THE ELECTRICITY COUNCIL RESEARCH CENTRE
CAPENHURST CHESTER CH1 6ES

VENTILATION REQUIREMENTS IN ROOMS OCCUPIED BY SMOKERS: A REVIEW

by G.W. Brundrett

Job No. 019

Confidential Declassified

December, 1975

VENTILATION REQUIREMENTS IN ROOMS OCCUPIED BY SMOKERS: A REVIEW

by

G. W. Brundrett

SUMMARY

The fresh air needed to dilute cigarette smoke to an acceptable
level is the dominant criterion for ventilation design of buildings.
The literature is reviewed and brought to a common basis of dilution
air per cigarette. Non-smokers are more sensitive to smell and
nose irritation than smokers but eye irritation affects both.
Humidity has an important influence on irritation, lower humidities
increasing the irritation.

Health criteria are compared with the compounds released in the
cigarette smoke. Carbon monoxide is the most critical if the EPA
recommended limit of 9ppm is accepted. Nine cubic metres of
fresh air are needed per cigarette. Preferred values of $26m^3/h$
per person agree well with current ventilation guides.

The little data available suggests a wide difference between people
and care must therefore be taken in choosing mean votes for an
assessment of smoke. If the smoke is considered acceptable by
the average person, then 26% of the population are likely to find
it objectionable. Some allowance for this spread of sensitivities
is proposed.

Application of the research data to offices shows a particular
problem related to office size. If the office contains a hundred
or more people then the population in it can be considered
representative of the working population i.e. containing 50% smokers.

CONTENTS   Page No.

If the office only contains a small number of people then it is
likely to contain a wide variety of smokers/non-smokers/heavy
smokers/light smokers from time to time. Some provision to cater
for different needs of such offices is suggested.

Finally comparison of British and American recommendations
agrees reasonably well with the smoking habits of the two
countries in normal large offices. The British IHVE Guide
1970 treats smoking in the same way as body odours and relates
it to personal space. The ASHRAE Guide more correctly
treats it as a simple contaminant.

The preferred ventilation criteria would be related to body odours
in crowded areas and smoking requirements in more spacious areas.

1.   BACKGROUND

Insulation techniques to minimise the heat loss through the fabric
of a building exist and are being widely used. The other type of
heat loss is through ventilation.[1] Current research is seeking
low cost solutions for controlled ventilation and the key question
is how much ventilation is needed. One criteria is the dilution
of cigarette smoke to an acceptable level of comfort and health.
This note surveys the available literature in four fields.
The first is that of smoke generation by the cigarette, the
second is the sensitivity of people to smoke, the third is the
toxicity of smoke to the passive smoke and the fourth is an
examination of ventilation needs.

2.   SMOKE GENERATION

When a cigarette is smoked the products of combustion are divided
between the mainstream products and the sidestream ones. The
mainstream products are drawn through the cigarette by the smoker
during the puff period. Those mainstream products not absorbed
by the smoker are expelled in subsequent breaths. The sidestream
smoke is released directly into the room air during the smouldering
combustion stage which occurs between puffs. Most research has
concentrated on identifying and quantifying the products of the
mainstream smoke to enable the toxic compounds to be reduced. Only
recently has interest revived in the sidestream smoke so that the
problems of the non-smoker working in a smoky room can be examined.

Machine simulated smoking tends to use a 35 ml puff of two
second generation at a rate of one puff a minute. The butt
length is usually 23 or 30 mm and the tobacco has a 10% moisture
content. This characterizes the smoker. In general more tobacco
is burned during the smoulder period than the puff period (20% to
110% more in the sidestream).

Reviews of smoke generation by Wynder and Hoffman 1967 and
Hoegg 1972 show the complexity of the combustion process. The
sidestream smoke released depends upon the smoulder rate. Tobaccos
with high smoulder rates such as Turkish types have over three
times the tobacco burned during the smoulder period than the puff
period (Johnson 1973). Hensen & Haley 1935 and Neurath 1964 showed
the nicotine in the sidestream to increase with increasing moisture
content in the tobacco. Smoker habits will also influence the balance
between sidestream and mainstream. Deep, frequent puffs will increase
the mainstream smoke at the expense of the sidestream.

The general agreement that the sidestream and mainstream combustion
products are proportioned according to the amount of tobacco burned
in smouldering and puffing does not apply to certain compounds.
Bogen 1929 found more ammonia in the sidestream. Johnson 1973 agreed,
finding over a hundred times more in the sidestream and some ten
times more pyridine. He also noted that hydrogen cyanide was

principally in the mainstream.

The particular problem of oxides of nitrogen was raised by
Haagen-Smit, Brunelle & Hara 1959 and studied by Bokhoven et
al. 1961. Bokhoven found equal volumes of nitric oxide and nitrogen
dioxide which amounted to 0.04 mg and 0.51 mg respectively.
Galuskinova 1964 searched for benzpyrene, a product of cigarette
smoke, and found it varied with the number of cigarettes smoked
in rooms.

More recently attention has been directed towards the carbon
monoxide dangers of cigarette smoke. More carbon monoxide is
released in the sidestream than the mainstrem. Brunneman and
Hoffman 1974 showed how the mainstream carbon monoxide and carbon
dioxide increased with time as the cigarette was smoked. The
quantity per puff doubled from first to last puff. Russell,
Cole, Idle and Adams 1975 studied a wide range of British
cigarettes and found the mainstream yield of carbon monoxide varied
from 5-20 mg per cigarette for conventional cigarettes, with a
higher value of 28 mg for a semi-synthetic one. In the low nicotine
cigarettes the carbon monoxide increased with nicotine content
of the tobacco but there was no clear relationship for the high
nicotine ones. A summary of the work on carbon monoxide generation
is given in Table 4.

Analyses by Hobbs 1956 indicated acrolein to be an important product
of mainstream smoke. Work by Weber 1975 using a smoking machine
in an environmental chamber showed significant amounts of
acrolein. Data on acrolein in cigarettes is given in Table 1.
Illustrations of general chemicals in smoke are given in Table 2
and the differences between authors of the major compounds are
shown in Table 3.

This analytical work on smoke defines yields in terms of a cigarette.
The concentrated sidestream compounds need diluting to an
acceptable level for health and comfort. Treating smoke as a
simple contaminant means that the necessary dilution can be most
clearly expressed in terms of fresh air per cigarette. This

also has the advantage of comparing the subjective results
of different authors on a common basis. It has two disadvantages.
The first is that the early American cigarettes contained one
gram of tobacco while British filter cigarettes contain approximately
600 mg. Fortunately the smoking habits in America are such that
a large stub is usually discarded unlike British practice. The
tobacco content of current American Filter cigarettes is
also lower ($\sim$ 875 mg) than in earlier years. The second potential
problem is the wide difference in tar and nicotine between brands
which can vary by an order of magnitude (Department of Health 1974).
There has been a significant reduction in tar content over recent
years but fortunately the tar and nicotine contents of the current
market leaders are similar, Table 5, Figure 1.

The smoke in rooms is the sum of the sidestream smoke and the
exhaled smoke. Mitchell 1962 found that 20-50% by weight of
the mainstream smoke was retained in the smoker even when no smoke
was inhaled. Retention was 82% when inhaled for five seconds
and reached 97% after thirty seconds. The longer the smoke was
retained the smaller were the exhaled particles. Bokhoven &
Niessen 1961 measured the absorption of nitrogen oxides and
carbon monoxide. They found between 82-87% of the carbon monoxide
adsorbed and 87-96% of the nitrogen oxides.

3.   IDENTIFICATION OF SMOKE DISCOMFORT

The three types of problem associated with tobacco smoke are poor
visibility, unpleasant odour and personal distress through
headache or irritation of the eyes or throat. There is common
agreement amongst non-smokers of the types of irritation, with
eyes being the most sensitive, Table 6.

The visibility criteria is dependent upon the viewing position.
Cinemas, where the direction of view is in line with the projection
beam, are relatively insensitive to smoke cloud. Enclosed sports
arenas where the principal lighting is directly over the action
do have to consider the appearance of the smoke haze.
Leopold 1945 studied this by experimenting with the ventilation
of a large sports arena. He measured the acceptability of the
atmosphere by recording the impressions of five trained individuals
who included one non-smoker and one heavy smoker. The recommended
ventilation for an acceptable appearance was 32-53 m^3/h/person.
Less than 20% of a sample of the spectators were smoking. This
would be approximately 26 m^3/cigarette. When the fresh air was
reduced to 20-34m^3/h/person the cloud became objectionable
(approx. 17 m^3/cig.). Eye irritation was experienced at the slightly
lower flows of 19-31 m^3/h/person (approx. 16 m^3/cig.).

The nature of the activity means that spectators enter and leave
at the same time, enjoying two hours of entertainment. They
rapidly acclimatise to the odours and no problems of unpleasant
smells were noted.

Odour sensitivity and irritation to eyes tend to change with
time. The sense of smell rapidly adapts to a new odour while the
irritation effects become stronger with exposure. Yaglou 1955
investigated three types of response to people smoking in a
room. One type was that of an observer freshly entering the
room, one was the of non-smokers who had been exposed to
tobacco smoke for 2-4 hours and the final type was the
response of the smokers themselves.

Acceptable strength of the tobacco smoke was defined as one of
moderate odour or irritation with little or no objection. The
visitor required a dilution of $9m^3$/cigarette for acceptability.
The comparable figure for the non-smoker was 5.5 m^3/cigarette.
The smokers were unable to smell the smoke odour and based their
judgements on irritation of the eyes, nose and throat and
headaches. The dilution required for this was $4m^3$/cigarette.
At smoke dilutions of $1m^3$/cigarette and less the smoke odour was
difficult to perceive by everyone, irritation becoming the major
response (Figure 2).

In an earlier study Yaglou 1937[15] examined the disappearance
characteristic of tobacco smoke odours once the smoking had
stopped. Rather than naturally decaying, the odour intensity
of the stale tobacco smoke increased with time for the first
hour or two and only then diminished (Figure 3). The practical
implication of this is that rooms in which smoking is permitted
should be small in size and highly ventilated so that the residence
time of the combustion products is kept as short as practicable.
Yaglou also measured the effectiveness of the air distribution
system which was supplied through perforations near to the ceiling
and extracted at floor level. At low air flow rates ($26m^3$/h ~ 0.65
air changes/hour) the supply air mixed well with the room air and
was practically 100% effective in diluting the air around the room
occupants. At high air flow rates ($550 m^3$/h ~14 air changes/hour)
the effectiveness of the air supply was down to 65% because of
the by-passing of air straight into the exhaust. The effectiveness
of the air distribution system should receive particular attention
at high ventilation rates.

Harmesen and Effenberger 1957 investigated room pollution and
carefully graded air quality in terms of chemical concentrations
of nicotine, carbon monoxide and the physical concentration
of particulates. They found the quality slightly disagreeable to
non-smokers at nicotine concentrations below $1mg/m^3$. From
Neurath's data (1964) this would mean dilutions of $4m^3$/cigarette
for the sidestream component alone.

Keuhner 1953 used a dilution principle to assess the odour strength
of cigarettes. He found that the odour of tobacco smoke was
insensitive to the brand of cigarette, its burning rate or its
freshness.

Halfpenny & Starrett 1961 undertook a careful study on the
ventilation needs for aircraft passengers. Likely contamination
levels were assessed from specially undertaken field surveys.
Subjective assessments were made on a group of people sitting inside
a simulated aircraft under a range of contamination conditions.
The influence of charcoal filters on odour level was also
investigated. The test procedure maintained a single smoke
concentration for each test and the irritation level was recorded
once the maximum steady response was reached i.e. after 25-30 minutes.
Humidity was uncontrolled, with the majority of experiments (80%)
carried out between 40-48% r.h. The range of humidity
encountered varied from 24-59%. The conclusions showed irritation
of eyes, nose and throat to be the comfort criteria since after
a few minutes' adaptation observers were unable to detect tobacco
smoke. Accepting their finding that an average American cigarette
burns 550 mg of tobacco we can interpret the results in terms
of fresh air per cigarette. Threshold irritation occurred at
$26m^3$/cigarette, moderate irritation occurred at smoke dilutions
of 15.6 m^3 fresh air/cigarette and objectionable levels were
6.9 m^3/cigarette. Personal differences in irritation to the
same smoke concentration were large, Figure 4.

Johansson & Ronge 1964 investigated the irritation effects
of a room which was progressively filled with smoke. The
strongest irritation effects occurred under warm dry conditions.
The three responses studied were eye irritation, nose irritation
and air quality. Air quality was the most sensitive factor.
Non-smokers were much more sensitive than smokers requiring
approximately 5.5 m^3/cigarette dilution air. Smokers accepted
a dilution of 1.6 m^3/cigarette. Eye irritation was the next most
sensitive factor with little difference in response between
smokers and non-smokers. Threshold irritation occurred at

dilution levels of approximately 1.6 m^3/cigarette. Nose irritation occurred with non-smokers at dilutions of approximately 3.7 m^3/ cigarette. The noses of the smokers were less sensitive and threshold irritation occurred at 1.6 m^3 fresh air/cigarette.

More detailed physiological studies were later made (1965). A significant difference in the development of irritation in the eyes and nose occurred. Eye irritation was higher. For non-smokers nose irritation increased rapidly during the first ten minutes and then remained constant. Eye irritation rose continuously with the smoke concentration.

Surveys of aircraft environments have shown the sensitivity of people with respiratory problems to smoke. The U.S. Department of Health 1971 commissioned measurements on two types of flight. The first was military transport of large numbers of young people over long distances. These planes ran full and carried 165-219 passengers for 7-11 hours. The second were ordinary domestic flights of an hour's duration in planes of 88-128 seat capacity running two-thirds full. The monitoring confirmed that there was no build up of toxic products in either case. The small personal space is compensated by a high air change rate of 15-20 per hour. Passenger responses were similar for the two groups.

Over three thousand passengers were interviewed, of which 56% were smokers. Over 60% of non-smokers reported annoyance from the smoke. More surprisingly one-third of the young military personnel had a medical history of respiratory problems which increased to 41% for the relatively older group flying on the domestic routes. Over 70% of the smokers who had respiratory difficulties were annoyed by other smokers.

The low relative humidity on aircraft (10-20% r.h.) accentuates the respiratory dryness and would be expected to increase the irritation which smoke creates. The results would not normally apply directly to ordinary work conditions. However it does suggest that normal populations contain a significant proportion of people who are particularly sensitive to irritants. Care must be taken in translating results from the laboratory where healthy subjects are carefully selected to a normal work situation containing a wide spectrum of physical disorders. The particular

sensitivity to smoke of people with lung or heart trouble is now becoming recognised (Huber 1975).

Current research at the University of Zurich by Dr. A Weber 1975 is extending the research direction of Johansson and Ronge by investigating many more criteria and measuring the gas composition inside the environmental chamber. For acceptable air quality a fresh air dilution of 10.5 m^3/cigarette was needed. Acrolein was generated in significant quantities and reached the permissible 8h exposure limit of 0.1 ppm at a smoke dilution rate of $3m^3$/cigarette. Acrolein is one of the most powerful toxic lacrimators which is effective at very low concentrations and is particularly quick acting to irritate the conjunctiva and mucous membranes of the respiratory organs (Prentiss 1937).

Speer 1968 investigated the symptons of a group who reported an allergy to smoke and compared them with a normal group of non-smokers. There was little difference between the two suggesting smoke to be irritative rather than allergic in character. The proportion experiencing eye irritation was particularly large (70%).

4.   THE INFLUENCE OF ROOM CONDITIONS ON ODOUR

The three room conditions which influence odour irritation are
airflow pattern, humidity and temperature. The airflow pattern
can gently direct cigarette smoke into the faces of nearby
people creating a local concentration several orders of magnitude
higher than the general environment. Humidity has two
different types of influence. The first is to determine the
moisture content of the tobacco. The second is the effect on
odour sensitivity. The moisture content of tobacco is primarily
determined by the relative humidity of its environment and can
vary from dry to 24% water by weight (when in a saturated atmosphere).
In normal conditions approximately 10% water is likely. This water
content has an influence on the burning rate. Higher moisture content
tobaccos burn more slowly. Jensen and colleagues 1935 related
this to a higher nicotine release in the sidestream and hence
more odour generation into the room.

The influence of temperature and humidity on odour perception
was studied by Kerka & Humphreys 1956. Assessments were made by
a panel of trained staff, equally divided between men and women
and moderate smokers and non-smokers. The technique used was
a very sensitive one of walking into the room and sniffing for
a first impression and then again five seconds later. Yaglou's
assessment scale was adopted for scoring.

The odour intensity was diminished by both increasing temperature
and increasing humidity. In the comfort region of $21^{\circ}C$
changing the relative humidity from 30-60% lowered the odour
intensity by one-quarter of a vote. This is approximately the
same reduction which a temperature rise of $5^{\circ}C$ could create
(Figure 5). The irritation has a similar pattern but was not
so well defined.

Speed of adaptation to odour was also studied. Assessments over
a six-minute period showed a reduction in odour intensity of one
vote although this was compensated by an almost equal rise in
the irritation sensation (Figure 6.).

Assessments of odour intensity over a range of smoke concentrations showed these test methods to require a much more dilute smoke for acceptability than did Yaglou's panel in 1955, Figure 2. Acceptability was a dilution of 120 m^3/cigarette.

Johansson & Ronge 1964 investigated the influence of two relative humidity levels 33% and 85% at 25°C on irritation created by tobacco smoke. They confirmed that dry conditions increased the irritation of eyes and nose. Subsequent tests (1965) showed that in a cool environment around 18-19°C the effect of humidity was less and irritation was highest at moderate humidities.

5.   THE INFLUENCE OF SMOKE ON THE PASSIVE SMOKER

Jones, 1923, in studying the build up of carbon monoxide from
cigarettes, found that irritation of the eyes occurred at
9 ppm of carbon monoxide which was well below any health limits
of the period. Anderson & Delhamn 1973 measured the carbon monoxide
build up over two hours in a ventilated test room containing
smokers and non-smokers. The mean carbon monoxide level was
4.5 ppm and the mean particulate concentration was 3 mg/m^3 with
a maximum of 13 mg/m^3. The maximum nicotine concentration was
0.38 mg/m^3. Most test subjects experienced eye irritation and
a few had headaches under these conditions.

Hoegg 1972 reviewed the existing literature, and measured the
carbon dioxide, carbon monoxide and particulate content of both
the mainstream and sidestream smoke. This for the first time
enabled him to calculate the effective cigarette consumption
of from 0.01-0.2 per hour by non-smokers in the average closed
space. The particulate matter frequently exceeded the standard
recommendation of 0.26 mg/m^3. Harke 1970 found that the theoretical
assimilation of smoke compounds did not correspond with the real
situation but overestimated the absorption. Carbon monoxide
measurements in the blood and the nicotine content in the urine
were compared for non-smokers and smokers sharing the same room.
The non-smokers had less than one hundredth of the nicotine content
of deep inhaling smokers. Further studies, Harke et al. 1972,
included the measurement of acrolein and aldehydes showed that intense
smoking was needed to exceed the maximum allowable concentrations
(30 cigarettes in an unventilated room of 38.2 m^3). Harke and
Bleichart 1972 studied skin temperature, electrocardiograms, blood
pressure and pulse for smokers and non-smokers in a smoke filled
room. The skin temperature of the smokers decreased after
starting to smoke. No physiological change was noted in the
passive smokers.

Russell Cole & Brown 1973 measured the carbon monoxide absorbed
in the bloodstream of twenty volunteers of which six were
smokers who inhaled. In an unventilated room of 43 m^3 the

average carbon monoxide concentration was 38 ppm. There was a sixty percent increase in carboxyhaemoglobin in the bloodstream of both groups although the smokers' blood contained 5.9% at the start of the experiment compared with the non-smokers' average of 1.6%. Subtle perceptual abilities such as visual acuity, brightness threshold and time interval discrimination may be impaired at carboxyhaemoglobin concentrations in the bloodstream of 3%. Three non-smokers reached this. Further investigations, Russell and Feyerabend 1975, revealed that of 39 urban non-smokers half had measurable quantities of nicotine in their plasma, all had nicotine in their urine. Measurements from smokers and non-smokers after 78 minutes' exposure to heavy smoking showed that while smokers had a far higher level of nicotine in their urine (1236 ng/ml) the normal non-smoker concentration of 10.7 ng/ml had increased to 80 ng/ml after exposure.

This growing concern for the non-smoker prompted a seminar organised by Rylander 1975. Corn reviewed the sidestream smoke with emphasis on the particulate content. Coagulation of these particulates results in an increase in modal size by a factor of three over four minutes (0.15 dia. at the start). The decay rate of particulates was twice that of the carbon monoxide content. McNall showed that high performance filters could remove the particulate matter. Activated charcoal, the most suitable filter for the removal of the vapour constituents was not so successful in removing the irritants and tobacco odours. Inhalation of smoke was considered by Muir. Carbon monoxide absorption would be affected by nose or mouth breathing. Particulate matter was more complex. Nose breathing will filter much of the particulate matter, though special compounds such as nicotine can be absorbed from the nose mucous. Cederlof and Colley searched for epidemiological data. Prevalence of coughs in children was associated with their parents' smoking habits, prevalence being lowest when both parents were non-smokers and highest when both parents smoked.

Taylor found little evidence of allergy. Stewart reviewed the response to carbon monoxide, showing how low concentrations (1-5% carboxyhaemoglobin in blood) accelerated the flow in normal healthy people but could create distress to a heart patient with little reserve. Large amounts (2-9% in blood) reduced the exercise tolerance. Headaches were expected at 16-20%, though such concentrations may be lethal for severe heart patients. Kilburn highlighted the lack of health data for non-smokers exposed to a tobacco smoke environment.

The U.S. Surgeon General's report 1972 concluded that tobacco can contribute to discomfort and that in some situations the carbon monoxide concentration may exceed the threshold limit value. This may be harmful to people already suffering from chronic bronchopulmonary disease and coronary heart disease. Other components of smoke such as the oxides of nitrogen and the particulate matter have been shown to affect animals but their influence on humans is not known. Fletcher and colleagues 1973 reviewed the problem for the British Royal College of Physicians and reached a similar conclusion. They could find no evidence of other people's smoke being dangerous to healthy non-smokers, but it could be extremely irritating and cause distressing symptoms especially for people already affected by heart of lung disease. The smoke from pipes and cigars was found to be at least as irritating as that from cigarettes. Caution was urged with regard to carbon monoxide levels since overcrowded, ill-ventilated rooms or enclosed spaces such as cars could contain concentrations higher than those permitted in industry.

In addition to the nicotine, carbon monoxide and particulate matter discussed so far, the Surgeon General's U.S. Report 1964 included the relative concentrations of different compounds in the mainstream smoke and related these values to the acceptable tolerance levels. This data is used as the base for Table 2 taken with the current ACGIH 1971 values of tolerance. This emphasises the importance of acrolein.

Schmeltz, Hoffman & Wynder 1975 review the problems of the passive
smoker and while agreeing that no evidence of chronic illness is
available do show that increased respiratory ailments in   ·
children occur when exposed to smoke.

6.   ODOURLESS GASES: CARBON MONOXIDE AND CARBON DIOXIDE

Cigarette smoke contains a large proportion of carbon monoxide
and carbon dioxide. Both gases are toxic in sufficient concentration
and must be diluted with fresh air to an acceptable level. The
maximum concentrations are specified in terms of exposure
time and likely fitness of the inhabitants. Davies 1975 reviews
the limits specified for different purposes by several countries.
Normal occupations of eight hour duration for healthy people
have a maximum threshold value (TLV) of 50 ppm for carbon monoxide
in America. The British IHVE Guide 1970 accepts these standards.
Exposure for continuous periods of ninety days and longer call
for a lower concentration and spacecraft have
a TLV of 15 ppm of carbon monoxide. The most sensitive criteria
is that of the general population who include a number of very
young, sick and aged people. The American recommendation for
this group is 9 ppm. The Russians ask for 1 ppm, Table 7.

Sensitivity to carbon dioxide is low and unlikely to be noticed
below concentrations of 10,000 ppm. Above this concentration breathing
will deepen and at 30,000-50,000 ppm there is a conscious need
for increased respiratory effort which is objectionable.
The use of carbon dioxide as a guide for other contaminants
such as body odours has led to the suggestion of an upper limit
of 1000 ppm. Recent Russian work of Goromosov 1968 proposes
an even lower value of 500 ppm.

Recent studies by Hoegg 1972 and Johnson and colleagues 1973 showed
a high release of carbon monoxide in the sidestream smoke of
cigarettes of 56-88 mg/cigarette. Sporzolini & Savion 1973 only
measured 3-5 mg/cigarette with Italian Cigarettes. Taking the
data of Hoegg as the worst case and allowing for a non-inhaler
so that only 55% of the carbon monoxide is absorbed by the
smoker we need 1.65 m^3 of fresh air per cigarette to prevent
the carbon monoxide from exceeding 50 ppm. Jones & Fagan 1974
used the slightly smaller carbon monoxide value proposed by
the American Surgeon General in 1962 but also took into account
the small natural carbon monoxide release from people and

achieved similar values.

The carbon monoxide released from people was found to be 0.39
mg/person/hour by Conkle 1967 in measurements on a simulated
spacecraft. Owens & Rossano 1969 used a value of 11.6 mg/h
for a non-smoker and 17.4 mg/h for a smoker. Such wide differences
are difficult to explain. Davies 1975 shows how 75-80% of
the carbon monoxide in a submarine comes from cigarette smoking.
Electrical fires, cooking and personal emission provide the rest.
In urban areas cars can generate a high background level of carbon
monoxide which would have to be added to the carbon monoxide
from the cigarette smoke. The daily fluctuations of carbon
monoxide concentration in a London street were monitored by
Lawther and Commins 1970. They found a progressive build up
over the day reaching over 50 ppm at 18.00 h. Measurements
of the carbon monoxide in work areas showed that peak
concentrations of 100 ppm could exist near to smokers. Their
general conclusion from a wide study of the problem was that
smoking outweighed the contribution to carbon monoxide pollution
made by traffic. Godin, Wright & Shephard 1972 sampled five
hundred points in Toronto. They found the ambient concentration
related to traffic density. Their estimation of the carbon monoxide
exposure of a typical city dweller was on average 2 ppm at
home, 3 ppm at work and 20 ppm car driving and walking. Spot
checks in a busy ferryboat showed the carbon monoxide levels to
be much lower in the non-smoking areas (3 ppm) than in the
smoking compartments (18.4 ppm). They noted that the combination
of smoking and high ambient outdoor concentations could bring
indoor concentrations of carbon monoxide above the permitted 24
hour level.

7.   PARTICULATES

Hoegg 1972 reviewed the nature of the particulate phase in smoke.
The particulates are submicron sizes (0.2μ for mainstream smoke,
0.15μ for sidestream smoke). Few particles in the sidestream
smoke measured more than 0.7μ dia. and none larger than 2μ were
found during Hoegg's three hour observation period. These sizes
are considered respirable i.e. can reach the periphery of the
human lung.

Biersteker, de Graff and Nass 1965 measured indoor and outdoor
smoke concentrations in sixty houses in Rotterdam during winter
when the windows were more likely to be closed. Outdoor levels
of $0.08-0.36$ mg/m^3 were recorded and the indoor range was
$0.06-0.3$ mg/m^3. The presence of smokers in the house increased
the particulate level significantly but the dominant factor was
outdoor pollution. It was unusual for the indoor level to exceed
the outdoor one. Typical American dust concentrations in rural
and suburban districts are $0.06-0.6$ mg/m^3 and is an order of
magnitude higher in industrial districts. Samples suggest a
seasonal variation in mean dust size from $2-3\mu$ in winter to 1.2μ
in summer, combined with a lower dust concentration in summer,
(Whitby 1957, Waibel, & Wanner 1974). Measurements in a
laboratory residence in Kansas showed typical indoor dust
concentrations to be 0.07 mg/m^3 (Annis 1973). Yocum, Clink and
Cole 1971 measured particulates in Hartford, USA and found the
outdoor concentration varied from 0.05 to 0.1 mg/m^3 while
the range of two houses varied between $0.04 - 0.07$ mg/m^3.
Lefcoe 1971 carried out particle counts in domestic premises and
shows how smoking one cigar raised the particle count from 10
to 100 times the original figure. The particle counts stayed high
for at least three hours. Hoegg 1972 quantified this by
weighing the total particulate matter in the mainstream and
sidestream smoke. On average the mainstream smoke contained
36.2 mg/cig. whereas the total sidestream smoke contained only
25.8 mg/cigarette. Some 20-50% of smoke particles are retained
in the mouth from the mainstream smoke when the smokers do not
inhale. Smokers who inhale retain 70% of the mainstream smoke
particles. The particulates released to the room will be from 37mg/cig.

for the smokers who inhale, to 55 mg/cig. for those who do not.
Accepting the threshold limit value TLV of 10 mg/m^3 (Bridge &
Corn 1972) then this will be equivalent to an air dilution rate
of 3.7-5.5 m^3 air/cigarette.

Newsome and Keith 1957 investigated the influence of smoking conditions
on 'tar yield'. The relative humidity of the atmosphere was shown
to have a strong influence on smoke generation. Lower relative
humidities increased the smoke generation. There was a 50%
increase in smoke when the relative humidity was decreased from
80% to 25%.

Hinds and First 1973 measured the nicotine concentration in a
range of public rooms such as restaurants, cocktail lounges, and
airline waiting rooms and also in commuter trains and buses. Their
estimate of cigarette smoke concentration was an order of
magnitude lower than that estimated by Hoegg 1972 or Bridge &
Corn 1973. This was because the volume of space in such areas
was not the small office volume used by the earlier authors but was
estimated to be 28-4,200 m^3/person. In such public areas the annoyance
is more likely to occur through peak concentrations of smoke or
irritation due to the gaseous compounds.

Rylander 1974 outlined the findings of a World Health Organisation
working party on the progressive health risks of persistant exposure
to particulates. Respiratory symptoms would be expected if the
annual arithmetic mean particulate concentration exceeded 0.1 mg/m^3,
patients with pulmonary disease would be expected to worsen under
daily smoke averages of 0.25 mg/m^3 and hospital admissions would
be expected to be higher in areas of daily averages of 0.5 mg/m^3.
Community Air Quality Standards 1969 recommend average particulate
concentrations below 0.075 mg/m^3 to avoid any undesirable effects
to anyone, including the very young, the very old and the sick.
This extreme calls for air dilution more than two orders of
magnitude greater than the Threshold Limit Values recommended
for workers. Recommended maximum concentrations for particulates
are summarised in Table 8.

8. COMPARISON OF GUIDES (SEE APPENDICES 1 & 2)

Recommendations for appropriate fresh air requirements are made in
the Institution of Heating and Ventilating Engineers 1970 Guide
and in the Draft Code of Practice CP3 for British Standards.

The IHVE Guide gives two sets of fresh air recommendations. The
first (Table A1.7) is for offices and residences where the occupation
density is known. This has a minimum value related to the personal
space and is based on Yaglou's 1936 work on acceptable body odours.
The recommended values for rooms where smoking is not permitted is
50% higher than the minimum. When smoking is permitted the recommended
dilution is double the body odour minimum. The second (Table A9.24)
recommends fresh air quantities for air conditioned spaces. This
proposes three levels of fresh air ventilation. One is 29 m^3/h per
person for factories where smoking is not allowed. The second is
43 m^3/h per person in offices where heavy smoking is expected.
The third value is 90 m^3/h for executive offices where very heavy
smoking is likely.

The British Standard Draft Code of Practice elegantly offers
a range of different criteria from which the appropriate vantilation
needs can be derived. Condensation problems, combustion needs,
odour dilution and tobacco smoke annoyance are considered in detail.
The dilution for acceptable cigarette smoke is chosen to be 10 m^3/cig.

American requirements (ASHRAE 1972) vary from an absolute minimum of
8.5 m^3/h per person in non-smoking areas to 42.5 m^3/h per person in
rooms where smoking is permitted. Recommended values are 13 m^3/h
per person for no smoking areas and 68 m^3/h per person in smoking
areas. Present American practice interprets these guidelines to
give a fresh air rate of at least 17 m^3/h per person in apartments
and preferably 34 m^3/h/person. Board rooms where very heavy smoking
is likely have at least 51 m^3/h per person and preferably 85 m^3/h/
person. Offices vary from a minimum of 25 m^3/h/person
for the general office where smoking is permitted to 51 m^3/h/person
for the preferred value of a private office containing people likely
to smoke heavily.

From these recommendations two factors emerge. The British Guide
treats smoking as it if were a body odour and the difference between
areas where smoking is permitted and where it is not is a factor
of two. The Americans have similar preferred dilution rates to the
British for general office but at minimum permissible rates
advise five times more air for smokers. The Americans treat
smoke as a simple contaminant, Figure 8., but offer the designer
a very wide choice of dilution.

9. DISCUSSION

The literature shows that our sense of smell is good but fatigues
quickly. Yaglou 1955 showed how much more sensitive observers
entering a room were to smell than the occupants themselves.
Consolazio and Pecora 1947 and Kerka and Humphreys 1956 also found
this. The rapid decline in smell perception was countered by an
increase in irritation of respiratory passages and eyes with time.
Johansson & Ronge 1965 showed how eye irritation was proportional
to the smoke concentration while nose irritation was not. The survey
work of 'Which' 1975 and the current research of Dr. Weber, ETH
Zurich confirms the eye sensitivity. Analysis of the aircraft
survey work 1971 revealed a significant proportion of the
'normal' public have a respiratory history and these people
are particularly affected in their breathing in the dry smokey
atmosphere of aircraft.

Only one reference has been located which highlights the differences
in sensitivity between people. Halfpenny and Starrett 1961 showed
that their assessment panel had a wide range of responses to
each smoke concentration. On a six point scale from 0 = no smell
to 5 = intolerable the standard deviation in assessments was
0.73 vote. This wide difference between people means that when the
average vote is say the threshold vote of 1.0 then one quarter of
the population will say the odour is moderate i.e. vote 2.0 and
2% will find it objectionable and vote 3.0. This means that it is
possible for the same atmosphere to be intolerable to one
person while only just of perceptible irritation to another. This
wide variation suggests that for 98% success we should consider
the mean smoke dilution one vote lower than we normally would
use. Using the average value will only satisfy 74% of the population
(Figure 4).

Examination of the cigarette smoke suggests the three main
health factors to be carbon monoxide, particulate matter and acrolein.
The permitted limit for 8 hour exposure to carbon monoxide has
progressively been lowered over recent years and is now 50 ppm

by volume (ACGIH 1971). The preferred limit is 9 ppm (EPA 1971).
If this lower figure is accepted then cigarette smoke will
require a dilution of 9 m^3/cigarette. The next most sensitive
index is the particulate matter released into the atmosphere by the
cigarette. If the maximum ACGIH value of 10 mg/m^3 is not to be
exceeded then the dilution necessary will be 5 m^3/cigarette. In
dry atmospheres where more smoke is created it may have to
be higher (Newsome & Keith 1957). One of the most powerful
of the pungent gases is acrolein which is a toxic lacrimator
specifically irritating the conjunctiva of the eyes and the mucous
membrane of the respiratory passages. Its effect is practically
instantaneous. The maximum permitted average level is 0.1 ppm for
an eight hour exposure although occasional excusions up to 0.3
ppm are permitted. Dilution rates of at least 3 m^3/cigarette
are needed to ensure a sufficiently low acrolein concentration
(Figure 8).

The wide range of findings between researchers are shown in Figure
2. This may reflect the differences in the tobacco used and in the
many ways of smoking it. More accurate analyses of ordinary smoking
conditions are now needed. The more recent results suggest an
average dilution of 20 m^3/cigarette to cater for the average
person. This is twice the amount needed for the most sensitive
ACGIH health recommendations for the working environment. To
allow for differences between people we should double the dilution
to 40 m^3/cigarette to cater for 98% of the population.

Applying these results to British practice is difficult partly
because of lack of comparable data on subjective response and tobacco
chemistry and partly because the smokers habits are different.
The amount of tobacco burnt per cigarette depends on the size of the
original cigarette and the length of the butt thrown away. This
butt length is believed to reflect the purchasing power of the
smoker. The American 'King size' cigarette is 85 mm long and average
butt lengths are 30-31 mm. With a tobacco weight for a plain
cigarette of approximately 1 gm this suggests each cigarette burs
650 mg of tobacco. British plain cigarettes are 700 mg/cigarette

and 70 mm long with an average butt length of 20 mm i.e 500 gm
tobacco burnt per cigarette. (Wynder & Hoffman 196).
Conveniently several research studies burn 500-600 mg/cigarette.

The Threshold Limit Value refers to airborne concentrations of
substances in which workers may be repeatedly exposed day after
day without adverse effect. The wide range of individual
susceptibility means that a small percentage of workers may experience
discomfort at concentration at or below the threshold limit. The
ambient Air Quality Values are much more sensitive and are designed
to avoid undesirable effects on the most sensitive receptor. Such
values are particularly appropriate for the outdoor pollution levels.
Hoegg 1972 points out that since we spend most of our life indoors
we should concentrate more effort on achieving such high standards
indoors.

10.   DESIGN IMPLICATIONS

Caution is needed in translating laboratory studies into practical
situations. In the laboratory every precaution is taken to ensure
uniform mixing within the room and fans ensure this. In normal rooms
the air flow pattern, velocity and turbulence can result in non-uniform
conditions within the room. Smoke has a relatively large particle
size ($\sim 0.2\mu$) and therefore has a very low natural diffusion. The
degree and uniformity of dilution therefore depends upon the mechanical
mixing with the room air.

Accepting an average cigarette consumption of 17 per day per smoker
for Britain and 29 for USA we need to calculate appropriate clean
air dilution rates. Assuming eight hours sleep and three hours
over the day for meals the average consumption will be 1.3 cigs/hour
for British smokers and 2.2 cigs/hour for Americans. The minimum
air flow for this average smoker necessary to keep the carbon monoxide
level below 9 ppm is 12 m^3/h for Britain and 20m^3/h for America.
Preferred values will be at least 52 m^3/h per smoker in Britain
and 88 m^3/h in America. The probability concept of Halfpenny &
Starrett 1961 can be applied to large open plan offices containing
one hundred people or more. Such an office is likely to represent
a normal population cross-section and only half will smoke. This
means that the ventilation rate per person will be half that needed
for the smoker. This agrees with the current British Guide. However
the worst situation is that of the two person office where there
is a high probability that both may smoke or one may smoke at a
higher rate than average. For offices of small size it would be
desirable to introduce some flexibility in design so that while the
fresh air for the building would be constant there would be some
adjustment between offices to cater for individual differences
in smoking habits. The probability levels of the offices of
different sizes containing smokers is shown in Figure 10. Such
an approach could be extended as more data becomes available on
smoking habits.

For comparison the minimum amount of fresh air ventilation needed
to control body odours in an office of 8 m^3 per person is
approximately 20 m^3/h/person. Where smoking is permitted the

-28-

corresponding fresh air is 40 m^3/h/person. The American minimum is 8.5 m^3/h per person in non-smoking areas and 42 m^3/h with smoking. Preferred values for U.S. offices are 51 m^3/h. The empirical development of the air conditioning engineers in refining their codes of practice in the light of experience agrees with the laboratory expectations of large offices.

Body odours are related to personal volume and odour concentration while cigarette smoke is a simple pollutant and only relates to smoke concentration. Ventilation air should be considered separately for these two functions and the highest value chosen. In offices where the personal volume is small the ventilation should be based on body odours, in spacious offices the ventilation should be based on likely smoking habits. This approach is used by ASHRAE.

11.   CONCLUSIONS

1.   The amount of fresh air needed to dilute cigarette smoke
     is the dominant design criterion for ventilation design.
     Over twice the air is necessary for the average smoker
     than for the dilution of normal body odours.

2.   Environmental standards are reviewed and compared with the
     products of burning tobacco. Most of the research in
     cigarette smoke has been concerned with the mainstream
     inhaled smoke. It is only recently that the sidestream
     smoke, which affects the passive smoker, has been
     studied in depth. Carbon monoxide is the most critical
     health factor if the recommended limit of 9 ppm is accepted.
     Nine cubic metres of air are needed per cigarette to keep
     below 9 ppm. Particulate matter from cigarettes is the
     next most sensitive and acrolein, a toxic lacrimator
     particularly sensitive to eyes and respiratory passages,
     is the third.

3.   Comparison of the different research studies on a
     common basis of air dilution needed per cigarette shows
     a wide variation in results. This can partly be
     attributed to the differences in tobacco, smoking
     conditions and my crude assumptions taken to bring the
     data on a common base. The little data available on
     differences between people suggests that these are wide.
     The mean assessment of an environment would only satisfy
     74% of the population and to cater for 98% requires a
     doubling of the air flow.

4.   Application of laboratory data to offices shows a wide
     difference between small offices and large offices.
     Large offices of 100 or more people are likely to be
     representative of the country's working population.
     Small offices are much more likely to contain a wide
     variety of occupants, on some occasions all smokers and
     other times all non-smokers. Some flexibility in design
     of such offices to cater for these differences is
     proposed.

5.   There is reasonable agreement in the Codes of Practice
       of Britain and America to reflect the smokers habits
       of the respective countries for normal large office conditions.
       The British IHVE Guide over-supplies dilution air in crowded
       smoky rooms and undersupplies in spacious rooms where smoking
       is permitted. There is a strong argument of principle
       in favour of treating smoking as a simple contaminant
       as the Americans do rather than linking it with body odour
       dilution.

6.   More research is needed into the variability between people
       on the detailed air movement within rooms, and on the
       detailed gas composition in rooms containing smokers.

12. REFERENCES

1.   American Conference of Government
                                      Industrial Hygienists.   .
                                      Committee on threshold limits
                                      1971.

2.   American Industrial Hygiene
                                      Association Journal. Total
                                      particulate matter. AIHAJ, 30
                                      428-434, July/August, 1969.

3.   Andersen, I.B.   Human nasal mucosal function
     Lundqvist, G.R. &   under four controlled humidities.
     Proctor, D.F.   Am. Rev. Resp. Disease, 106,
                                      438-49, 1972.

4.   Anderson, G. &   Halsoriskerna vid passiv rokning.
     Dalhamn, T.   (Health Risk due to passive smoking).
                                      Lakartidning, 70, 2833-2836, 1973.

5.   Annis, J.C. &   Vacuum cleaning: a source of
     Annis, P.J.   residential airborne dust.
                                      ASHRAE Symp. Bull. C1-72-1, 15-20,
                                      1972.

6.   ASHRAE Handbook of Fundamentals.
                                      Chapter 11, Odors, 1972.

7.   ASHRAE Handbook of Fundamentals
                                      (1972). Chapter 22. Heat gain
                                      due to ventilation and infiltration,
                                      420-22, 1972.

     Banaszak, E.F.,   Hypersensitivity pneumonitis
     Thiede, W.H. &   due to contamination of an air
     Fink, J.N.   conditioner. New England Journal
                                      of Medicine, 283 (6), 271-276
                                      1970.

     Benson, F.B.,   Indoor-outdoor air pollution
     Henderson, J.J. &   relationships - a literature review
     Coldwell, D.E.   National Env. Res. Centre, U.S.
                                      Department of Commerce, Public AP
                                      112 August, 1972.

     Bergen, J. von.   Industrial odor control. Chemical
                                      Engineering Report. August, 239-
                                      250, 1957.

     Bogardus, H.F. &   Studies of the Naval Facilities
     Ramskill, E.A.   Engg. Command. Protective Shelter:
                                      Summer Trials. NRL Report 6656
                                      Chapter 3, 33-35 1968.

Bogen, E.

The composition of cigarettes and cigarette smoke. J. Am. Med. Assoc. 83, 1110-1114, 1929.

Bokhoven, C. & Niessen, J.H.

Amounts of oxides of nitrogen and carbon monoxide in cigarette smoke, with and without inhalation. Nature, 192 (4801) 458-459, 1961.

Bradford, J.A.
Harlow, E.S.
Harlan, W.R. &
Hanmer, H.R.

Nature of cigarette smoke. Ind. & Engg. Chemistry, 29 45-50, 1937.

Bridge, D.P. &
Corn, M.

Contribution to the assessment of exposure of non-smokers to air pollution from cigarette and cigar smoke in occupied places. Env. Res. 5, 192-209, 1972.

British American Tobacco Corporation. Telephone data. 1975.

British Standards. Draft Code of Practice CP3, Chapter 8: Ventilation, 1974.

Brundrett, G.W.

Some effects of thermal insulation on design. Applied Energy, 1, (1), 7-30, 1975.

Brunnemann, K.D. &
Hoffman, D.

Chemical studies on tobacco smoke. J. Chromatographic Science, 12 (2) 70-75, 1974.

Cameron, P.

Second hand tobacco smoke: children's reactions. Journal of School Health, 42 (5) 280-284, 1972.

Carhart, H.W. &
Piatt, V.R.

Chemical Constitutents of Nuclear-Submarine atmospheres. Chapter 8. NRL Report 6053, US Naval Research Laboratory, Washington, D.C. 1963.

Cederlof, R, and
Colley, J.

Epidemiological investigations on environmental tobacco smoke. Scand. J. Resp. Dis. Suppl.91, 47-49, 1974.

Coburn, R.F.
Forster, R.E. &
Kane, P.B.

Considerations of the physiological variables that determine the blood carboxyhemoglobin concentration in man, Journal Clin. Invest. 44 (1) 1899-1910 1965.

Community Air Quality Guides. Alderhydes. Am. Ind. Hyg. Assoc. J. 29, 505-512, 1968.

Community Air Quality Guides. Phenol and Cresol. Am. Ind. Hyg. Assoc. J. 30, 425-428, 1969.

Conkle, J.P.
Mabson, W.E.
Adams, J.D.
Zeft, H.J. &
Welch, B.E.

Detailed study of contaminant production in a space cabin simulator at 760 Mn of Mercury. Aerospace Medicine, 38 (5) 491-499, 1967.

Consolazio, W.V. &
Pecora, L.J.

Minimal replenishment air required for living spaces. ASHVE Paper 1310, 127-156, 1947.

Corn, M.

Characteristics of tobacco sidestream smoke and factors influencing its concentration and distribution in occupied spaces. Scandinavian J. of Resp. Dis. Supplement 91, 21-36, 1974.

Crowden, G.P.

The height of rooms in dwellings in relation to health and comfort J. Roy. Sanit, Inst. 72, 108-120, 1951.

Davies, D.M.

The application of threshold limit values for carbon monoxide under conditions of continuous exposure. Ann. Occup. Hyg. 18, 21-28, 1975.

Dreyfus, M.,
Croiset, M.,
Courant, P. and
Berthier, J.

Hygrothermique et ventilation. CSTB Report REEF 58, 1958.

Environmental Protection Agency. A guide for air polution episode avoidance. Office of Air Programs, North Carolina, USA, June, 1971.

Eysenck, J.H.   Smoking and personality.
            British Medical Journal,
            1456-60, 14th May, 1960.

Fassett, D.W.   Industrial Hygiene and
            Toxicology. Vol. II -
            Toxicology - Aldehydes and
            acetals. 1967.

Fletcher, C.M.   Pipe and cigar smoking: Report
Donovan, J.W.   of an expert group appointed
Lawther, P.J.   by action on Smoking and
Waller, R.E.   Health. Practitioner,
and Ball, K.P.   210, (1259) 645-652, 1973.

Fuchs, N.A.   The mechanics of aerosols.
            Pergamon Press, 1964,
            184.

Galuskinova, V.   3, 4 Benzpyrene determination
            in the smoky atmosphere of
            social meeting rooms and
            restaurants. Neoplasma,
            11 (5) 465-468, 1964.

Godin, G.   Urban exposure to carbon
Wright, G.and   monoxide. Arch. Env. Health.
Shephard, R.J.   25, 305-313, 1972.

Goromosov, M.S.   The physiological basis of
            health standards for dwellings.
            World Health Organisation,
            Geneva, 1968. Public Health
            Paper 33.

Halfpenny, P.F. &   Control of odour and irritation
Starrett, P.S.   due to cigarette smoking aboard
            aircraft. ASHRAE 3, 39-44,
            1961.

Harke, H.P.   Zum problem des 'Passiv-Rauchens'
            (The problem of passive smoking)
            Munch. Med. Wochensehr,
            112, (51) 2328-2334, 1970.

Harke, H.P.   Problems of passive smoking.
Baars, A,   Int. Arch. Arbeitsmen. 29,
Frahm, B,   323-339, 1972.
& Peters, H.

Harke, H.P. and   Problem of passive smoking.
Bleichert, A.   Int. Arch. Arbeitsmed.29,
                        312-322, 1972.

Harmsen, Von H.   Tabakrauch in Verkehrsmitteln,
and Effenberger, E.   Wohn-und Arbeitsraumen. Arch.
                        Hyg. Bakteriol. 141, 383-400,
                        1957.

Hauser, T.R. and   Analysis of aliphatic fraction
Pattison, J.N.   of air particulate matter.
                        Env. Sci. Technol. 6, 549-555,
                        1972.

                        Health Department Great
                        Britain. Nicotine and tar
                        yield in cigarettes June, 1974.

Hendler, E.   Chapter 3. The gaseous requirements.
                        Physiological problems in space
                        exploration. ed. Hardy, J.D.
                        Thomas Publishers, Illinois,
                        U.S.A.

Henson, C.O. and   Studies on the nicotine content
Haley, D.E.   of cigarette smoke. J. Agric.
                        Res. 51 (3), 267-276, 1937.

Hill, L.   Humidity and ventilation.
                        JIHVE 11, 1910.

Hinds, W.C. and   Concentrations of nicotine and
First, M.W.   tobacco smoke in public places.
                        New England Journal of Medicine,
                        292, 844-845, 1973.

                        HMSO. Social Trends (4).
                        Smoking Habits, 1972.
                        1973.

                        HMSO. Social Trends. No. 5,
                        p.146. 1974.

Hobbs, M.E.   Some compounds of gas phase
Osborne, J.S. and   of cigarette smoke. Anal. Chem.
Adamek, S.   28, 211-215, 1956.

Hoegg, U.R.   The significance of cigarette
                        smoke in confined spaces.
                        M.Cc. Thesis. Department of
                        Env. Health, University of
                        Cincinnatte, 1972.

Hoegg, U.R.

Cigarette smoke in confined spaces. Environmental Health perspectives 2, 117-128, October, 1972.

Hoffman, D.
Rathkamp, G.
Brunnemann, K.D. and
Wynder, E.L.

Chemical studies on tobacco smoke. Science of the total Environment. 2, 151-171, 1973.

Hoffman, D. &
Wynder, E.L.

Smoke of cigarettes and little cigars: an analytical comparison. Science, 178, 1197-1199, 1972.

Huber, G.L.

Smoking and the non-smoker. New England J. Medicine, 292, 858-859, 1975.

Hurtley, W.H.

Ventilation in relation to expired air and dust. JIHVE 12, 39-54, 1911.

Institution of Heating and Ventilating Engineers Guide 1970. IHVE, London, 1972.

Jensen, C.O. &
Haley, D.E.

Studies on the nicotine content of cigarette smoke. J. Agric. Res. 51 (3), 267-276, 1935.

Johansson, C.R. &
Ronge, H.

Akuta irritationseffekter av tobaksrok i rumsluft. Nord. Hyg. T. 46, 45-60, 1964.

Johansson, C.R. &
Ronge, H.

Klimatinverkan pa lukt och irritationseffekt av tobaksrok Preliminart meddelande. Nord Hyg. T. 47, 33-39, 1965.

Johnson, W.R.,
Hale, R.W.,
Nedlock, J.W.
Grubbs, H.J. &
.Powell, D.H.

The distribution of products between mainstream and sidestream smoke. Tobacco Science, 17, 141-144, 1973.

Jones, G.W.
Yant, W.P. &
Berger, L.B.

Carbon monoxide hazards from tobacco smoke. U.S. Bureau of mines Report of Investigations 2529, 1923.

Jones, R.M. &
Fagan, R.

Application of mathematical model
for the build up of carbon monoxide
from cigarette smoking in rooms
and houses. ASHRAE Journal
49-53, August, 1974.

Kee, G.W.

Your place in the 'Smart Man's
War'. Heating, Piping and
Air conditioning. 14,
(8), 463-466, 1942.

Keith, C.H. &
Tesh, P.G.

Measurement of the total
smoke issuing from a burning
cigarette. Tobacco Science
26, 61-64, 1965.

Kerka, W.F. &
Humphreys, C.M.

Temperature and humidity effect
on odour perception. Trans.
ASHAE 65, 531-552, 1956.

Kilburn, K.H.

Effects of tobacco smoke on biological
systems. Scand. J. Resp. Dis.
Suppl. 91, 63-78, 1974.

Koelega, H.S. &
Hoster, E.P.

Some experiments on sex
differences in odour perception.
Ann. N.Y. Acam. Sci. 237, 234-260,
1974.

Kuehner, R.L.

The effects of moisture content
on the diffusion of odours in
the air. ASHVE Trans. 53, 77-90,
1947.

Kuehner, R.L.

The bacteria and odor control
problem in occupied spaces.
ASHVE Trans. 59, 77-79, 1953.

Kuehner, R.L.

Validity of odour measurements.
Ann. N.Y. Acad. Sci.
58, 175-186, 1954.

Keuhner, R.L.

Humidity effects on the odor
problem. ASHAE, 62, 249-256,
1956.

Lawther, P.J. &
Commins, B.T.

Cigarette smoking and exposure
to carbon monoxide. Ann. N.T.
Acad. Sci. 174, 135-147, 1970.

Lefcoe, N.M. &
Inculet, I.I.

Particulates in domestic
premises. Arch. Env. Health,
22, 230-238, 1971.

Lemberg, W.H. Brandt, A.D. & Morse, K.	A laboratory study of minimum ventilation requirements: ventilation box experiments. Trans. ASHVE 41, 157-170, 1935.
Leopold, C.S.	Tobacco smoke control - a preliminary study. ASHVE Trans. 51, 255-270, 1945.
Luquette, A.J. Landiss, C.W. & Merki, D.J.	Some immediate effects of a smoking environment on children of elementary school age. J. School Health, 40, (10), 533-536, 1970.
MacEwen, J.D.	Toxicology. Chapter 10, 455-467, from Bioastronauts data book. NASA SP 3006 2nd. ed. 1973.
McNall, P.E.	Reduction of tobacco smoke contaminants in interior spaces by means of filtration. Scand. J. Resp. Dis. Suppl. 91, 37-43, 1974.
Michels, K.M. Phillips, D.S. Wright, R.H. & Pustek, J.	Odor and olfaction: a Bibliography, 1948-1960. Perceptual and Motor skills, 15, 475-529, 1962.
Mitchell, R.J.	Controlled measurement of smoke. Amer. Rev. Resp. Dis. 85, 526-533, 1962.
Muir, D.C.F.	Tobacco smoke inhalation, 44-46. Scand. J. Resp. Dis: Suppl. 91, 1974.
Neurath, G. Ehmke, H. and Schneemann, H.	Uber den Wassergehalt von Haupt - und nebenstromrauch. Beitrage zur tabakforschung 3, (5), 351-357, 1966.
Newsome, J.R. and Keith, C.H.	Original not seen but abstracted from Wynder, E.L. & Hoffman, D. 1967 (Ref. 125).
Owens, D.F. & Rossano, A.T.	Design procedures to control cigarette smoke and other air pollutants. ASHRAE Semi-annual meeting, Chigaco, Illinois, Jan, 27-30, 1969, 75, 93-102.

Parker, J.F. & West, V.R.	Ed. Bioastronautics data book. NASA SP 3006. 2nd ed. 1973.
Penkala, S.J. & Oliveira, G. de	The simultaneous analysis of carbon monoxide and suspended particulate matter produced by cigarette smoking. Environmental Research, 9, 99-114, 1975.
Prentiss, A.M.	Chemicals at war. McGraw Hill 1937.
Rice, R.L. Perrier, R.S. & Runeckles, V.C.	A weight loss technique for determining rate of static burn. Tobacco Science 14, 173-175, 1970.
Russell, M.A.H. Cole, P.V. and Brown, E.	Absorption by non-smokers of carbon monoxide from room air polluted by tobacco smoke. The Lancet, March 17th, 1973. 576-579.
Russell, M.A.H. Cole, P.V. Idle, M.S. and Adams, L.	Carbon monoxide yields of cigarettes and their relation to nicotine yield and type of filter. British Medical Journal, 12th July, 1975, 71-73.
Russell, M.A.H. & Feyerabend, C.	Blood and urinary nicotine in non-smokers. The Lancet, 25th January, 1975, 179-186.
Rylander, R.	Perspectives on environmental tobacco smoke effects. Scand. J. Resp. Diseases 1974, Suppl. 91.
Saunders, R.A. and Saalfeld, F.E.	Improved methods for the detailed analysis of trace contaminants in Submarine atmospheres. US. Navel Laboratory Report 6251, 1965.
Schievelbein, H.	On the question of tobacco smoke. Internist 14, 236-343, 1973.
Schmeltz, I., Hoffmann, D, and Wynder, E.L.	The influence of tobacco smoke on indoor atmospheres. Preventine medicine, 4, 66-82, 1975.

Seiff, H.E.   CO as an indicator of cigarette
                                     caused pollution levels in
                                     intercity buses. Fed. Highway,
                                     Admin. U.S. Dept. Transportation,
                                     1973.

Spier, F.   Tobacco and the non-smoker.
                                     Archives of Environmental
                                     Health, 16 (3), 443-446, 1968.

Stewart, R.D.   The effects of low concentrations
                                     of CO in man. Scand. J. Resp.
                                     Dis. 56-62, 1974.

Stewart, R.D.   Experimental human exposure to
Peterson, J.E.   carbon monoxide. Arch. Env. Health
Baretta, E.D.   21, 154-164, 1970.
Bachand, R.T.
Hosko, M.J. &
Herrman, A.A.

Sullivan, R.J.   Air pollution aspects of odourous
                                     compounds. NAPCA Dept. Health,
                                     Washington, Contract PH-22-68-25,
                                     September, 1969.

Taylor, G.   Tobacco Smoke allergy: does it
                                     exist. Scand, J. Resp. Dis. Suppl.
                                     91, 50-55, 1974.

                                     Tobacco Research Council,
                                     London, 1975.

Turk, A.   Measurements of odorous
                                     vapors in test chambers:
                                     theoretical. ASHRAE J. Oct.
                                     1963, 55-58.

                                     U.S. Department of Health,
                                     Education and Welfare.
                                     Smoking and health: Report
                                     of the advisory committee to
                                     the Surgeon General of the
                                     Public Health Service. PHS
                                     Publication 1103, January, 1964.

                                     U.S. Department of Health.
                                     Report AD 736097. Health aspects
                                     of smoking in aircraft. December
                                     1971.

Viessman, W.

Weigh odor control methods
carefully. Heating, Piping,
Air Conditioning
September, 1959, 249-250

Waibel, M. &
Wanner, H.U.

Suspended particulate matter
and benzopyrene emissions.
Experimentia, 30, 1559-1562,
1974.

Weber, A.

Preliminary results from a
study of tobacco smoking.
ETH, Zurich, Switzerland. 1975.

'Which'. Consumers'
Association report on cigarettes.
280-285, 1971.

'Which'. More about Smoking
Consumers Association report.
February, 1975, 56-59.

Whitby, K.T.
Algren, A.B.
Jordan, R.C. &
Annis, J.C.

The ASHAE air borne dust survey.
Heating, Piping & Air
conditioning, 185-192 November,
1957.

World Health Organisation.
Air quality criteria and guides
for urban air pollution.
WHO Tech, Rep. Series 506, 1-35pp.
1972.

Wynder, E.L. &
Hoffman, D.

Tobacco and tobacco smoke.
Academic Press, N.Y. 1967.

Yaglou, C.P.

Ventilation requirements for
cigarette smoke.
Trans. ASHAE 1955, Paper 1534,
25-31.

Yaglou, C.P.
Riley, E.C. &
Coggins, D.I.

Ventilation requirements,
Heating, piping and air
conditioning 8, 17, 65-76,
1936.

Yaglou, C.P.
Riley, E.C. &
Coggins, D.I.

How much outside air is
necessary for ventilation.
Heating and Ventilating,
31-35, March 1936

Yaglou, C.P. and
Witherridge, W.N.

Ventilation requirements.
Trans. ASHAE 42, 423-436

Ziel, H.E. &
Sleik, H.

The economic factors in
converting saturated air for
ventilation. Heating, piping
and Air conditioning. 42,
(7), 367-372.

13.   ACKNOWLEDGEMENTS

TABLE 1

ACROLEIN PRESENT IN CIGARETTE SMOKE

Author	Machine smoking: Laboratory studies		
	mainstream mg/kg	sidestream mg/cig.	Total mg/cig.
Newsome, Norman & Keith 1965	0.07		
Wynder & Hoffman 1967	0.007		
Harke, Baars, Frahm & Peters 1972			0.4-0.6
Hoffman, Rothcamp, Brunneman & Wynder, 1973	0.075		
Weber, 1975			0.7

TABLE 2

GASES FOUND IN CIGARETTE SMOKE   (from Hobbs 1956 quoted in Surgeon General's Report)

	Conc. ppm	Threshold limit values for 8h exposure‡ ppm	Ratio above threshold	Toxic action on lung*
Carbon monoxide	42,000	50	840	Unknown
Carbon dioxide	92,000	5000	18.4	None
Methane, ethane etc.	87,000	500*	174	None
Acetylene, ethylene	31,000	5000*	6.2	None
Formaldehyde	30	2	15	Irritant
Acetaldehyde	3,200	100	32	Irritant
Acrolein	150	0.1	1500	Irritant
Methanol	700	200	3.5	Irritant
Acetone	1,100	1000	1.1	Irritant
Methyl ethyl ketone	500	250*	2	Irritant
Ammonia	300	25	12	Irritant
Nitrogen dioxide	250	5	50	Irritant
Methyl nitrite	200	–	–	Unknown
Hydrogen sulphide	40	10	4	Irritant
Hydrogen cyanide	1,600	10* ø	160	Enzyme poison
Methyl chloride	1,200	100	12	Unknown

*Values from Surgeon General report 1972

‡American Conference of Governmental Industrial Hygienists 1971

øOn skin

TABLE 3

CHEMICAL ANALYSES OF MAINSTREAM AND SIDESTREAM TOBACCO SMOKE

		CO mg/cig.	CO_2 mg/cig.	Nicotine mg/cig.	Furfual mg/cig.	Aldeydes mg/cig.	Ammonia mg/cig.	Phenols mg/cig	Hydrogen cyanide µg/cig.	Pyridines µg/cig.	Oxides of nigrogen mg/cig.	Acrolein µg/cig.	TPM mg/cig.	Tobacco smoked mg/cig.
Bogen 1929	M	3.5	38	0.2	0	0.4	0							
	S	14	605	9	0.4	1.3	3.0							
Jenson & Haley 1935	M			1.5										
	S			1.8										
Bokhoven & Niessen 1961	M	9	53											
	S													
Neurath et al 1964	M			1.5				0.2						347
	S			4.1				0.6						411
Keith & Tesh 1965	M	16.2	68.1						300				40.6	
	S													
Newsome, Norman & Keith 1965	M	23	77			1.1F	0.13		290			79		
	S													
Wynder & Hoffman 1967	M											70	~26F	
	S													
Scassellati & Savino 1968	M	22F	72F	0.46F			0.1-0.15F				0.012			
	S	3-5F	57-98F	0.8-1.7F			7-7.5F				0.077			
Hoegg 1972	M	18.6											36.2	
	S	87.6											25.8	
Hoffman & Wynder 1972	M	18F	60F	1.4F		0.77F			361F	27F		71F	20.3F	
	S													
Hoffman 1973	M	16.2	66.8	1.4F		0.77F	0.8	0.28	~360F	27F		71F	20.3F	
	S													
Johnson et al. 1973	M	22	76	} 2.6:1*			0.5		305	} 20:1*				230
	S	56	617	}			5.3		17	}				490
Brunneman & Hoffman 1974	M	16.3F	54.6F											
	S													
Penkala & Oliviera 1975	M	82.7											} 17.3	
	S												}	

* assumed 10 puffs per cigarette

+ only ratios given: sidestream to mainstream

F signifies filter cigarette

M signifies mainstream smoke

S signifies sidestream smoke

TABLE 4

CARBON MONOXIDE GENERATION BY CIGARETTES

Author		Machine smoking			People smoking
	Year	Mainstream mg/cig.	Sidestream mg/cig.	Total mg/cig.	Total in room cal. as mg/cig.
Jones, Yant and Berger	1923				47 calculated
Bogen	1929	3.5-18.6	14		
Harmsen and Effenburger	1957				126-188 calculated
Keith & Tesh	1965	16.2			
Srch	1967				22 calculated
Bogardus & Rampskill	1968				48 author's own data
Harke	1970			79	
Bridge & Corn	1972			129	89 author's est.
Harke, Baars, Frahm, Peters & Schultz	1972			70-94	>45
Hoegg	1972	19	88		
Hoffman, Rathcamp, Brunnemann & Wynder	1973	16.2			
Johnson, Hale, Nedlock, Grubbs & Powell	1973	22	56	78	
Scassellati-Sporzolini Savino	1973	18.9-23.4	3.0-4.9	21.9-28.3	
Hoffman, Rathcamo, Brunnemann & Wynder	1973	16.2			
Russell, Cole and Brown	1973				>22 calculated
Brunnemann & Hoffman	1974	13			
Penkala & Oliviera	1975			82.7	
Russell, Cole Idle & Adams	1975	4.9-28.1			
Davies	1975				100 calculated

TABLE 5

MARKET SHARES OF TOP FOUR BRANDS OF CIGARETTES 1973

Share*	Brand	Filter	Approx. wt. tobacco per 1000 cigs.* gms	Nicotine[x] yield mg/cig.	Tar Yield[x] mg/cig.
18.5	Players No. 6 filter	Yes	550	1.3	19
18.5	Embassy Tipped	Yes	750	1.3	19
7.0	Embassy Regal	Yes	700	1.1	17
6.0	Benson & Hedges King size	Yes	900	1.2	19

[x]Health Department: Great Britain June, 1974

*Tobacco Research Council

TABLE 6

PHYSICAL IRRITATION CAUSED BY SMOKERS

BOGEN	SPEER		CAMERON	"WHICH" CONSUMER MAGAZINE
1929	1968		1972	February 1975
U.S. Sample size not given	U.S. 250 non-allergic, 191 allergic		U.S. 1710 children	British: 1155 adults
smokers	non-smokers		7-15 yrs. old	non-smokers
Ill-effects: % population	Ill-effects: % population		Ill-effects: % population	Irritation type: % population
	Non-allergic	Allergic		
Shortness of breath 35%	Eye irritation 69%	73%	Eye irritation 47%	Stinging eyes 26%
Biting and irritation 30%	Nose symptons 29%	67%	Cough 37%	Coughing 16%
Coughing 30%	Headache 32%	46%	Headache 12%	Difficult breathing 8%
Burning 15%	Cough 25%	46%	Nasal irritation 11%	Nasal irritation 6%
Nausea 10%	Wheezing 4%	22%	Throat, nausea 5-10%	Sore throat 6%
Palpitation of heart 5%	Sore throat 6%	23%		Nausea 5%
Hoarseness 5%	Nausea 6%	15%		Headache 3%
Salivation 5%	Hoarseness 4%	16%		Dizziness 1%
	Dizziness 6%	5%		

TABLE 7

CURRENT MAXIMUM RECOMMENDED EXPOSURE LEVELS FOR CARBON MONOXIDE (AFTER DAVIES 1975).

Group	Country	Designation	Max. carbon monoxide conc. ppm by volume	Reference
normal occupations (eight hour exposure)	UK	TLV	50	IHVE 1970
	USA	TLV	50	ACGIH 1973
	DFR	MAK	50	MAK werte liste 1971 from Harke et al 1972.
	Czech.	TLV	30	ACGIH 1971
	USSR	TLV	18	Justov & Tiunov 1971
totally enclosed occupations (continuous exposure)	UK (submarines)	MPC_{90}	25*	Davies 1975
	USA (submarines)	MPC_{90}	25	NASA 1973
	USA (spacecraft)	MPC_{90}	15	NASA 1973
	USA (spacecraft)	MPC_{1000}	15	NASA 1973

TLV Threshold limit value   MPC Maximum permissible concentration (suffix denotes exposure days)

* Recommended to change to 15 ppm

TABLE 7 continued......

Group	Country	Designation	Max. carbon monoxide conc. ppm by volume	Reference
general population (continuous exposure)	USA	MPC	9	EPA 1971
	DFR	MPC	8	Knelson 1972
	USSR	MPC	1	Kustov & Tiunov 1971

MPC Maximum permissible concentration (suffix denotes exposure days)

TABLE 8

CURRENT MAXIMUM RECOMMENDED EXPOSURE LEVELS FOR PARTICULATES, PHENOLS AND ALDEHYDES

Group	Pollutant	Authority	Designation	Maximum concentration		Source
				mg/m^3	ppm by volume	
normal occupations 8h exposure/ day	particulates	ACGIH 1971	TLV	10.0	-	IHVE 1970
	phenol	ACGIH 1971	TLV	19.0	5.0	IHVE 1970
	cresol	ACGIH 1971	TLV	22.0	5.0	IHVE 1970
	formaldehyde	ACGIH 1971	TLV	3.0	2.0	IHVE 1970
	acrolein	ACGIH 1971	TLV	0.25	0.1	IHVE 1970
general population (continuous exposure)	particulates	WHO 1972	respiratory symptoms	0.1	-	Rylander 1974
		AIHA 1969	AQV	0.075	-	AIHAJ 1969
	Total phenols	AIHA 1969	AQV	0.1	-	AIHAJ 1969
	formaldehyde	AIHA 1968	AQV	0.15	0.1	AIHAJ 1968
	acrolein	AIHA 1968	AQV	0.025	0.01	AIHAJ 1968

WHO = World Health Organisation; AIHA=Am.Ind. Hyg. Assoc.; AIHAJ = Am. Ind. Hyg. Assoc. Journal

AQV = Air quality value; TLV = Threshold limit value; ACGH = American Comm. Gov. Ind. Hyg.

APPENDIX 1

IHVE 1970 GUIDE

Section A1   Comfort p.9

In offices and residences where there is no process load and where
an acceptable non-odorous atmosphere is needed.

TABLE A1.7

Minimum ventilation rates where density of occupation is known

Air space/person m^3	Fresh air supply					
	Minimum		Recommended Minima			
			No smoking		Smoking	
	1/s	m^3/h	1/s	m^3/h	1/s	m^3/h
3	11.3	41	17.0	61	22.6	81
6	7.1	26	10.7	39	14.2	51
9	5.2	19	7.8	28	10.4	37
12	4.0	14	6.0	22	8.0	29

This is attributed to the work of Yaglou 1936

Section A9   Estimation of Plant Capacity

TABLE A9.24   Recommended fresh air quantities for air conditioned
rooms

Examples*	Smoking	Recommended/person		Minimum +			
		1/s	m^3/h	person		per m^2	
				1/s	m^3/h	1/s	m^3/h
Factories	none	8	29	5	18	0.8	2.9
Hotel rooms	heavy	12	43	8	29	1.7	6.1
Offices – private	heavy	12	43	8	29	1.3	4.7
Residences – av.	heavy	12	43	8	29	–	–
Executive offices	very heavy	25	90	18	65	6	21.6

* more comprehensive list in original   + take the greater of the two

APPENDIX 1   continued

Section B2   Ventilation and air conditioning requirements

Table B2.1   Minimum ventilation rates where density of occupation is known

Identical to Table A1.7 based on odour removal

Table B2.2   Mechanical ventilation rates for various types of building

Offices 4-6 air changes/hour

Table B2.4   Recommended fresh air quantities for air conditioned rooms

Identical to Table A9.24

Section C6   Statutory and other regulations

Four Codes of Regulations for textile industries prescribe a standard
of ventilation in terms of carbon dioxide. The basic requirement is
that the carbon dioxide inside shall not exceed that outside by 8/10,000.
Normally 800 ft^3/person/h($23m^3h$) would comply.

The four Acts are:

The Spinning and Weaving of Flax and Tow Regulations 1906.
The Hemp and Jute Regulations 1907.
The Cotton Cloth Factories Regulations 1929.
The Jute (safety, Health and Welfare) Regulations 1948.

APPENDIX 2

BRITISH STANDARDS: DRAFT CODE OF PRACTICE CP3 CHAPTER 8
PART 1 VENTILATION (Document 74/12264 September 1974)

EXAMPLES OF RATES OF VENTILATION DURING PERIODS OF OCCUPANCY

Room	Assumptions	Criteria	Requirement*		Approx. air changes per hour
			1/s	m^3/h	
Kitchen (during cooking + two hours)	$U = 1.74$ $W/m^2{}^\circ C$ outside 5°C inside 20°C (a) gas cooker (b) electric cooking (c) 12 kW flued gas boiler	No condensation on walls	(a) 15 (b) 10 (c) 12	54 36 43	
Bedrooms	$U = 1.7$ $W/m^2{}^\circ C$ two people 20 m^3 outside 0°C inside 10°C	(a) acceptable odour dilution (b) no condensation on walls	10 6	36 22	1.8 1.1
Living rooms	four people 48m^3 3 kW flued gas heater	(a) acceptable odour dilution (b) air for combustion	16 3	58 11	1.2 0.2
Bathrooms	one person 14 m^3	(a) acceptable odour dilution (b) no condensation on walls	3.5	13	1.0 3.0
W.C.	.7 m^3	acceptable odour dilution	8	29	4
General office	7.5 m^3/person	acceptable odour dilution	6	22	3
Individual office	15 m^3/person 3 cigarettes/hour	acceptable odour dilution annoyance by tobacco smoke	3 8	11 29	0.8 2
Schools	5m^3/person	acceptable odour dilution	8	29	6

*values are not additive - use largest appropriate

APPENDIX 3

PROBABILITY OF OFFICE SAMPLE CONTAINING SMOKERS

The average percentage of smokers for Britain is approximately 50% of the adult population. In catering for large group sizes the ventilation design can assume this value. However as the group size reduces we have to consider the possibility of our group containing more smokers than the average population. The extreme of this is the individual office which may contain a smoker or not and hence the design has to ventilate on the probability of smoking.

Let us now consider probability theory:

  let n be the group size

  P_s be the proportion of smokers in the group

  q_{ns} be the proportion of non smokers in the group

The standard deviation σ of the population of smokers is given by

$$\sqrt{n\,P_s\,q_{ns}}$$

Accepting 99.9% probability of catering for all the smokers (3σ, one tail) we have

No. in group	Mean no. of smokers	Standard deviation σ	99.9% limit (3σ)	No. of possible smokers at 99.9% confidence	% group population
100	50	5	15	65	65
50	25	3.5	10.5	35.5	71
20	10	2.25	6.75	16.75	84
10	5	1.6	4.8	9.8	98

Similar values can be derived at probabilities of 95% (1.7σ, one tail) and 90% (1.2σ, one tail).

WEIGHT PER CIGARETTE
mg

TAR
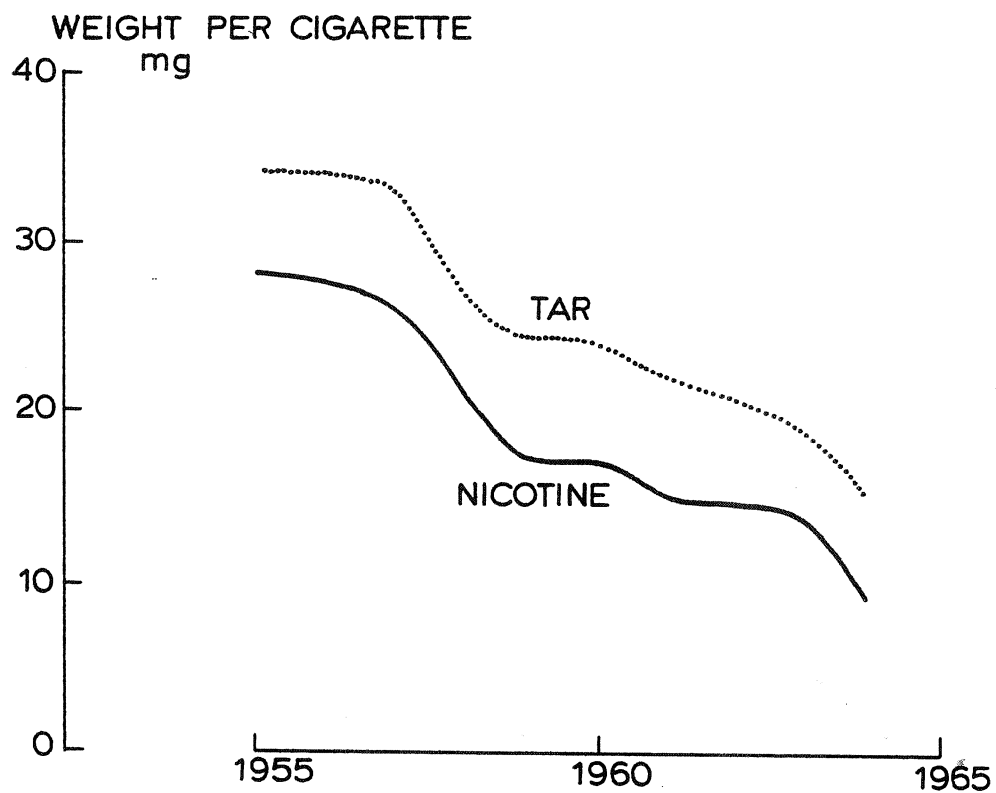
NICOTINE

MOSHY 1967
ED. WYNDER & HOFFMAN
ACADEMIC PRESS

FIGURE 1.
CHANGE IN TAR AND NICOTINE IN AMERICAN
CIGARETTES.

ECRC/M 870

FIGURE 2.
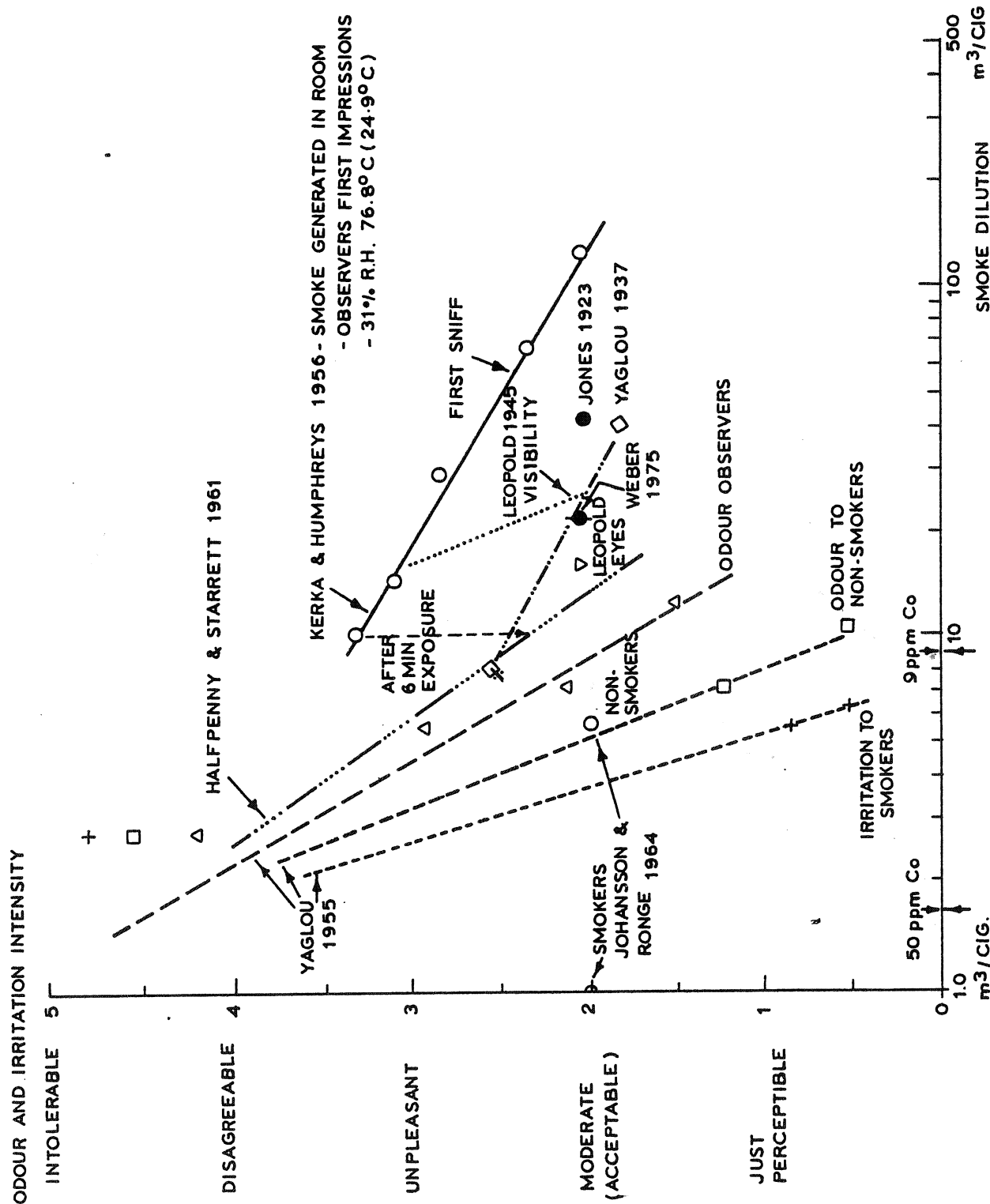PERCEPTION OF ODOURS AND IRRITATION AS A FUNCTION OF SMOKE DILUTION.
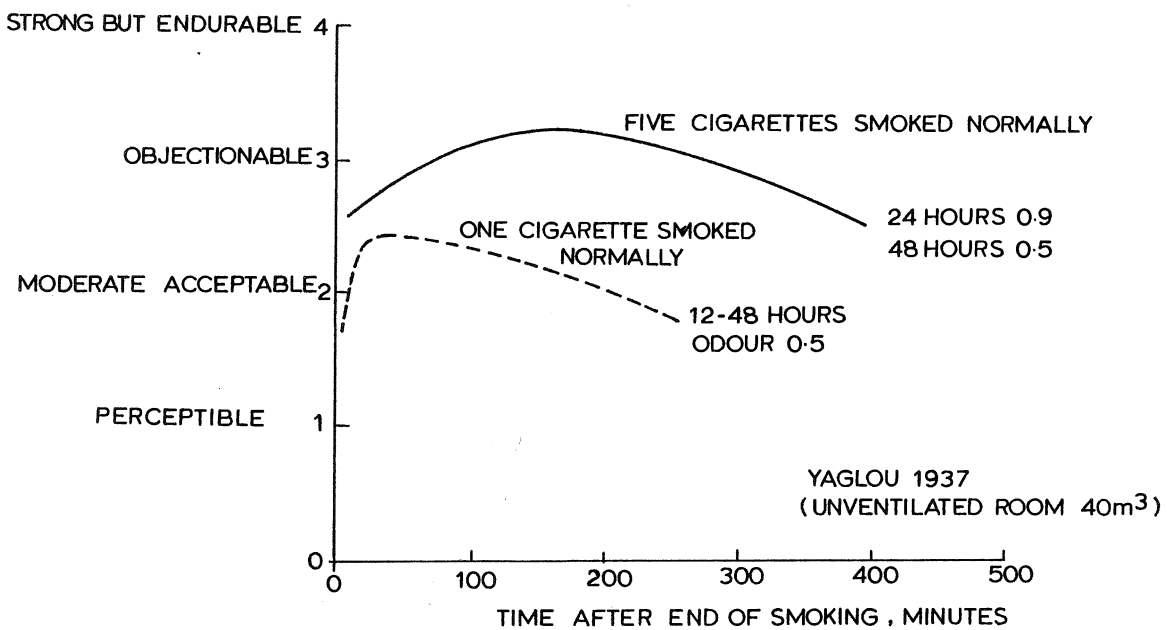
ODOUR INTENSITY SCALE

STRONG BUT ENDURABLE 4

OBJECTIONABLE 3

FIVE CIGARETTES SMOKED NORMALLY

24 HOURS 0·9
48 HOURS 0·5

ONE CIGARETTE SMOKED
NORMALLY

MODERATE ACCEPTABLE 2

12-48 HOURS
ODOUR 0·5

PERCEPTIBLE 1

YAGLOU 1937
(UNVENTILATED ROOM 40m^3)

0

0   100   200   300   400   500

TIME AFTER END OF SMOKING, MINUTES

FIGURE 3.
DISAPPEARANCE OF TOBACCO SMOKE IN A CLOSED ROOM.
    ECRC/M 870
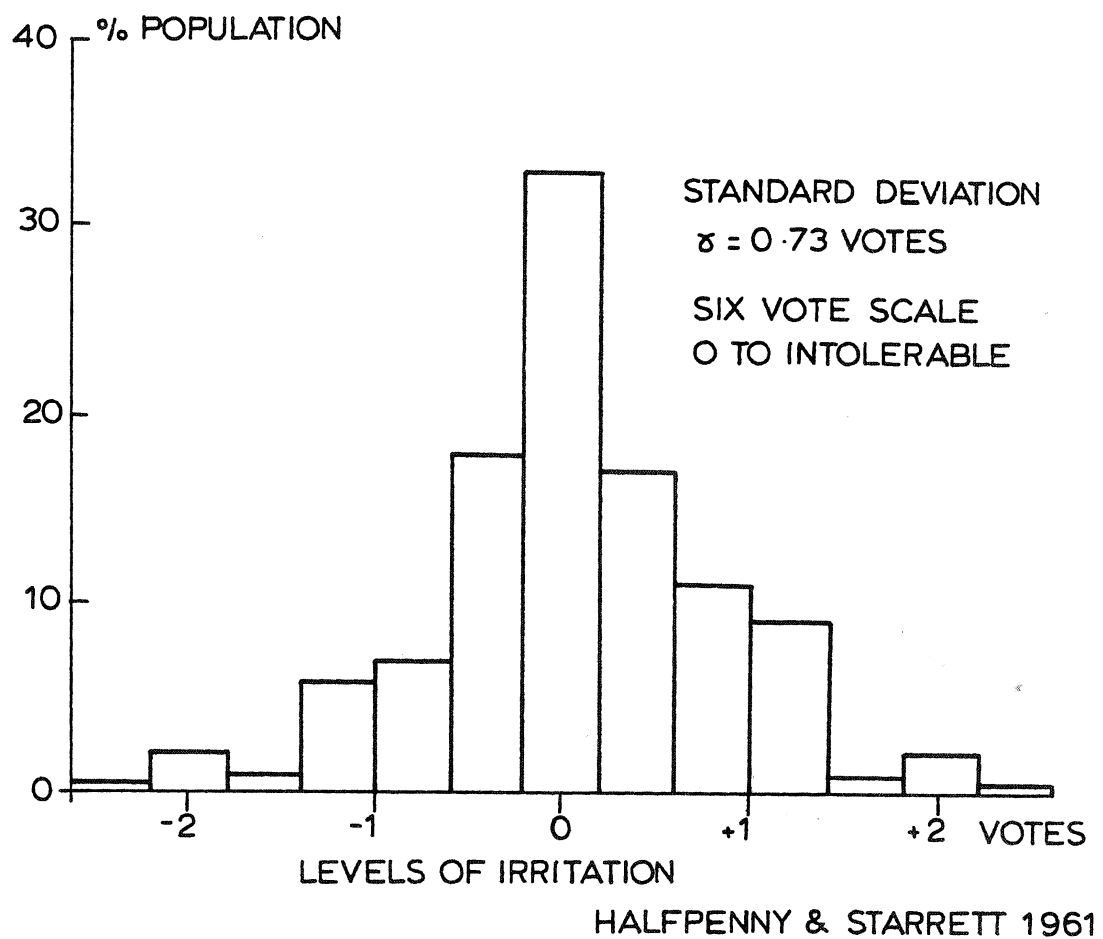
FIGURE 4.
AVERAGE DISTRIBUTION OF JUROR RESPONSES
TO IRRITATION.

ECRC/M870

ODOUR INTENSITY
─────────────

OBJECTIONABLE 3

MODERATE,ACCEPTABLE 2

PERCEPTABLE 1

RELATIVE HUMIDITY

30%

50%

70%

90%

15   20   25   30
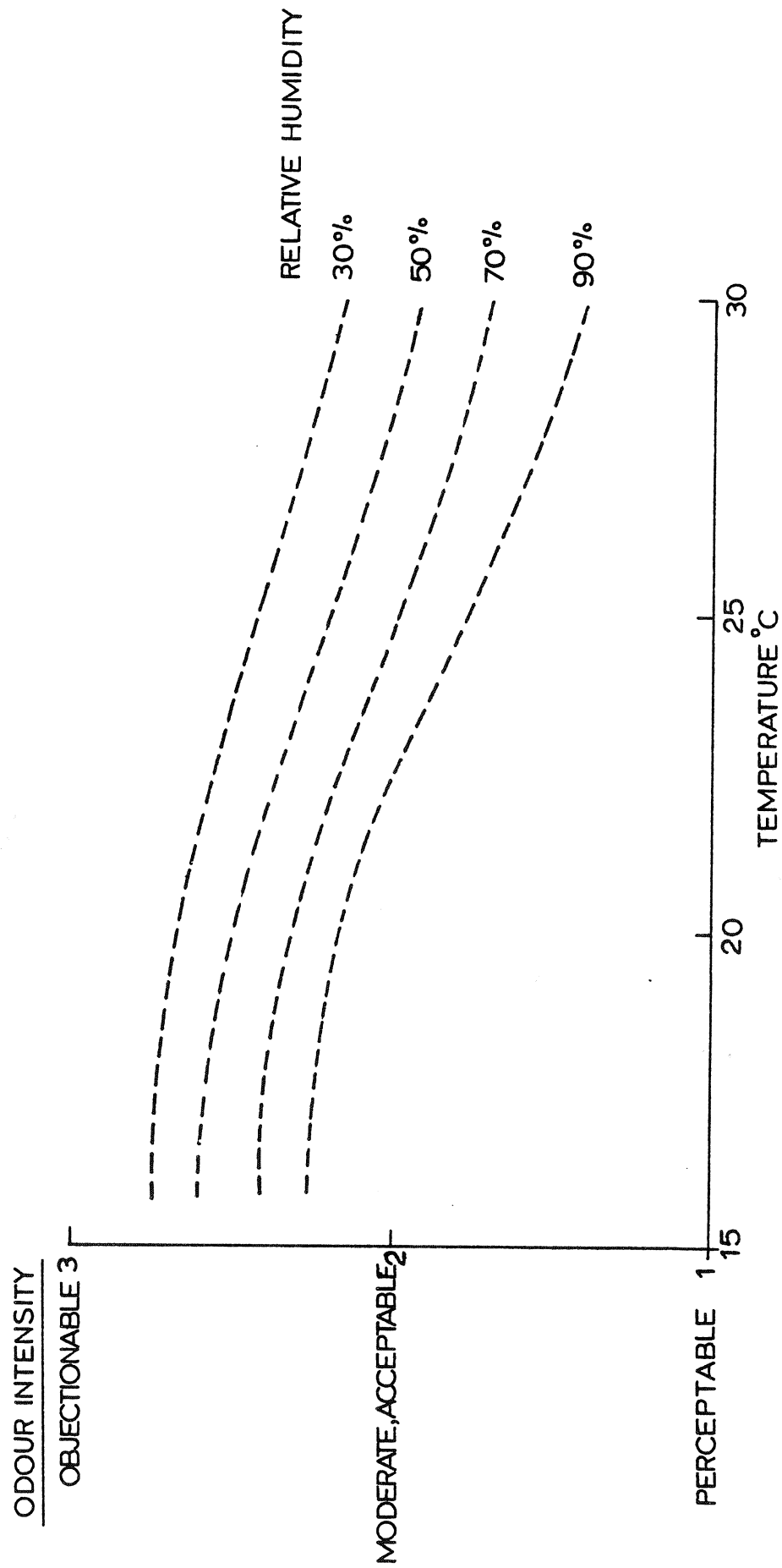
TEMPERATURE °C
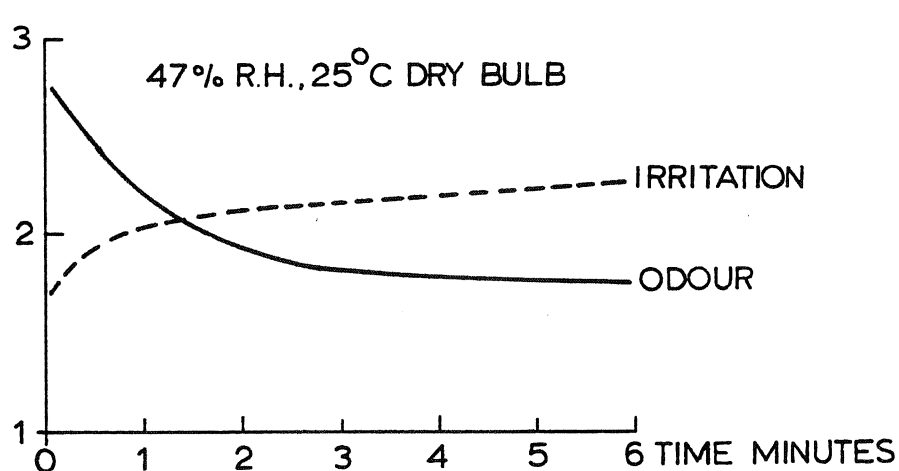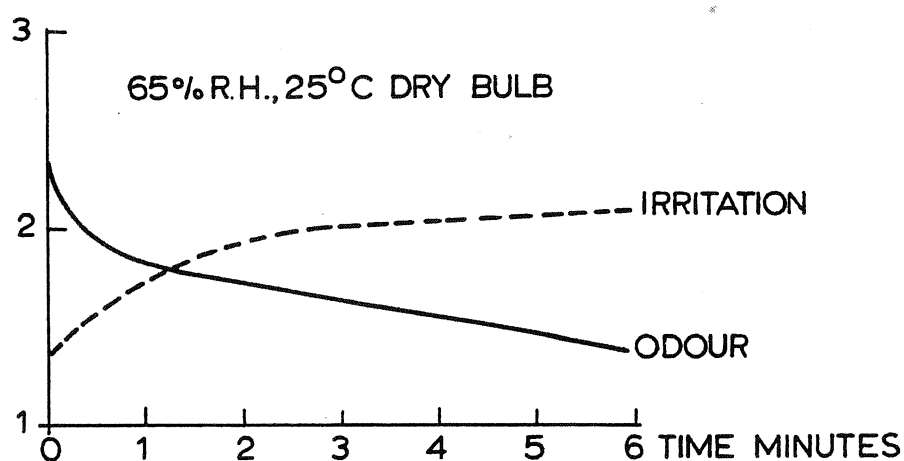
KERKA & HUMPHREYS 1956

FIGURE 5.
THE INFLUENCE OF TEMPERATURE AND HUMIDITY ON ODOUR INTENSITY.

ECRC/M 870

FIGURE 6.
CHANGE WITH TIME OF SMOKE ODOUR SENSITIVITY
AND IRRITATION.

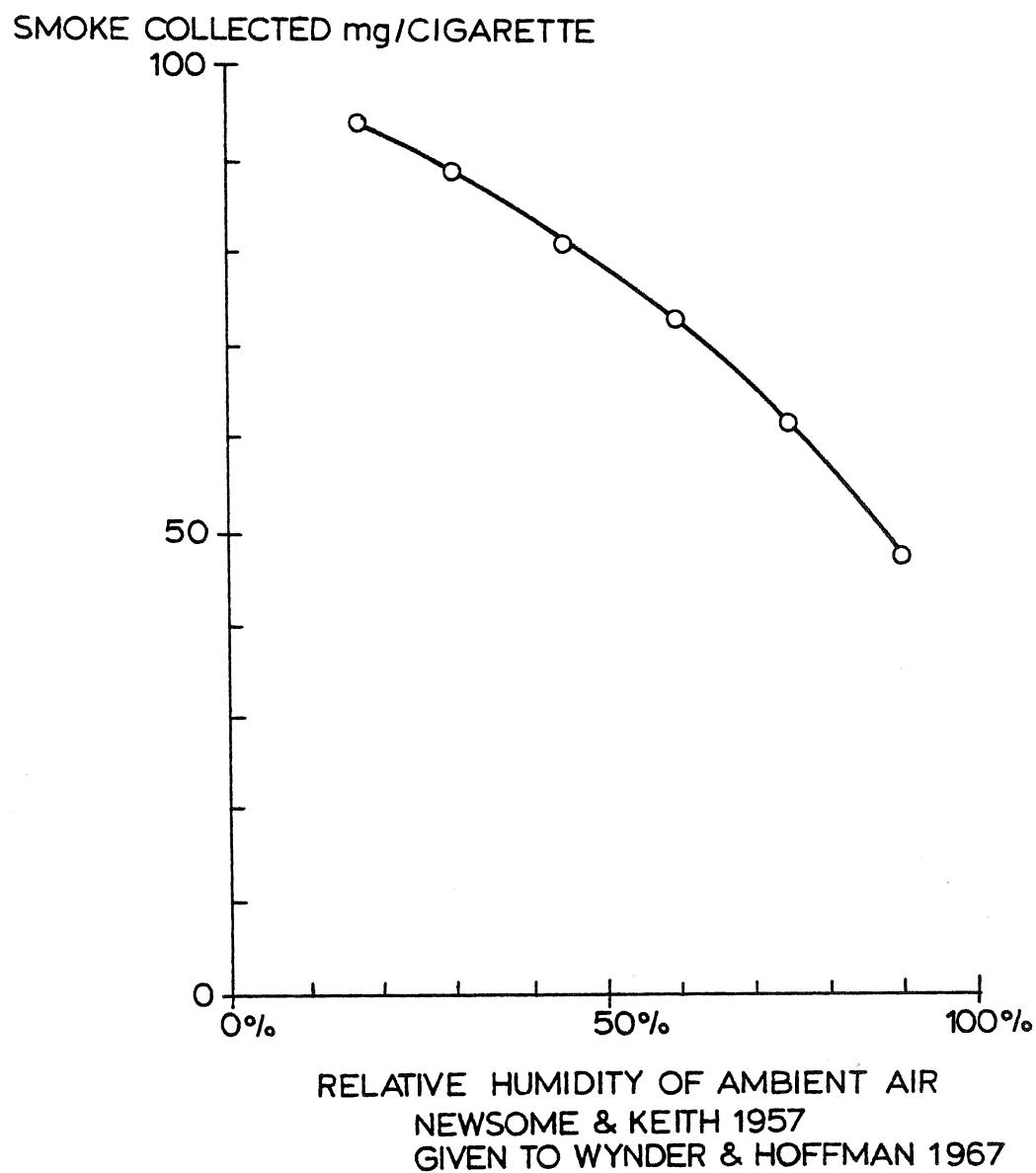ECRC/M 870

SMOKE COLLECTED mg/CIGARETTE

FIGURE 7.
RELATIONSHIP BETWEEN SMOKE RELEASE AND
ROOM RELATIVE HUMIDITY.

ECRC/M 870
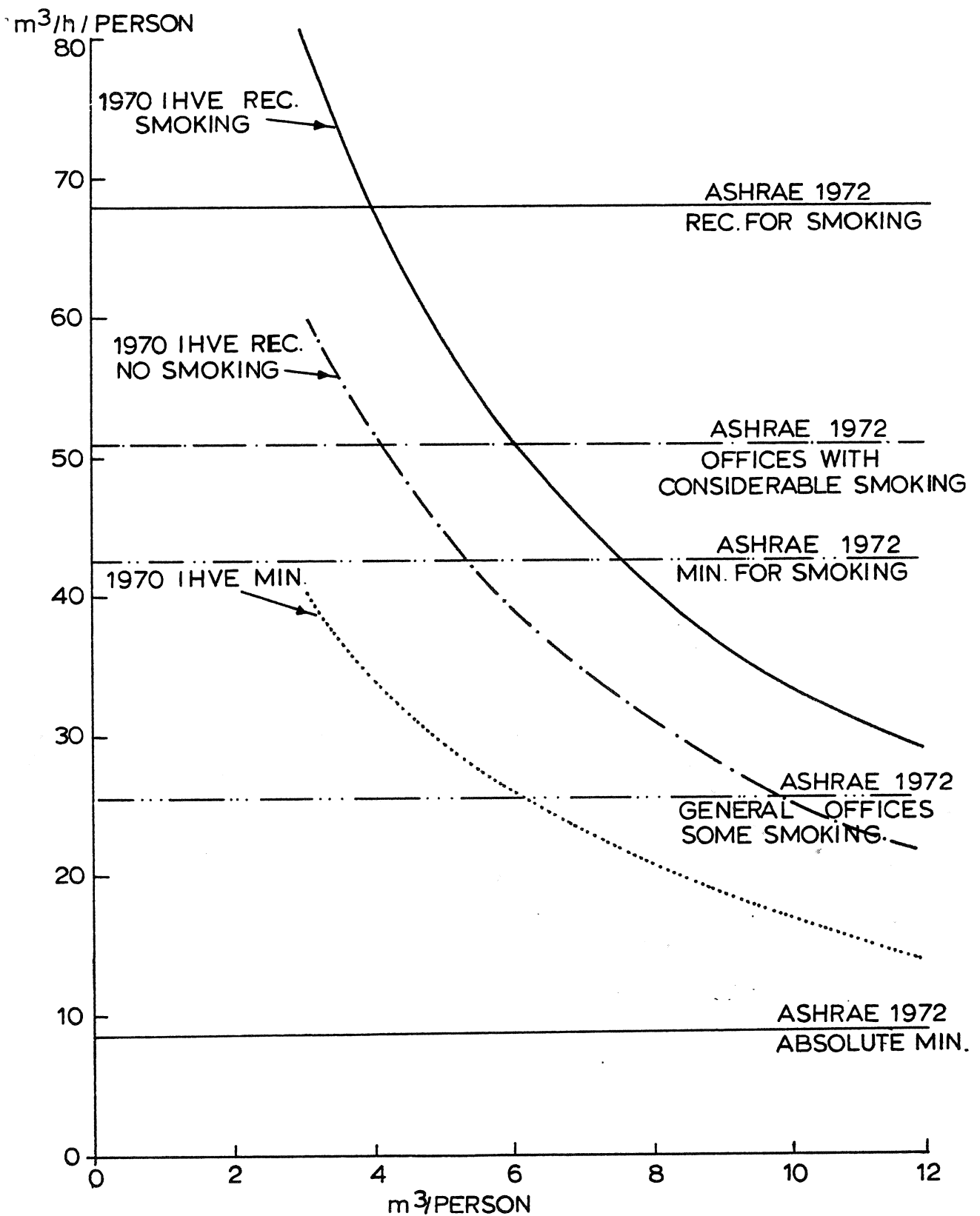
FIGURE 8.
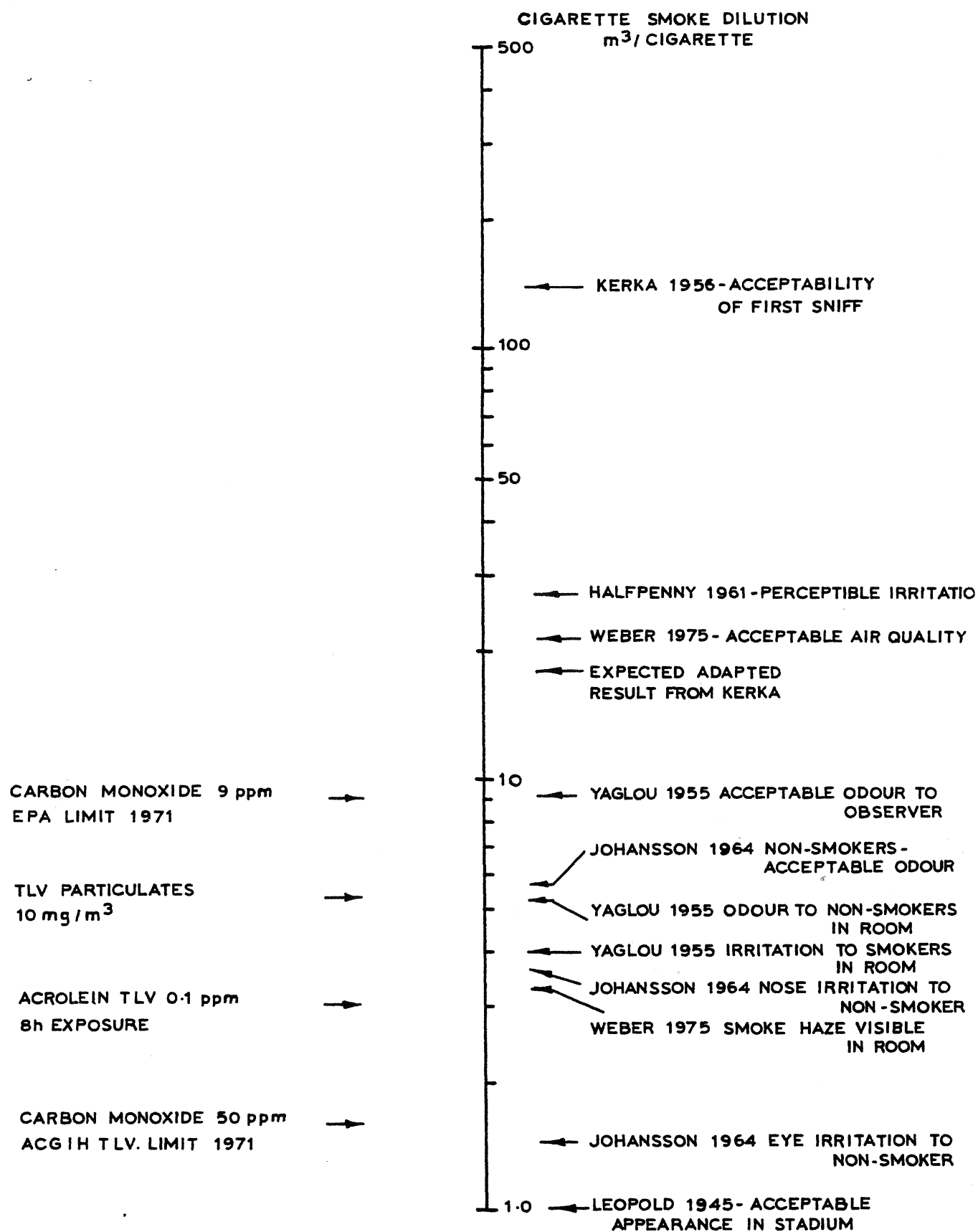**COMPARISON BETWEEN AMERICAN AND BRITISH**
RECOMMENDATIONS.

ECRC/M 870

CIGARETTE SMOKE DILUTION
m³/ CIGARETTE

—500

← KERKA 1956-ACCEPTABILITY
OF FIRST SNIFF

—100

—50

← HALFPENNY 1961-PERCEPTIBLE IRRITATIO

← WEBER 1975- ACCEPTABLE AIR QUALITY

← EXPECTED ADAPTED
RESULT FROM KERKA

—10   ← YAGLOU 1955 ACCEPTABLE ODOUR TO
OBSERVER

CARBON MONOXIDE 9 ppm →
EPA LIMIT 1971

JOHANSSON 1964 NON-SMOKERS-
ACCEPTABLE ODOUR

TLV PARTICULATES →
10 mg/m³

YAGLOU 1955 ODOUR TO NON-SMOKERS
IN ROOM

← YAGLOU 1955 IRRITATION TO SMOKERS
IN ROOM

ACROLEIN TLV 0·1 ppm →
8h EXPOSURE

← JOHANSSON 1964 NOSE IRRITATION TO
NON-SMOKER

WEBER 1975 SMOKE HAZE VISIBLE
IN ROOM

CARBON MONOXIDE 50 ppm →
ACGIH TLV. LIMIT 1971

← JOHANSSON 1964 EYE IRRITATION TO
NON-SMOKER

—1·0   ← LEOPOLD 1945- ACCEPTABLE
APPEARANCE IN STADIUM

FIGURE 9.
COMPARISON OF HEALTH RECOMMENDATIONS WITH
SUBJECTIVE RATINGS.

ECRC/M 870

PROVISION FOR SMOKERS IN THE ROOM

99·9% PROBABILITY OF MEETING SMOKERS VENTILATION NEEDS.

95%

90%

ASSUMED 50% POPULATION SMOKE

NUMBER IN ROOM
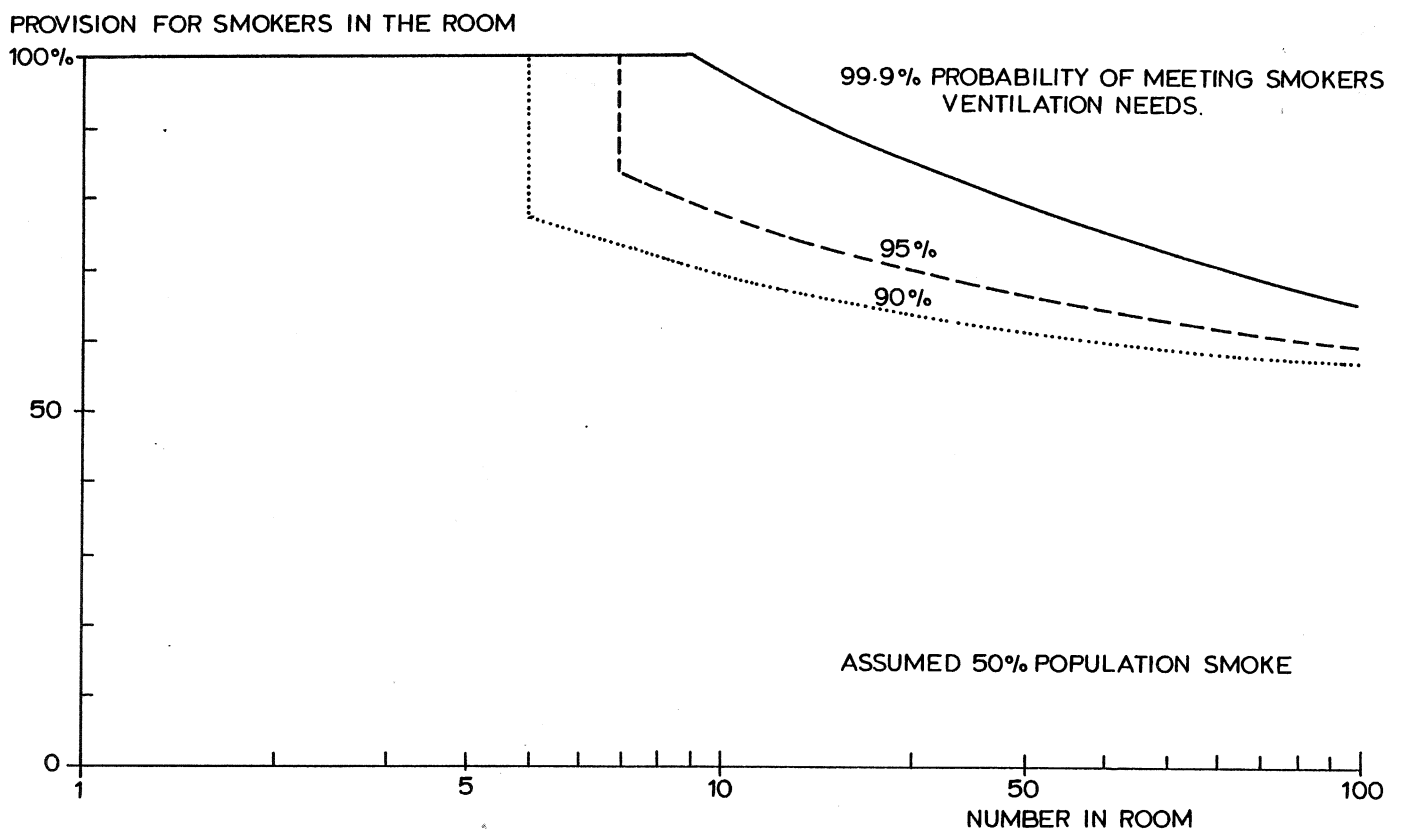
FIGURE 10.
PROVISION FOR SMOKERS IN THE ROOM AS A FUNCTION OF GROUP SIZE.
ECRC/M 870   (SEE APPENDIX   )