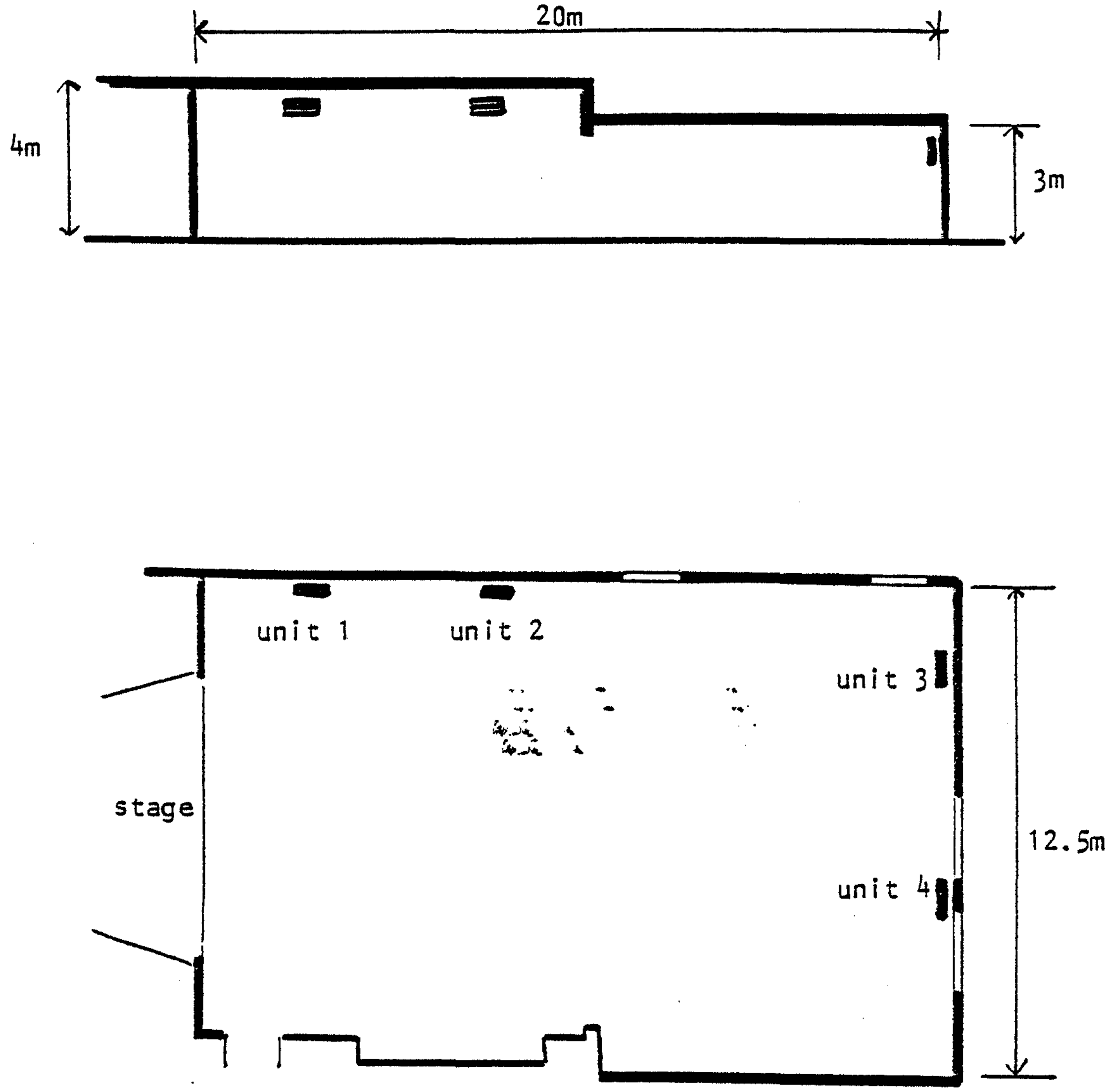


Figure 3 Plan and elevation of Club B

ECRC/N1078

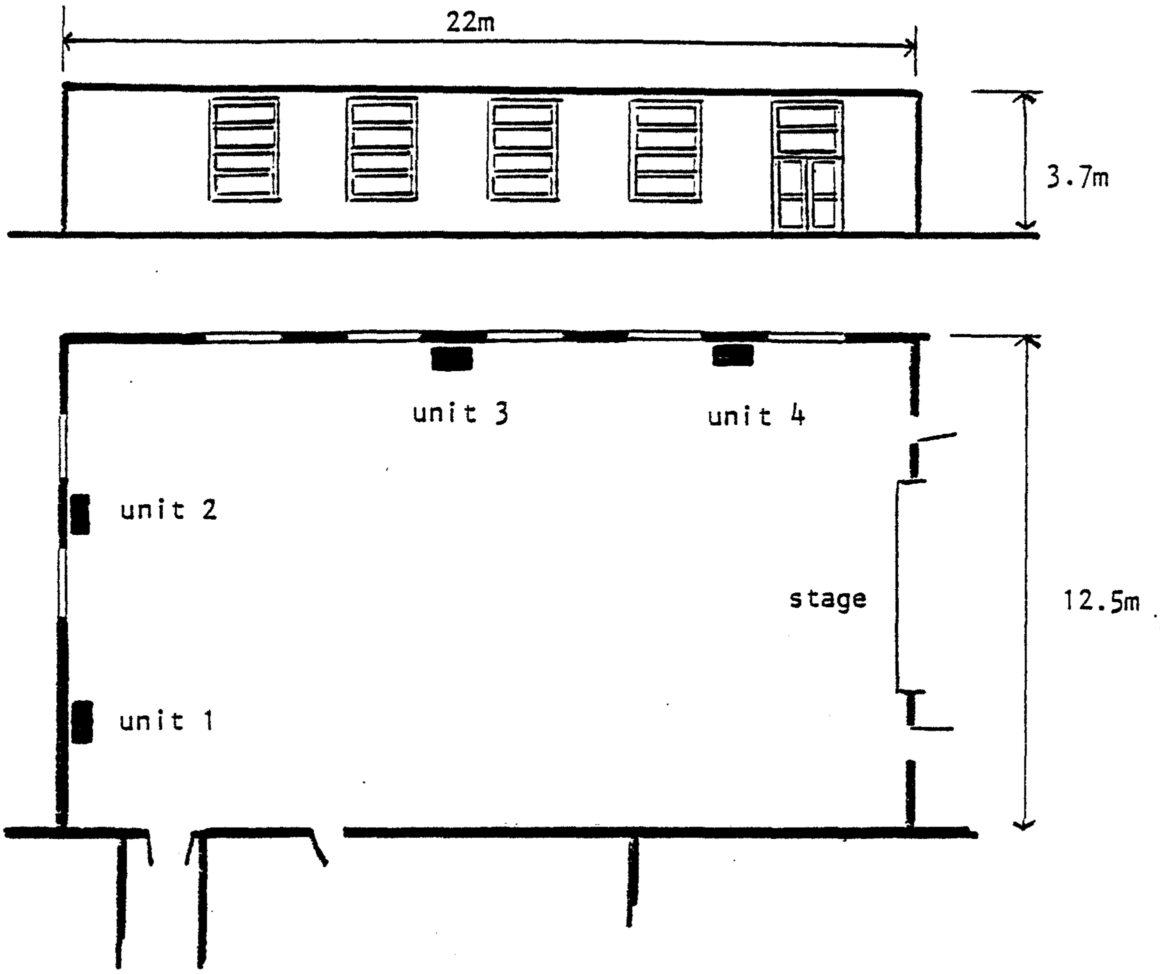


Figure 2 Plan and elevation of Club A showing location of four air conditioning units

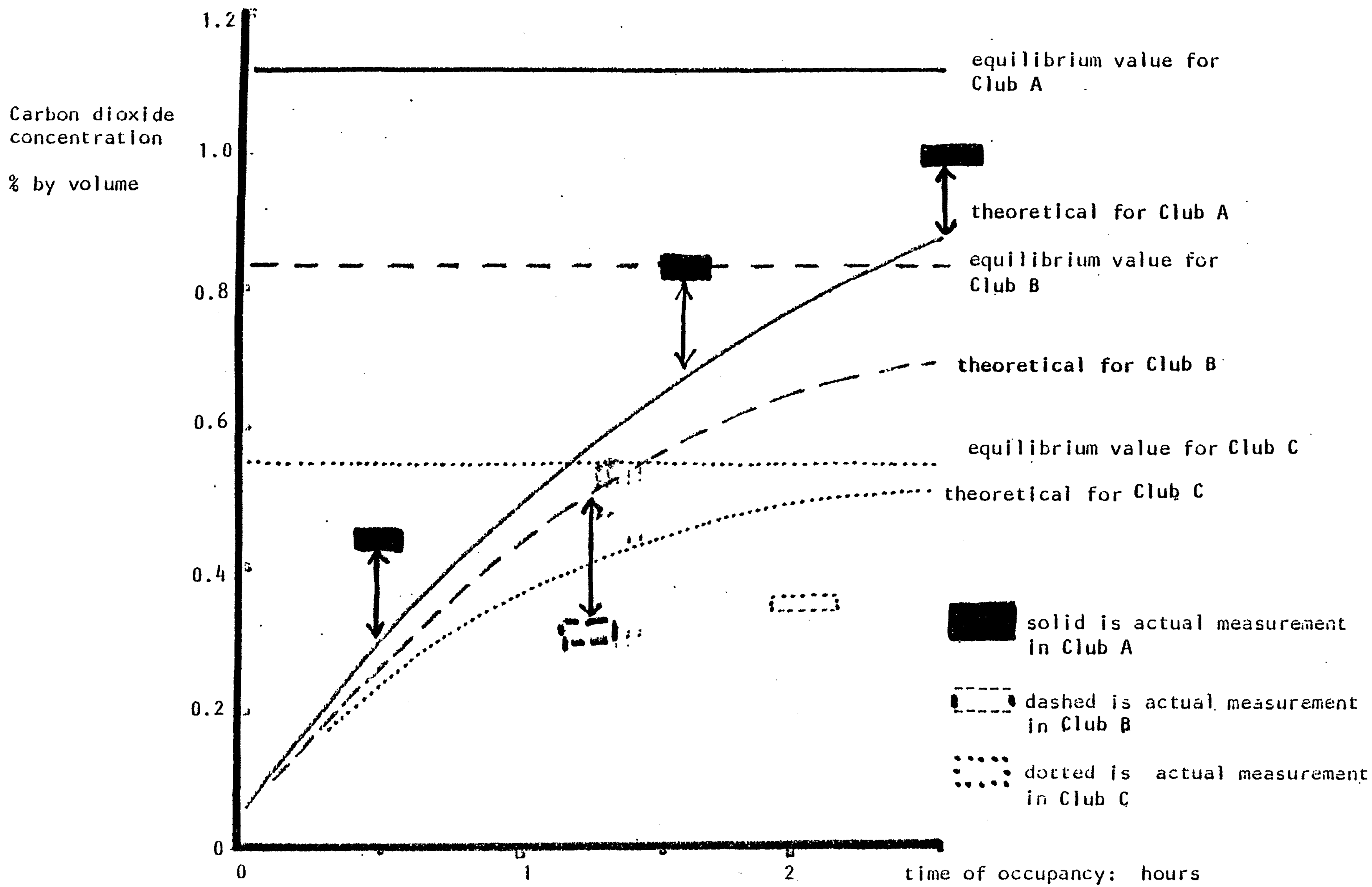
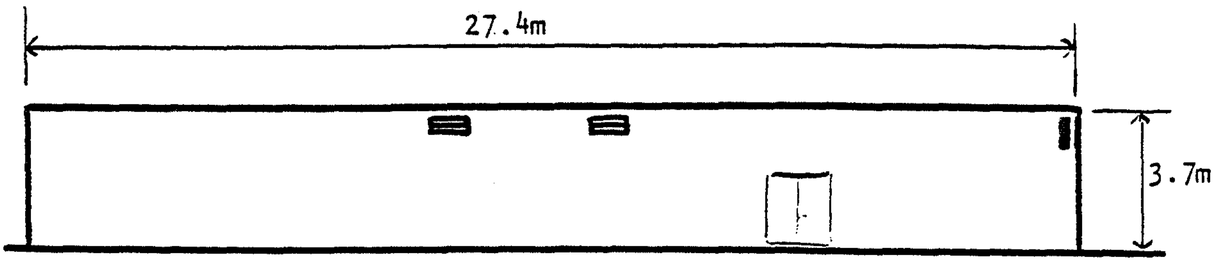


Figure 5 Growth of carbon dioxide concentration



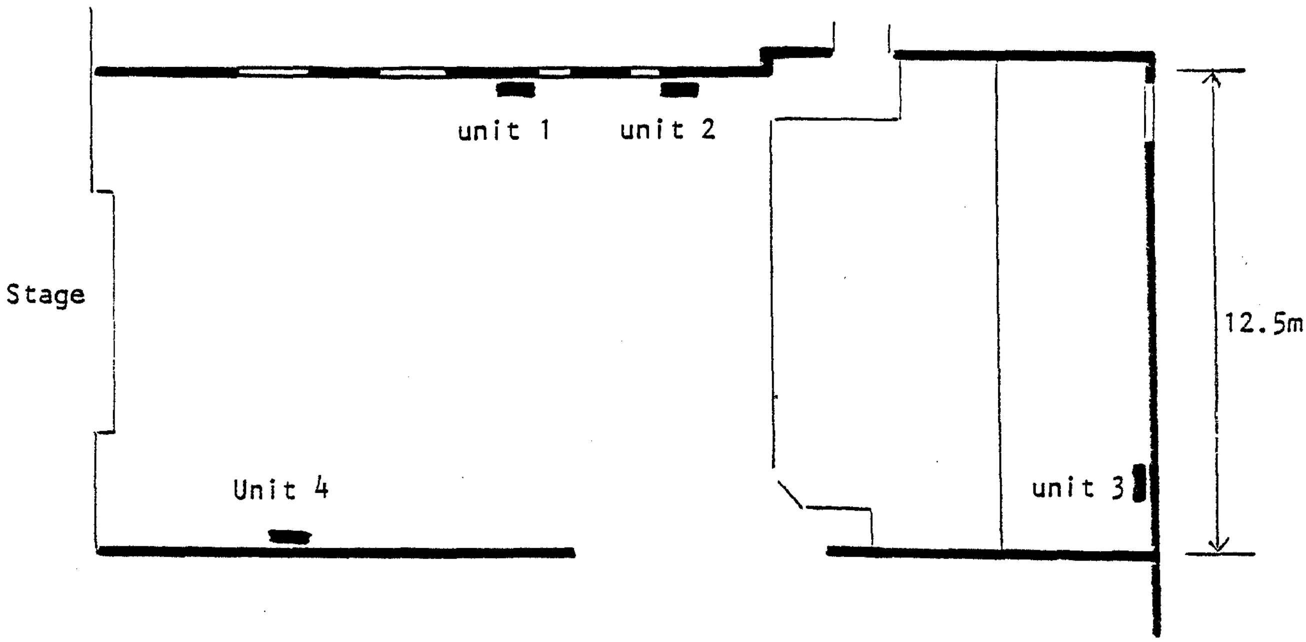


Figure 4 Plan and elevation of Club C

ECRC/N1078