INDOOR ENVIRONMENT: HEALTH ASPECTS OF AIR QUALITY, THERMAL ENVIRONMENT, LIGHT AND NOISE

Preface

The World Health Organization (WHO) and the United Nations Environmental Programme (UNEP) are striving to ensure greater consideration of environmental health measures in the planning and development of human settlements and housing. The preparation of environmental health criteria and guidelines is useful to decision makers and professional personnel not only in the health sector, but in such sectors as housing, public works and socioeconomic planning. It can serve as an underpinning for health promoting regulation of the built environment, and as a source of guidance about health promoting measures for design, construction and maintenance practitioners including architects, planners, engineers and builders.

The focus of this book is on the four important physical-chemical factors of the indoor environment. In recent years there has been a growing awareness of the health significance of the indoor environment by public health scientists, as well as those of other concerned fields. This has been sparked by the recognition that (a) some factors of the indoor environment may manifest adverse health effects which exceed those of the outdoor environment (e.g. air quality), and (b) vulnerable segments of the population (e.g. children, the elderly) depending upon latitude and season may spend a high proportion of time indoors and are thus disproportionally exposed to any adverse health conditions.

An effort has been made to include the most current scientific information about how the four physical-chemical factors relate to, and impact on health. Information has been drawn on a wide latitudinal scale from a great variety of sources. In this sense the book will be applicable to involved agencies and personnel in all countries. The last chapter contains guidance about how the guidebook may be used, and approaches that could be taken to accelerate improved practices for health promoting indoor environments. The information should be particularly useful in developing countries where application of new and updated knowledge has lagged behind the regulatory and construction practices of developed countries. It is hoped that this book will help to increase awareness of the health implications of the indoor environment, and the practical measures which can be taken to avoid hazards and create health promoting conditions; and further, that it will stimulate consideration of needed policies and actions on the part of relevant national sector agencies.

The idea for this book arose from discussions between representatives of the United Nations Center for Human Settlements (UNCHS), UNEP and WHO, which highlighted the need for new and improved ways of dealing with environmental conditions in low-income settlements. A WHO/UNEP Technical Panel on Environmental Health Aspects of Housing and Urban Planning which met in Moscow, USSR, in April 1985 selected this topic as a priority subject for an information and guideline document. A Working Group met in Moscow in November 1985 to consider the orientation of the document, and to prepare an annotated outline. Subsequently, the Panel in a meeting in Leningrad, USSR, in October 1986 reviewed and provided guidance on the early drafts. A list of the Panel and Working Group members is

presented below.

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INDOOR ENVIRONMENT: HEALTH ASPECTS OF AIR QUALITY, THERMAL ENVIRONMENT, LIGHT AND NOISE

Chapter 1. The aims and structure of the Guidebook

Basic Aim

The primary aim of this Guidebook is to provide a clear summary of current scientific information and experience on human health in relation to the indoor environment. The promotion of health in this context includes the fostering of comfort and well-being, as well as the reduction of the risks of ill health due to adverse indoor environments. Most people spend by far and away the greatest proportion of their lives inside buildings of various types. Shortcomings in indoor environments are therefore very significant for human health.

Indoor climate is strongly influenced by the impacts of outdoor climate. Any balanced summary of the effects of indoor climate on health has to include consideration of the impacts of the outdoor environment on the indoor environment. A particular emphasis has been laid on the needs in developing countries. The information is intended to help member states in the task of securing substantially improved indoor environmental conditions for people in buildings, in order to promote a better state of health in all countries. It is assumed governments will wish to take the lead role in achieving these goals, both in the formal and informal building sectors, but that many others will have significant contributions to make, which will be strengthened by access to improved and organized knowledge. Social and psychosomatic aspects of indoor environmental health have not been considered in the Guidebook.

Target Groups

The Guidebook on Indoor Environment is aimed at professional personnel in Government Agencies having responsibility for policy and for setting standards and norms for the indoor environment (housing, schools, administrative buildings etc.). This would include health, housing and planning agencies. The guidelines are applicable to personnel in agencies and groups responsible for increasing the awareness of improving indoor environment from the point of view of health (e.g. improving the education of professional cadres associated with building education of the general public

and also education within in the health sector). The Guidebook aims to communicate in a reasonably clear way at this professional level. The reinterpretation of the contents at the simpler level needed for full community participation is a task that must be undertaken locally.

Building Types Covered

The material presented is applicable to practically all building types. A special emphasis however has been placed on the health requirements in dwellings, the building type in which the majority of mankind spend most time. Specialized fields like factory ventilation for industries carrying out toxic and hazardous processes, air conditioning of hospital operating theatres etc, have been excluded.

The Growing Importance of Indoor Environment for Health

The increasing concentration of the human population in urban areas is presenting unprecedented threats to health and well being. Evolutionary processes throughout time have conditioned man to live in balance with both the health hazards and the health reinforcing features of the natural environment. The massive relocation of population to urban areas (by the year 2000, fifty percent of the world's population will live in urban areas) has great potential to create a serious imbalance in which environmental factors adverse to health may begin to dominate. New threats to health are being posed in modern society by the proliferation of chemicals, increasing industrialization, high rates of energy utilization, and congestion of buildings and activities. Serious overcrowding of living spaces is occurring, while simultaneously people are being deprived of access to many of the resources of the natural environment, which used to contribute positively to their health and well being. The environmental forms and structures of many contemporary urban developments are completely chaotic. This is especially so in the relatively unplanned informal settlements, which form such a characteristic part of the larger cities of the developing world. Special efforts are therefore needed to both control and alleviate the hazards posed by modern urban

conditions, and also to maintain and enhance those natural and man enhanced environmental features which afford positive support to health.

There is a widely held view that the main causes of indoor pollution lie mainly outside dwellings. However, as the Guidebook later shows, indoor environments are often much less healthy than outdoor urban environments. Indoor pollution is a major problem in its own right, which will not go away simply by improving the outdoor urban environment. Adverse indoor environments, sustained over considerable periods of time, are often precursors to serious disease, for example, as discussed in Chapter 3, sustained indoor air pollution from wood burning stoves can lead to severe chronic respiratory diseases and carcinomas.

We not only need to "green" the outdoor environment, but also the indoor environment. Furthermore, we have to "green" the indoor environment in ways that are compatible with the "greening" of the wider environment.

Indoor Environment Areas Covered in the Guidebook

This Guidebook is concerned with four main indoor environment areas which are of great importance for securing the health of people indoors in buildings:

(i)	The indoor thermal environment
(ii)	Indoor air quality
(iii)	Indoor lighting environment
(iv)	Indoor noise environment.

The objective has been to provide:

(i)   Current scientific information on the relationship between these factors in the indoor environment to health.

(ii)   Suggested general measures and approaches for health promoting environmental management.

Indoor Environment Health Goals

Preventive medicine should have a high profile in setting public health goals for the indoor environment. The health issues in the indoor environment can be divided into issues influencing the causation of specific diseases, and issues relating to the state of human physiological, perceptual and emotional well being. Furthermore, human productive performance is strongly influenced by indoor environmental conditions. Adverse indoor environments thus handicap successful economic development by substantially lowering human productivity. They are also a factor causing absenteeism through illness, further lowering output.

There are therefore two main health based objectives in the improvement of indoor environments, which emerge in the context of this Guidebook.

One objective is the achievement, by systematic and affordable means, of more satisfactory control of all recognized indoor health risks resulting from:

(i)	Adverse indoor thermal environments
(ii)	Poor indoor air quality
(iii)	Unsatisfactory indoor noise conditions
(iv)	Unsatisfactory indoor lighting conditions.

The second objective is to provide, again by systematic and affordable means, appropriate indoor conditions for effective human visual and auditory perception in conditions of thermal and respiratory comfort, in order to achieve indoor environments, which favour an effective, healthy, productive, creative, and socially acceptable lifestyle in buildings. This does not imply a constant environment.

A positive view of health must give a lot of importance to the second goal.

Indoor environments have to be responsive to changes in needs across the course of the day and year, therefore recognition has to be given to the variations in perceptual and thermal environments required to match the diurnal indoor patterns of work, social activity, family activity and rest, essential for human health and well being. This implies giving proper attention to issues of environmental controls to regulate the indoor environment to match human needs, for example cutting down on daylight and artificial light during relaxation, increasing it to carry out more difficult visual tasks, like sewing and reading. Such controls are often best operated by people to match their own needs. Control in indoor environments is also strongly linked with economy of energy use, and assumes a greater importance, now global warming has been identified as a key world problem.

Environmental Realism

As this Guidebook is particularly intended to help developing countries, careful attention has had to be given to identifying what actions are realistic in the face of the existing resource limitations. Taking account influences which may exacerbate or ameliorate effects of indoor environments on health, an attempt has been made to present the health implications of various levels of environmental conditions at three levels:

1. Desirable   i.e. levels of environmental conditions which promote human health and well being.

2. Permissible   i.e. levels of environmental conditions which are not

3. *Incompatible*   ideal, but which are broadly neutral in their impact on health and well being.

3. *Incompatible*   i.e. levels of environmental conditions which, if maintained, would adversely affect health and well being.

Environmental Exposure

Environmental exposure, and environmental vulnerability to that exposure, should be evaluated. Exposure may be continuous or may be episodic, for example a rare, very severe heat wave. Indoor environmental design standards for building new and for upgrading existing buildings must consider:

(i)   The intensity of exposure, recognizing that (due to variations in climatic conditions, cycles of industrial processes and many other factors) occasionally there will be exceptional conditions.

(ii)   The duration of exposure, for example taking into account that women, children and aged people spend a larger portion of their time in the home environment; and

(iii)   The particular vulnerability of certain groups.

Vulnerable Groups

The vulnerable groups specifically identified in this Guidebook are:

(a)   infants and young children
(b)   pregnant women and mothers nursing young children
(c)   elderly persons
(d)   handicapped and disabled people
(e)   under nourished people, particularly in cold environments.

Influence of the Outdoor Environment

The indoor environment is strongly influenced by the outdoor environment. The achievement of satisfactory indoor environments is partly dependent on the success with which the outdoor planning of settlements deals properly with control of the outdoor environment. The formation of the outdoor environment has to be regulated so as to improve the possibilities of securing a good indoor environment by appropriate building design. Good outdoor environmental planning implies in the context of indoor environments, planners accepting responsibility for ensuring that the outdoor environment at the building facades meets acceptable standards. This process has a very strong climatic component. Very close liaison has been maintained with World Meteorological Organization (WMO) in preparing this Guidebook.

Health Control Options

The analysis of indoor pollution environment protection shows there are several control options. The control options depend very much on the location of the cause of the adverse indoor environment. Action plans for improving indoor environments need to consider very carefully the different control strategies suitable to control different impacts. A broad classification of options is set out below.

Outdoor Sources

(i)   Control at source i.e. outside the building
(ii)   Distance control (moving source away from facade)
(iii)   Control at the outdoor/indoor interface (facade control)
(iv)   Control by appropriate location of the indoor activity in relation to the position of the outdoor health disturbing factor (room location control, e.g. putting bedrooms on quiet side of building).

Indoor Sources

(i)   Source control inside building
(ii)   Extraction or attenuation control within the room space
(iii)   Control at the indoor/outdoor interfaces (in-between room control)
(iv)   Control by appropriate location of the indoor activities within the building (room location control).

In general it is far better to control pollution at source, rather than after dispersal. Policy implementation implies a capacity to exercise proper control of the impact of outdoor environments on indoor environments through the establishment of norms and standards. The Guidebook provides quantitative material that should be of assistance in setting such norms and standards for control purposes.

Implementation Chapter

The final Chapter explains how to use the material in the Guidebook as a tool of policy. It suggests that each country should prepare a policy statement for the improvement of the indoor environment, and then implement an action plan. The steps needed in the implementation of the action plan are indicated. Very strong stress is laid on the need for multi-disciplinary working on an inter-sectoral basis. The needs of informal sector which present an especially difficult challenge, are discussed as well as the needs of the form sector. It is very strongly recommended that any new administrative responsibilities identified should be

met by building on existing structures and implementing suitable training to fill gaps in current capabilities. This final Chapter also discusses education and training in the broadest sense. This must involve the general public. No attempt has been made to identify the precise cadres involved in various professional areas at the technical level as these differ so much from country to country. It is, however, clear that much work at the day to day level will devolve to groups like building inspectors, hygiene workers, para-medicals etc. The programmes for indoor environment improvement will need effective mobilization at the wider social level, as well as within the structures of government. This step will be especially important in the informal sector.

Density

The influence of density and overcrowding on health are deliberately not discussed per se in this Guidebook. It is considered that the adverse effects of high density on health are expressed through the adverse influence of such occupancy conditions on the various aspects of indoor environment discussed in detail in the Guidebook. It is better to analyze the consequent indoor environmental impacts of density in a proper scientific environmental way, in order to achieve an understanding of the likely health impacts. Such an approach can also help indicate the probable environmental benefits of different corrective measures. Density, as used by architects and planners, is essentially a geometric concept, and not an environmental concept. High density may refer to a large number of occupants per unit floor area, several occupants per room, or a very high plot coverage. The buildings may be high or low. Very high plot coverage causes severe deterioration of the natural outdoor climate at the building facade, e.g. loss of sunlight, low UV irradiation, inadequate daylight, poor dispersion of pollutants, weak natural ventilation, but conditions are very much worse if the surrounding buildings are tall rather than low. The three dimensional shapes of the spaces about buildings, structure the impacts of the external climate on the external facade. These impacts require analysis in environmental terms. In the control of cross infection, it is better to have fewer occupants per room than more floor area per person. There will be more ill health in a highly polluted room occupied to low density than in a small well aired well lit unpolluted room occupied to high density. Therefore, the onus has been placed on any users of this Guidebook interested in the inter-relationships between building density, plot ratios and health, to reformulate their problem in indoor environmental terms instead.

Referencing Policy

No attempt has been made to provide comprehensive bibliographies. The world literature in the areas discussed is very extensive. The primary reference material has been drawn from the publications of UN Agencies, especially those of WHO, WMO and UNEP. Use has been made of publications by the regional offices of WHO, as well as those produced by WHO Geneva. Other key international references have been included, for example to internationally used environmental engineering manuals. Some reference has been made to the work of international standardizing bodies, especially the International Standards Organization (ISO), which deals with standards in acoustics and indoor thermal environment, and the Commission Internationale de l'Eclairage, (CIE) which deals with daylighting and artificial lighting.

Cross Links with other International Issues of Current Concern

As this project has progressed, several new important international perspectives have emerged. The issues of global warming and the greenhouse gases have come well to the fore. There is also the issue of the impact of CFC's (chloro-fluoro-carbons such as freon), the key current refrigerant gas, on the ozone layer and the problem of meeting the Montreal Protocol. This strongly impacts on air conditioning policy. The Bruntland report has provided an overview concerning sustainable development and environment. The importance of energy conservation, and natural cooling has moved up the international agenda. Energy is very critical for sustaining healthy indoor climates in adverse climates. Health policy has to relate to other aspects of development, so an attempt has been made to indicate where the key intersectoral interactions occur at appropriate points in the Guidebook.

Chapter 2
Thermal Environment

Introduction

The factors which determine the indoor thermal conditions are of primary importance for the performance of human activities, and maintenance of health and well-being. The factors are measured singly but they are act in combination, while the strength of one factor can be outbalanced by the strength of one or more other factors. The combination of the factors is often referred to as the **indoor microclimate**. This microclimate varies both in space and in time. The indoor microclimate is particularly strongly influenced by temporary outdoor climatic conditions in the local area or the surroundings. The combination of the factors indoors determines the thermal comfort which is based on **human judgement**. The thermal comfort of people is determined by the relationship between outdoor and indoor thermal climate.

Elements or factors

The thermal environment is determined by four elements which are assessed as factors:

temperature   humidity
heat radiation   air movement

These factors are expressed and qualified depending on the measuring method and definition in different ways:

Temperature:
            air, dry bulb temperature
            surface temperature (wall, floor etc)
            radiant temperature

Humidity:
            relative humidity
            absolute humidity, moisture content
            water vapor pressure
            dew point
            saturation deficit.

Heat Radiation:
            incident short wave infrared radiation
            outgoing long-wave infrared radiation.

Air movement:
            air velocity
            turbulent air velocity
            laminar air velocity
            air jets and streams
            air eddies, air rolls.

Measuring methods

The methods for measuring the physical factors indoors are identical with those used in the open atmosphere by the meteorological services. But there are additional instruments which have been particularly designed for the measurements inside enclosures, for gaining a more differentiated and detailed description of the conditions.

Temperature. The temperature of the air is measured with a dry-bulb mercury thermometer hanging in a free position. Recently electrical thermometers have come into use, and a number of hand-models and makes are commercially available. They are often combined with hydrometers. Values can be read directly in decimal figures. Precision should be in tenth of °C. For continuous recording, thermographs, alone or in combination with hygrographs and barographs are used. Surface temperatures are measured with fine wire thermocouples attached with tapes to the surface, or alternatively thermistor bead measuring devices pressed against the surface for short term measurements. For all situations it is always important to ensure proper shielding of the temperature measuring device from the radiation field. A mercury thermometer with its bulb in the sun does not measure the indoor air temperature.

Humidity. For instant determination humidity is calculated by measuring dry and wet-bulb temperatures using the mounted Assmann-type psychrometer. It consists of two thermometers of which one is covered with a wetted wick exposed to a mechanically aspirated air stream passing over it. Hand-held sling or whirling type psychrometers are also used, and are particularly suitable inside rooms in places sheltered from direct radiation. Humidity, water vapor pressure, and dewpoint, are then read from tables derived from the difference in the wet bulb and the dry bulb temperatures. For continuous measurement hair-hygrographs are suitable for recording of relative humidity at a resolution of 1%. Their reliability is limited unless they are kept carefully calibrated.

Short and long-wave heat radiation. Short wave radiation is measured with pyranometers. The common

instrument consists of a sensitive thermophile protected by one or two glass domes. The glass domes intercept the long wave radiation, so only short wave radiation reaches the detector. Long wave radiation is measured by means of the **globe thermometer** and is expressed as radiant temperature. The globe thermometer consists of a blackened hollow sphere of thin copper of 10 or 15 cm diameter, with a mercury thermometer inserted with its bulb placed at the centre of the globe, and the stem emergent. This blackened sphere absorbs the short wave and long wave radiation incident, and an equilibrium between gains and losses is established depending on the radiative field, and the rate of air movement over the surface of the globe. The temperature so measured is known as the globe temperature. If the radiant flux is positive, the globe temperature will be above room air temperature at that point; if the radiant flux is negative, it will be below. If the rate of air movement is known, and also the air temperature, the mean radiative flux can be derived from the globe temperature.

The structure of the thermal radiant field in rooms is complex, because of the wide range of temperatures encountered on different surfaces. It is common to simplify assessment by integrating the detailed directional impacts to obtain a mean value. The long wave radiative impact can be expressed as the mean radiant temperature, (MRT). The mean radiant temperature is the temperature of a perfect black body enclosure that would produce the observed total flux of radiation at the observing point. The mean radiant field at any point can be estimated using suitable instruments. Many radiative fields are very directional, for example the sun, or the beam from a reflector electric fire. The assessment of asymmetric radiative fields is more complex.

Air movement and velocity. As air velocities inside rooms are commonly low, only precision electrical hot-wire anemometers are suitable both to determine air streams of velocities as low as 5 cm/s and their direction. Mechanical cup anemometers are seldom of use inside enclosures.

Assessment of the Indoor Thermal Environment

There are six main components of the indoor thermal environment to be assessed in terms of their combined impact on the thermal sensation.

1.   *The indoor air temperatures at different points in the enclosure.*
2.   *The short wave radiative environment at different points in the enclosure.*
3.   *The long wave radiative environment which is especially influenced by the surface temperatures at different surfaces of the enclosure.*
4.   *The rate of air movement at different parts of the enclosure.*
5.   *The moisture content of the indoor air.*
6.   *The temperature of surfaces with which the body has direct contact. This is normally the floor.*

It is essential for human well-being that people should gain conditions of thermal comfort indoors in buildings designed for them (Goromosov, 1968). The conditions of thermal comfort are composed of the interaction between the thermal conditions, and the state of thermal adaptation and the clothing of the individuals. Defining the various acceptable combinations of thermal indoor microclimate, and providing the appropriate thermal conditions that are needed for comfort, are vital aspects of building environmental hygiene. Such information is essential in the process of setting thermal health criteria and thermal design norms for different seasons of the year for different types of buildings.

The indoor microclimate acts on man, directly as a key thermal and respiratory environmental factor, and indirectly, through the favourable habitats the indoor thermal environment may provide for other species, whose presence indoors may have adverse effects on the health of man. These include moulds growing on cold damp surfaces, mildew on blankets and clothing, insects like mites in warm dry carpets etc. The indirect impacts of the indoor thermal microclimate on health have to be evaluated as well as its direct impacts on thermal comfort.

The thermal parameters may **vary** considerably across an indoor space, both vertically and horizontally, for example people sitting near the windows will usually receive far more short wave radiation from the sun than those sitting at the back of the room. The body heat loss in winter by radiation to cold surfaces is greatest for those closest to the windows. With uninsulated roofs in the tropics, the long wave radiation falling on peoples' heads during daytime is usually much greater than that falling on their feet; under still indoor air movement conditions, in a single storied building, the air close to the roof during the heat of the day is often much warmer than the air near the floor.

The assessment of indoor thermal microclimate should always be based on thermal conditions at the living levels at the sites of the main human activities in each space. Gradients of temperature and air movement within this living zone, both vertical and horizontal, can affect comfort, as can adverse surface temperatures.

Instruments measuring combinations of factors

There are a number of criteria and indices which are designed to provide a comprehensive evaluation of the combined effects of the entire set of thermal effects on

people. Sometimes these indices have been used as the basis for developing special instruments, designed with the aim of providing analogous responses to the human body, for example the thermal comfort meter developed by the Technical University of Denmark (Madson, 1973). Such types of instrument are designed to register and indicate the heat exchange from their surfaces at temperatures close to that of the human skin or clothes. However they are unable to perfectly represent a person's thermal perceptions.

Physiological thermoregulation

"Man is a homeothermic organism. The regulation of the functions of the human body and physical and conscious activities depend on the generation, storage and dissipation of heat. The temperature of the human body is maintained nearly constant within the body core. All levels of structure of the body share in the regulation of the heat content, ranging from the intracellular systems, the cells, the organs, and the organ systems to the whole organism to achieve and maintain homeothermia. Homeothermia is an integrated function of homeostasis. Homeostasis is the embracing autonomic coordinating force that directs the functions at all system levels towards stability and efficiency of the body in response to the conditions and changes in the environment. Within homeostasis, homeothermia has a priority over other life sustaining functions and is of such vital importance that it does not depend on the autonomic regulation alone but is closely assisted by the consciousness"(Weihe, 1987).

There are currently well substantiated physiological classifications of the thermoregulatory state of adults and children exposed to different thermal environments. These thermal classifications are based on the degree of thermal strain engendered in response to the stress of different thermal microclimates. Three basic thermal conditions can be identified:

1. optimal thermal conditions, equal to thermal comfort;
2. permissible thermal conditions, equal to thermal discomfort;
3. unacceptable thermal conditions.

The thermal condition for people judged optimal, is characterized as the state of balance between heat gain and heat loss of the body at a level of minimum strain on the body's systems involved in the regulation of the maintenance of a neutral heat balance. The physiological and behavioral regulation mechanisms involved are summarized as temperature regulation. In this state, there are periodic fluctuations in skin temperature, and a relatively stable heat production. The sweat glands are inactive and there is the feeling of thermal comfort. The body core temperature

depends on age and ranges from 37 to 37.5 °C. The share of the heat exchange by evaporation amounts to 20-30% of the total heat loss.

The range of **permissible** thermal conditions for people is characterized physiologically by the presence of moderate strain on the systems involved in the temperature regulation. Extended exposure to such permissible conditions may reduce man's working ability by 10-20% compared with comfort conditions. Moderate thermoregulatory stress due to cooling leads to cold discomfort. It is characterised by a fall of temperature in the most distant parts of the body, although, at the chest, the temperature remains stable. The temperature gradient between the limbs and the deep body tissues is thus increased, and the rate of heat flow from the exposed surfaces of the body tends to rise. The latent period of the reflex responses to thermal effects, and the duration of the recovery periods of the skin responses and vascular responses after localised cooling, tend to become longer. They are accompanied by sensations of "warming comfort". At **permissible conditions for overwarm situations,** moderate thermal stress leads to heat discomfort. It is characterized by an increase in temperature in the limbs due to increased peripheral blood circulation, and activation of the sweat glands. The heat flow from the exposed body surfaces is much reduced under these conditions, while evaporation may amount to 40-50% of the total heat losses. The response time to thermal contact effects tends to decrease, and people evaluate their thermal state as on the warm side of comfort.

Severe and sharp cold stress, is characterized by the increase of heat production through muscle shivering in preserving the heat balance. When shivering is induced due to strong cooling, the heat production in the limbs increases. The resultant increase of heat in the organism initially increases the combined heat exchange by radiation and convection (i.e the intensity of heat flow to the environment per unit area increases). The skin temperature may also increase as a consequence. With further greater cooling, the skin temperature falls. Vasospasm (constriction of blood vessels) reduces the heat exchange, particularly in the limbs (severe thermoregulatory stress). This state is unstable, since extreme cooling tends to disrupt the heat balance and so reduce the body core temperature, producing extreme cold stress. Discomfort under conditions of strong cooling is also characterized by bradycardia and the development of inhibitory processes in the brain, thus reducing man's working ability. Thermal sensations range from "cold" to "very cold". Such extreme cold conditions are exceptional indoors and not often encountered.

In the case of very warm microclimates, **severe thermal stress** is characterized by reduced intensity of internal heat production, particularly in children, marked sweating to increase evaporative heat loss to exceed 50% of the overall heat losses and lower intensity of

heat flow per unit body area. The temperature of the body surfaces approaches that of the body core. The difference in temperature between the proximal areas situated towards the centre of the body and the distal body areas is largely eliminated. However the heart rate remains stable. The state of severe thermoregulatory stress due to heat is also unstable, and may lead to disruptions of the heat balance. The hindered rate of heat exchange, will result in accumulation of heat within the organism in spite of intensive sweating. The heart rate increases, and the body temperature may rise. Internal processes in the cerebral cortex slow down, and man's physical and mental working ability tends to decline. The thermal sensations are "hot" and "very hot". If the body temperature continues to rise, a total breakdown may occur with death from heat stroke. Very hot conditions are found indoors, especially in badly designed buildings with many windows.

Skin temperatures as an indicator

The regularity of the skin temperature changes in response to the prevailing thermal conditions in the indoor thermal microclimate, allows one to consider skin temperature as one of the most reliable physiological indicators of the thermal state of the human body. Skin temperature measurements can serve various purposes, for example the establishment of health criteria for indoor microclimates or outdoor clothes, or the investigation of acclimatization and adaptation. Means of skin temperature can be calculated from one point measurements over time, or based on measurements of at least 5 to 6 points across the human body surface, i.e. on the forehead, body and limbs. The average weighted skin temperature is established by taking the skin temperature at several predetermined points, and then weighting the readings according to the share of the total body surface area of which that point is representative. Naturally the more measurement points, the more accurate are the average weighted temperatures of the skin. Hardy and du Bois (1938) recommended 15 sites. Ranges of body and skin temperatures at different air temperatures are shown in FIGURE 1.

The warmest areas are the head and the trunk, the coolest the upper and lower extremities. At low air temperatures, the more distal the area, the lower the skin temperature. The range of the change of average skin temperature when man goes from extreme cooling to overheating is quite large, being approximately 15 °C.

With a stable body core temperature, when man is not exposed to the effects of extreme meteorological conditions, or carrying out intense muscular activity, man's thermal state can be physiologically characterized with sufficient accuracy by the value of the mean weighted skin temperature. Data on the mean weighted skin temperature can be used to

calculate the otherwise directly unattainable values of the quantity of heat in the body shell, whose mass and specific heat capacity are known. The shell mass in man amounts to about 50% of the body weight. An average temperature of the shell tissues can be accurately established, if one takes into account that, at a maximum, it differs 3 °C from the mean skin temperature (Burton and Edholm, 1955).

When the air temperature is high, or man is engaged in physical labour releasing heat from peripheral muscle combined with sweating, the weighted mean skin temperature ceases to be a sufficiently informative indicator of the human thermal state. The value is affected by the conditions of perspiration, and by the evaporation of sweat. Winslow and al. (1937) indicated that a skin temperature of 34-35.5 °C should be considered the critical temperature at which active perspiration begins. Belding and Hatch (1956) quote data indicating the critical skin temperature for the start of sweating for unacclimatized people as 36.5 °C, while, for acclimatized subjects, its value was 34.5 °C.

The pattern of the skin temperatures provides a more detailed physiological evaluation of man's thermal state, since it reflects the nature of the factors influencing skin temperature in the shell. Under changing thermal conditions exceeding the comfort range, the skin temperature values at the proximal and distal body areas go in different directions when thermal stress increases from the insignificant level to the moderate level (Fig. 1). On this evidence, it seems incorrect to use the mean weighted skin temperature as a leading criterion for the evaluation of the thermal state of man in conditions close to comfort. While the heat exchange from different spots of the body is very finely and accurately weighted, under conditions close to comfort, the mean skin temperature is a crude indicator. The averaging process can lead to the fact that the same values are found for adults and children of both sexes, in spite of considerable differences in the detailed distributions of skin temperature. The mean weighted skin temperature can serve as an auxiliary criterion that defines the thermal state of a standard person. A combination of spot and weighted mean skin temperatures are suitable indicators to show the transition from moderate thermal stress to severe thermal stress, particularly in the case of warm environments when the skin temperature at the limbs approaches that of the trunk (Fig. 1). Skin temperature changes indicate man's thermal state as long as perspiration is not occurring.

Perspiration and moisture losses

When the ambient temperature exceeds the body surface temperature, heat exchanges by convection and radiation almost cease, because of the diminishing temperature gradient between the deep and surface temperature. The only way to sustain an acceptably constant deep body temperature lies in heat dissipation

by sweat evaporation. At the point of thermal conditions where effective perspiration begins, the evaporation of sweat from the body surface either temporarily slows down or completely stops the skin temperature rise. The skin surface is always loosing some moisture due to insensible perspiration of moisture through the epidermis. The latent heat of its evaporation ensures the constant removal of 20-30% of the all the heat that is produced in the human organism. In physiological studies, the insensible skin perspiration is usually expressed as a proportion of the total losses of body water. The other evaporative losses due to evaporation from the respiratory tract, are smaller. Even for a man in a motionless state, the insensible moisture losses through the skin and respiratory tract amount to about 21 g/h/m2 of body surface area.

When the air temperature starts to rise, increased vasodilation and higher skin temperatures ensure that there is always some small increase in invisible perspiration. In overwarm situations, the secretion of the sweat glands begins to drastically increase the production of water at the body surface. The loss of heat will increase provided the sweat can evaporate freely from the wetted surfaces. Insensible loss can only to be said to occur when visible evidence of sweating and skin wetting is absent. This depends to a considerable extent on the indoor air humidity, and rate of air movement. The higher the indoor air humidity, the lower will be the hygrometric losses that can occur, without visible moisture forming on the skin. High water losses due to evaporation can occur indoors in dry desert areas, without the losses being perceived as active sweating.

The **volume of perspiration** in man also depends on insolation, in addition to air velocity, air humidity, the level of muscular work, and the insulation properties of clothes. Man's long range acclimatization to heat or cold, as the case may be, is also of considerable significance. When the air temperature is high, every rise of 0.5 °C results in an increment of perspiration of 18-20 g/h/m2 body surface area. Direct solar radiation causes an increase in perspiration of 200-220 g/h/m2 body surface area. This approximates to the effect produced by a rise of air temperature of 5.5 °C. The intensity of perspiration serves as an important physiological criterion in the evaluation of the thermal condition of man under warm thermal conditions. Sweating may be visible, for example, under sultry conditions, when the skin may be seen and felt to be wet, or invisible, for example, in dry desert climates.

Sweating with a wet skin when sedentary represents a state of discomfort. Wet sweating, when physically working or playing hard, is acceptable, but when trying to fall asleep, it is very disagreeable. The amelioration by physical activity is partly the result of the motion of the body and limbs through air, which enhances evaporation, and conductive cooling. If one moves out

of the area of thermal comfort into the zone of heat, there is the perception of warmth discomfort, and independently the unpleasant perception of skin wetness. A neutral state of skin moisture is desirable. As Givoni (1986) states:" In a desert, the ambient humidity is very low, and the daytime wind speed high. Discomfort is exclusively due to the feeling of excessive heat. The skin is actually too dry, though sweating is high (about 200 g/h for a resting person). The evaporative potential far exceeds the rate of sweat secretion, so that the sweat evaporation takes place within the skin pores. The skin's excessive dryness itself becomes a source of irritation...... In contrast to the dry desert situation, discomfort in a warm-humid region, especially in still air conditions, may be mainly due to skin wetness. The air temperature in such regions is often below 26 °C and the rate of sweat secretion, in the sedentary state, is rather low (about 60 g/h per person). In spite of the low rate of sweating, the skin becomes wet, because the evaporative potential of the still humid air is very low. The physiological thermal balance is maintained, in spite of the lower evaporative potential, because the required evaporation rate is achieved over a larger wetted area of the skin."

A realistic criterion to define the upper tolerance limits for the indoor thermal environment used in building design assessment is the maximum acceptable skin wetness ratio (Gonzalez et al., 1978). The skin wetness ratio has a maximum value of 1, when the whole skin surface is covered with evaporating moisture. Conditions become slightly uncomfortable when the value of the skin wetness ratio reaches 0.25, uncomfortable when the ratio becomes 0.45, and very uncomfortable when the ratio becomes 0.85. At a skin wetness ratio of 1.0, thermal breakdown will occur for everyone, except for short exposures.

A suitable measure in assessing **thermal responses to work rates for different activities** is to express internal heat production per square metre of body surface. The body surface area is estimated using the Du Bois formula weighting body weight with body height. The typical body surface area of a European male is about 1.8 m2 and of a European female is about 1.6 m2. When sleeping, the heat production is about 40 W/m2 (Watts per square metre). Seated, the heat production is about 55 W/m2. It raises with light housework to about 78 W/m2, and with moderately energetic housework to about 110 W/m2. Detailed figures for a wide range of activities may be found in Passmore and Durnin (1967). Humphreys (1976) suggests a representative average domestic level as 67 W/m2 , which is close to the USSR values of 63-78 W/m2. Thermal norms have to set in relation to activity rates.
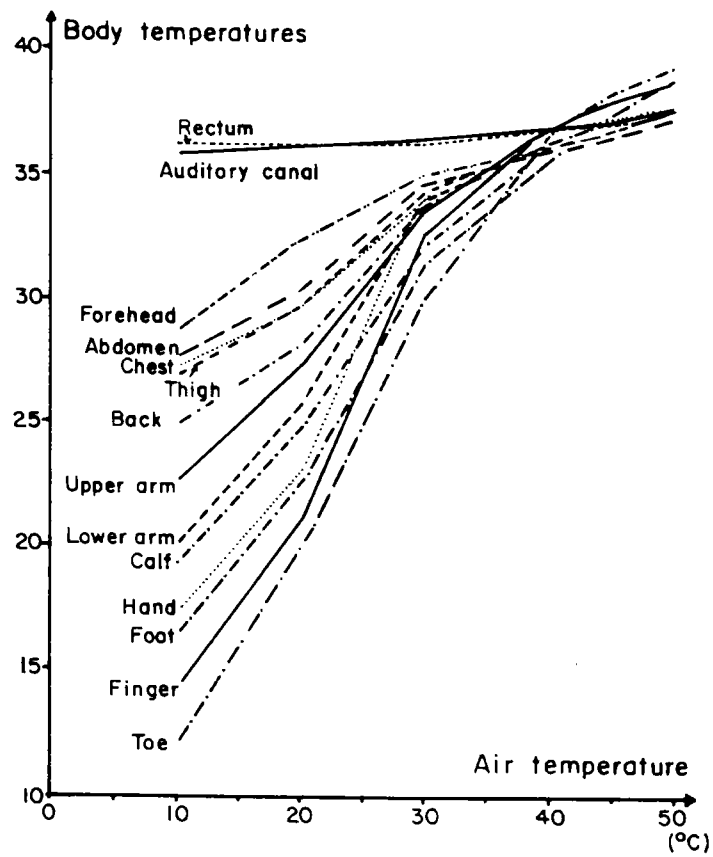
Fig. 1:- Body and skin temperature at different air temperatures.
(Source: Weihe, 1984).

Thermal perception

The evaluation of objective physiological response parameters serves to assist the evaluation of the perceptual responses of individuals, for the assessment of the impact of the microclimate on the thermal state of man. These perceptual responses are of the greatest significance in determining personal comfort. They are composed of an integrated reflection of the signals received by the receptor organs from the surrounding thermal environment. They result in kinds of awareness about the consequent state of the internal systems of the organism. Thermal perception responds faster to changes in the thermal environment than the mean skin temperature. A distinction exists between thermal sensation, which is a peripheral perception and thermal feeling, which is a inner, central perception of thermal comfort. The changes in thermal sensation are directly linked to changes in the vascular tone of the hands and feet which are the main heat emitters of the organism.

The central thermal perception is one of the most reliable criteria by which to evaluate the extent of thermoregulatory strain and the state of adjustment. Many of the scientists who have investigated the effects of various combinations of thermal microclimatic factors on man's thermal state, have relied heavily on the systematic analysis of thermal sensation evaluations. Studies of the thermal environment under different microclimatic conditions in residential and in public buildings require the experimental subjects to express their perception of the thermal environment on a suitable perceptual scale, while the experimenter measures their actual physical thermal environment. Two widely used perceptual scales used to evaluate individual thermal responses are the 7-point Bedford scale, and the 7-point ASHRAE scale (ASHRAE, 1985). The Bedford scale (Chrenko, 1974), which is a thermal comfort scale, uses the terms:-

> much too warm, too warm,
> comfortably warm, comfortable,
> comfortably cool, too cool, and much
> too cool.

The ASHRAE scale, which is a thermal sensation scale, uses the terms:-
> hot, warm, slightly warm, neutral,
> slightly cool, cool, and cold.

With the ASHRAE scale, conditions are regarded as optimal when they ensure evaluations of slightly warm, comfortable, or slightly cool for 80% of the building occupants.

There is a widely confirmed correlation between thermal perception studies and the more objective physiological response parameters. At the same time, it must be said, thermal perceptual studies in isolation do not allow one to pass a final judgement on man's

thermal state in any particular environment. Perceptual studies however do help evaluate correctly the detected shifts in the more objective physiologically based indices. Under indoor thermal conditions, regarded as comfortable, between 8 to 13% or even higher numbers of adults experience to some degree deviation from comfort with feeling of discomfort. This individual variation is explained by differences in the levels of heat production and heat exchange depending on body shape and posture, in the nature of the individual vascular responses, the thickness of the subcutaneous fat layers, clothing and eating habits, concentration, mood, and other conditions. Besides, since heat emission responses are based on conditioned reflexes, the response to different environmental conditions depends on: the previous experience of the subject, traditions, individual habits in clothes and food choices, on the social living conditions, the climate to which the individual is adapted, and housing. Individual people are sensitive to temperature changes as small as 0.5 °C/h, so the higher the fluctuation of temperature from the optimal, the greater is the proportion of people experiencing feelings of discomfort. There can be no such thing as a definite temperature that is optimal for all people at the same time.

Fanger (1972) has suggested that modern engineering facilities and equipment can ensure, based on the Mean Predicted Vote, (MPV), comfortable conditions for 95% of the people in a building. In the USSR, conditions are regarded as optimal if they ensure comfort for 75-85% of the people. Under conditions close to comfort in the zone of moderate thermoregulatory stress, an optimal thermal state is still ensured for not less than 65% of the occupants.

For establishing the optimal conditions of the thermal microclimate a combination or selection of the following indicators of the thermal state of man are used in the course of physiological and health studies:

- pattern of the skin temperatures across the body and the average weighted body temperature
- body core temperature
- rate of perspiration and the magnitude of the heat losses by evaporation
- state of the cardiovascular and the respiratory system
- amount of heat emission by convection and by radiation
- thermal comfort perception of the individuals exposed in the space
- physical and mental performance.

Among these the simplest and most reliable technique used to establish health criteria for thermal comfort remains the individual's perception of the thermal environment. The most informative objective physiological indicators to help differentiate between the state of thermal comfort and the "acceptably warm"

and "acceptably cool" states, are skin temperature changes, the instability of the vascular cutaneous responses, and, in warm conditions, the evaporative losses and the reduction in the variability in the intensity of heat emission per unit area from different parts of the body. In establishing the upper limit to the zone of moderate thermoregulatory stress due to warmth, the change of thermoregulatory stress from moderate to severe can be identified by the increased intensity of perspiration, the redistribution of heat losses between the various loss paths, and changes in the pattern of skin temperatures. The major criteria are the increase in the share of heat emission by evaporation, and the stabilization or even a reduction of skin temperature on the trunk and its drastic rise at the limbs. Working ability and capacity can be assessed by work performance assessment techniques.

Norms for the indoor thermal microclimate

Norms and standards for the indoor thermal microclimate for practical design applications, are stated in physical terms and not in physiological or perceptual terms. The determination of the quantitative links between the human thermal physiological-perceptual responses and the physical variables describing the indoor thermal microclimate is thus an issue of considerable practical importance.

The links between the physical factors and either physiological responses or human thermal perception, or both, can be explored through both physiological and thermal perception studies and physical heat transfer measurements in a climatic chamber (Fanger,1972), or field studies. Perceived thermal sensation of individuals in field situations can be used to build up quantitative response scales. If there is to be no change in thermal energy stored in the body, that the body temperature is to stay the same, the thermal gains must match the losses. The greater the activity rate, the higher the losses have to be to achieve a balance. If the balance cannot be achieved through the radiation and convection losses, the body clearly has to evaporate sweat to avoid overheating.

As the human thermal response depends on the interaction of thermal microclimatic factors, and human factors, some standardization of the human factors is first needed. In setting thermal norms for the indoor environment a number of variables need to be considered.

Important variables are:

> Age and sex
> Nutrition
> State of health
> State of adaptation to the climate
> Level of insulation provided by clothing
> Activity level

Occupation.

The special health risks of the old and disabled from thermal stress in tropical climates have been well set out by Weihe (1986). Heat is an important stress factor for the old, especially if their state of cardiovascular or respiratory health is weak. Disturbance of sleep, in particular, has serious cumulative strain effects, especially for older age groups, with circulatory disorders.

People poorly nourished or improperly clothed, will be more sensitive and vulnerable to cold. It is particularly important to protect the economically disadvantaged groups from cold by improved building design, if heating is ill affordable. With cool or cold seasons, there may be considerable suffering due to underheating of living spaces and lack of body insulation from adequate clothing. The issues of the effects of cold indoor conditions on building occupants in temperate climates have been summarized in a WHO-EURO (1987) report. It is stated:

1. There is no demonstrable risk to the health of healthy sedentary people living in air temperatures of between 18 °C and 24 °C. This temperature range applies under conditions of appropriate clothing, insulation, humidity, radiant temperature, air movement and stable physiology.

2. No conclusions could be reached on the average indoor ambient temperature below which the health of the general population may be considered endangered.

3. For certain groups, such as the sick, the handicapped, the very old and the very young, a minimum air temperature of 20 °C is recommended.

4. There is evidence that ambient air temperatures below 12 °C are a health risk for groups such as the elderly, the sick, the handicapped and pre school children.

5. At air temperatures below 16 °C, relative humidities above 65% impose additional hazards, particularly from respiratory and arthritic diseases and allergic reactions to moulds, fungi, house dust mites and allergens from domestic animals.

6. It should be recognized that the elderly and the very young may be at special risk when bedroom temperatures are low at night.

If the temperature drops below the lower end of the comfort temperature range, the body temperature, especially in old people, may begin to drop leading to hypothermia. For example house heating standards for

some old pensioned persons in the UK are too low in contrast with most of Europe, and considerable health problems are encountered in cold weather (Collins, 1987). At 16 °C, there is an increasing risk of hypothermia developing, and also of increased respiratory illness. The precise role of relative humidity is not clear. At 12 °C cardiovascular changes can be detected, especially in the old. At 6 °C thermoregulation begins to fail in the sedentary elderly, and there is a risk of fatal hypothermia developing which in a few cases leads on to death. Looking at the whole field of housing for the elderly, in effect low ambient temperature is of great significance in the UK as a factor affecting morbidity and mortality of elderly people from respiratory and cardiovascular disorders. This situation is probably generally true in many other temperate and cold areas of the world. Taking note of Fig. 1, cold extremities could make the elderly more accident prone indoors, but this link is not scientifically established. Fire accident risks are also likely to increase in cold buildings, as the result of elderly people trying to draw up too close to open flame and electric radiant fires to combat indoor cold.

Indoor thermal comfort analysis over recent years has usually been based on the thermal responses of healthy adults, wearing the customary clothing worn in that culture at that season. People are adapting to the local climate. Such acquired adaptation not only involves a physiological adaptation and a learned ability to regulate activity sensibly to climatic demands for parts of the day such as in very hot climates starting work early and resting in the shade during the extreme hot part of the afternoon. Investigations have to be asked about patterns of comfort across the 24 hour cycle of human activity.

Critical variables influencing indoor thermal comfort

A range of norms is needed to define indoor microclimatic standards for the different operational situations in buildings met in practice. These norms impinge on health in different ways. Depending on local climate, thermal norms are required to cover the following situations in the indoor environment:

1. To define recommended comfort conditions in heated, humidified and cooled buildings

2. To delineate the zones of acceptability in inadequately heated and cooled buildings

3. To identify the thermal comfort limits within which free running buildings should operate to remain in the satisfactory free running range

4. To specify upper limits of acceptability for overheated buildings operating in the unsatisfactory free running range.

If the radiant environment is assessed by substituting

the globe thermometer temperature for the air temperature, three variables play a role in practical indoor thermal climatic comfort norms:

1) Globe temperature.

2) Rate of relative air movement over the clothed body. Any motion of the body and limbs contributes to this relative air movement.

3) Air humidity, which effects the ease with which the sweat can evaporate.

The first variable is important if a person is in the comfort range without significant sweating and the rate of air movement is low. The first two factors need be considered if the environment is warm and sweat can evaporate freely from the skin.

The influence of the last factor may become dominant in humid conditions, where sweat cannot evaporate freely, in determining dissatisfaction with the indoor thermal environment. Under hot humid summer conditions, when temperatures rise into the zone where air movement is essential to evaporate sweat, it may be impossible to keep indoor relative humidities in a free running building below recommended levels.

Two trends are clearly visible in modern scientific assessment of indoor thermal microclimates. Some investigators give the highest priority to the quantification of individual parameters of the indoor microclimate. Other investigators concentrate on thermal warmth criteria or indices, which combine the impact of the different physical factors into single indices. As there are so many possible variables, it is usual in developing indoor thermal microclimatic norms to introduce some important simplifications and standardizations in order to establish thermal comfort zones for practical design assessment purposes.

(a) Standardization of activity rates.

It is normal in setting thermal norms for residential situations to assume a relatively low rate of activity indoors. The activity category usually adopted is performing physiologically relatively undemanding tasks, like reading and talking, while seated. Except in the case of factories, the more active pursuits tend to be carried out outdoors.

(b) Standardization of clothing insulation.

The insulation level offered by clothing exerts an important influence on the thermal comfort zone. Adjustment of clothing amounts is a vital technique for widening the comfort zone. In hot weather, people choose clothing of relatively low insulation value. Comfort clothing wishes are sometimes countered by social and cultural pressures, such as wearing a jacket in a hot office. The insulation unit for clothing usually

adopted is the "clo". One clo is the insulation offered by the typical western style winter suit. Half a clo is approximately the insulation afforded by a skirt and blouse, or by trousers and a shirt. Values for the insulation offered by different types of clothing may be found in standard publications, like the ASHRAE Handbook (1985) and Fanger (1972). It is reasonable in looking at the winter season, to assume a indoor standard of 1 clo, and, at the summer season, to assume a standard of half a clo clothing insulation.

Single index assessment

Many thermal studies have been devoted to developing a single index assessment of the thermal environment. They are limited to indoor and outdoor climates and some are limited to very specific microclimatic conditions. Only a few can be considered here. Considerable discussion on the topic of indices is found in the ASHRAE Handbook (ASHRAE, 1985), Kerslake (1972) and Givoni,1981).

One of the best known thermal indices is the Effective Temperature, ET, scale. The ET scale combines the effects of temperature, air movement and humidity. It was originally constructed by Houghten and Yaglou (1923) based on subjective judgements of healthy young persons moving between two controlled environments. ET is the temperature of still air saturated with water vapour, at which man experiences the same sensations of heat and cold as in the conditions under investigation. The ET scale provides satisfactory estimates of thermally equivalent conditions, when the dry bulb temperature is above 27 °C and the radiant heat is almost negligible. The scale overestimates the effects of humidity at lower temperatures and underestimates the effects of humidity at extreme heat tolerance levels.

Another rationally derived thermal index is the Standard Operative temperature introduced by Gagge (1940). Standard Operative temperature takes into account the combined effects of air temperature, radiant temperature, and air movement. It is the uniform temperature of an imaginary enclosure with which a person will exchange the same dry heat by radiation and convection (R + C) as in the actual environment. The scale was subsequently modified by Nishi and Gagge (1971) including the effect of humidity on evaporation as well, (R + C + E_{sk}), giving the Humid Operative temperature. This indicator is only accurately applicable, when the rate of air movement is moderate, the ratios of the convective and radiative components close to unity, and the values of the operative temperature are reasonably close to the air and mean radiant temperatures.

The measurement of the thermal radiative environment.

A number of different methods have been employed

for health studies of indoor radiation regimes. They are divided into two main groups: (1) methods based on physical factors, and (2) methods based on physiological responses. Not all of them provide a comprehensive description of the radiation regime in building enclosures, or yield a truly comparable analysis and evaluation of the thermal regime in buildings with different heating and cooling systems. These kinds of methods are often used to establish design standards for radiant panel systems, both for heating and for cooling. Health criteria for thermal radiation should be established on the basis of permissible variations in the parameters of the radiation field including air temperature.

(1) Methods based on physical factors

Physical methods include the evaluation of the combined effects of the radiative regime and the convective regime using weighted average temperatures of the air in the enclosure at living levels and the Mean Radiant Temperature, MRT. The MRT is the area weighted average temperature of the external and internal surfaces of the room. A more accurate assessment to match the formal definition requires using radiative transfer coefficients relating to the shape of the room as seen from the position being assessed. The Globe Thermometer provides a practical alternative to the measurement of the individual room surface temperatures. In practice different diameters of globe thermometer have been used in different countries, which has caused some confusion. The commonly used diameter is 150 mm. The smaller diameter globe thermometer of 100 mm diameter proposed by Missenard (1948) is often known as the dry resultant temperature. The MRT is calculated depending on the diameter from the relationship between mean enclosure air temperature and air velocity. For rest conditions it agrees well with results of physiological experiments in hot environments. As 0.10 m/s is a representative rate of indoor air movement in many building interiors, the theoretical globe temperature is often set as the mean of the enclosure air temperature and the MRT. The other physical alternative is to measure the actual irradiance regime at different points in the room to determine the amount of radiant heat flowing per unit area to differently orientated surfaces at each point. The Standard International Unit for irradiance is w/ m2.

The Missenard globe thermometer and other detectors of the overall surrounding radiation field do not enable an effective assessment to be made of the actual radiation exchanges. For dwellings in the USSR where man is exposed to heat flows from and to surfaces at different temperatures the "field of radiant energy" is measured. The principles of this technique are:

> Each point in the dwelling must be separately evaluated, because the radiation regime is characterized by an uneven distribution in

space

The entire human body is engaged in radiant heat exchange with definite parts of the surface area of all ambient objects, located within a 2 pi steradian solid angle within a hemisphere due to the fact most parts of the human body are convex.

The magnitude of the radiant heat exchange with each element depends on its orientation with respect to each element of the body. The vector nature of the problem means the impact varies at different point in the space.

To get a comprehensive picture of the prevailing radiation regime, the following factors must be considered: (1) the spatial unevenness, (2) the hemispheric irradiance, and (3) the vector nature of the radiant heat exchange with the human body.

In the USA, Gagge, Rapp and Hardy (1967) concluded that neither the concept of MRT, nor resultant temperature and Operative temperature could give a comprehensive picture of the effective radiant field. They recommended using an appropriate indicator to measure the radiant heat that falls on the human body. The indicator value is independent of the surface temperatures of the clothes and the human body. It is the sum total of the thermal radiation from all the different surfaces, including heat sources like panels and radiators and cold surfaces like windows. A radiometer was used that measured the hemispherical radiation from different directions.

The fundamental measurement of the actual hemispherical thermal irradiance seems the preferred measurement, rather than using instruments of compounded indices. In Germany a "Frigorimeter" has been used to measure the thermal radiation component of the indoor thermal environment (Frank, 1968). This instrument is known in the UK as the Comfortmeter (Schwarz, 1973). The instrument consists of a flat measuring metallic plate with a heat flux plate immediately attached to a metallic body containing an electric heater. The front face of the instrument is painted pink to match the thermal emissivity of the human skin (emittance = 0.954). By means of a proportional controller, any desired temperature can be selected and kept constant at the front face. By adjusting the heat flux plate temperature to the postulated skin temperature at any point, the rate of radiation and convection heat loss per unit area is measured. By subtracting the calculated convected component, using an appropriate assumed value of the convection heat transfer component and the surface temperature- air temperature difference, the thermal radiation component is found. The existence of a complex thermal radiation field does not hinder the measurements, for it is enough in assessing human comfort to establish the maximum and the minimum

thermal irradiance in the occupied zone as the two critical values. These two values determine whether the thermal irradiance lies within the permissible limits to secure an acceptably comfortable environment between the two extreme points of measurement. Madson (1973) developed a special measuring head to assess the thermal environment. The size of the head was in accordance with the finding by Fanger (1972) that the effective radiant area of a person is only 0.7 times the convection area. To give the correct weight to thermal radiation exchanges in different directions from the whole human body the head was given an ellipsoid shape, small seen from the top, and considerably greater seen from the side.

(2) Methods based on physiological responses

These methods correlate the impact of the radiative environment with the physiological responses and temperature sensations of an individual. They include (a) the evaluation of the radiation regime in relation to the permissible radiant heat losses from the human body into the environment and the permissible fall in skin temperature, and (b) the evaluation of the radiation regime according to the permissible increases of skin temperature at localized parts of the body which imposes limits on the permissible values of the irradiance.

To establish permissible panel temperatures the use of subjective voting techniques is acceptable. Subjects are typically exposed to a range of radiant conditions, in which the mean radiant temperatures and the air temperature are the same, but combinations of wall and ceiling temperature differ. Interest for heating design tends to centre on the permissible maximum ceiling temperatures. Griffiths and McIntyre (1974) found the combination of high ceiling temperature and cool walls was perceived cooler than an uniform environment for the same mean radiant temperature. They characterized the thermal radiation conditions at head level in terms of the vector radiant temperature. They used vector radiant temperatures of 26 °C at head level, with 20 °C for the whole body. A radiant vector temperature up to 20 °C was acceptable. For a large ceiling, with a radiation exchange factor at head level approaching 0.5, this implies a maximum panel temperature 10 °C above the MRT, i.e. 35 °C. As the panels become smaller, and the view factor increases, the maximum panel temperature can be raised, as long as the critical thermal radiant flux is not exceeded.

Fanger (1972) combined the thermal warmth scale voting technique with fundamental heat transfer studies of heat losses from the human body in climatic chambers on thermal comfort to produce a set of charts. The charts take into account six indoor microclimatic variabies at several standardized levels : temperature, humidity, relative air movement, levels of physical activity, and clothing insulation. The concept

"relative air movement" considers the movement of the air past the stationary person and the movement of the body through the stationary air. The charts provide a powerful tool for examining the effects of changes in the individual parameters of the indoor thermal microclimate. It may be seen from Table 1 that, for sedentary activities, with clothing insulation at 0.5 clo, the air temperature for a neutral warmth vote is predicted to range between 24.5 °C for very humid still air conditions up to 29.2 °C for very dry conditions with good air movement.

Table 1

Effect of relative air movement at different relative humidities on the predicted dry bulb temperature required to give a Fanger neutral warmth vote.

Clothing insulation 0.5 clo. sedentary activity.

Relative humidity	Relative air movement m/s	Dry bulb temperature °C
100%	<0.1	24.5
	0.2	25.4
	0.5	26.7
	1.5	27.8
80%	<0.1	25.0
	0.2	25.9
	0.5	27.2
	1.5	28.2
60%	<0.1	25.5
	0.2	26.3
	0.5	27.5
	1.5	28.5
40%	<0.1	26.0
	0.2	26.8
	0.5	27.9
	1.5	28.9
20%	<0.1	26.5
	0.2	27.2
	0.5	28.2
	1.5	29.2

If clothing insulation is further reduced to shorts only, or to a very thin dress, as is often the case indoors within the home in the hotter parts of the day in very warm seasons, the Fanger charts predict a neutral temperature comfort vote level around 27 °C for very humid still air conditions and 31 °C for very dry conditions with good air movement. Table 1 shows that under hot humid conditions, indoor thermal norms cannot be adequately specified by air temperature alone. In hot weather, good air movement is roughly equivalent to a 3 °C reduction in indoor air temperature compared with still air conditions.

The expanded use of radiant panel systems of heating and cooling in residential and public buildings has generated the need to know the maximum permissible temperatures on the surfaces of cooled or heated radiant panels. In the USSR, the permissible fall in surface temperature below room ambient temperature of a cooled panel was established to accord with the permissible maximum rate of heat loss from the surface of the human body, while the permissible maximum increase in temperature of a panel above room ambient temperature was evaluated on the basis of a threshold maximum value of the thermal radiation falling on a person. The additional radiation level is set low enough so it is not directly perceived by a person and so does not negatively affect his thermal comfort. The panel temperature standards reflect the intensity of radiant heat exchange of people with their surrounding surfaces.The suggested maximum and minimum panel temperature standards resulting from this approach varied over a broad range. Every panel temperature standard has to be used exclusively for the specific conditions for which it has been established, such as panel size, height of mounting, type of enclosure, and outdoor design temperature. The proposed panel temperature standards are related to the rate of thermal radiation emission from the skin surface which depends on the individual responses of skin blood vessels to heat and cold, the radiant emittance of the skin, the deep body temperature and the type of clothing. The thermal radiation impacts should be characterized in terms of absolute physical values, as is done for other factors in the indoor thermal environment, for example the air temperature. This approach is feasible because the thermal radiation energy field impacting on the various clothed and bare parts of the body will remain unchanged, provided external conditions are unchanged, even though the net exchange is different for various parts of the human body.

Subjective comfort voting techniques have been applied to investigate systematically the effects of asymmetric thermal radiation on thermal comfort at thermal neutrality (Olesen et al. 1973). The basic experiments were carried out using young subjects. One wall of the controlled environment chamber was raised in temperature while the opposite wall was reduced in temperature, while the mean radiant temperature was kept constant. Subjects in minimal clothing with an insulation of about 0.1 clo recorded whether they could detect the asymmetry of thermal radiation between one heated and one cooled wall, and comfort or discomfort. At a 5% discomfort limit, using the worst radiant exposure which is back and sides exposed to the cold surface, a maximum permissible drop of 5 °C in mean radiant temperature was established as the limiting criterion.

Vertical movement of cold air after contact with the floor also often occurs. Cold draughts close to the floor surface may amplify the problems of cold extremities. Conductive heat flow will occur from any body surfaces

in direct pressure contact with cold floor (Billington, 1967; Munro and Chrenko, 1948). Contact may be foot contact or through sleeping on the floor. In walking across a floor, or on first lying on the floor, the conductive heat loss is a dynamic heat flow. Under steady state conditions, the rate of heat flow is dependent on the temperature difference between the surface and the body element, normally the feet, in contact, and the thermal insulation between the two. The loss is then dependent on the product of volumetric heat capacity and the thermal conductivity of the flooring material below. A good thermal insulators for floor coverings for underheated situations is wood, while compacted mud and brick are moderate, and dense concrete poor isolators. Appropriate thermal choice of flooring materials is important for health. With floor warming systems, the floor temperature is above the indoor air temperature. If the floor becomes too hot (>29 °C; ISO, 1984), people complain about overhot feet, excessive foot sweatiness, and increased leg fatigue. The critical maximum temperature to avoid complaints appears to be about 27 °C (Billington, 1967). Sedentary people will accept slightly higher floor temperatures.

Many scientists continue to feel that the use of such combined indices for assessing thermal microclimates discourages proper evaluation of accurate quantitative measurements of man's thermal sensations. They have preferred to use the theories of heat and mass transfer, and objective indicators of thermal responses, based on some defined measurable physiological indicator such as mean skin temperature. Such investigations are laborious and cannot include larger numbers of individuals. Suitable for hot climates is the acceptable skin wetness ratio, considering the percent of sweat wetted surface to total body surface (Gonzales et al, 1978).

Attempts have been made to quantify the effects of the indoor thermal environment in sleeping spaces in low cost housing and also the level of blanket insulation needed to protect against cold during sleep (Van Straaten, 1967). A person sleeping alone with one light blanket plus thin night apparel should obtain a reasonably undisturbed nights sleep at temperatures as low as 12.8 °C. At lower air temperatures, the frequency of awakening may become excessive. It was estimated that the limiting acceptable air temperature can be further lowered by about 7 °C for one additional blanket, and by about 14 °C, down to -1.2 °C. for two additional blankets. Cold bedrooms in cold climates have the disadvantage of providing higher relative humidity. As bedding materials are highly hygroscopic, the bedding absorbs water during sleep, and drying may not fully occur during the day. Increased bedding dampness, has a poorer insulation value than dry bedding and requires considerable heat to evaporate off some of the absorbed moisture, when the bed is first occupied. This effect can lead to severe initial heat loss on getting into bed, to the point of

chilling and feeling uncomfortable.

The relative humidity indoors in a heated building in cold climates always is below the relative humidity outdoors, though the water vapour pressures indoors and outdoors would be fairly close. In residential buildings, considerable added moisture to the internal air stems from the normal domestic living processes, like bathing, cooking and drying of clothes, the breathing and insensible evaporation of the occupants . Therefore, in domestic buildings, the vapour pressure indoors is often substantially above the vapour pressure outdoors. This often leads to surface condensation. In offices and public buildings, this added water is usually much less than in domestic buildings. Lower indoor relative humidities are often experienced in such heated buildings. The lowest humidities tend to occur during dry cold spells in winter, when the outdoor vapour pressures are very low. This situation can lead to complaints due to the excessive drying effect on the nasal passages. In private houses the complaints are more often associated with too high relative humidities, favouring the development of house dust (Koorsgaard, 1979). High indoor vapour pressures in inadequately heated buildings often lead to serious surface condensation on the colder parts of the enclosing room surfaces, favouring the growth of moulds. Of the five main requirements for growth of moulds: spores, food, oxygen, suitable temperatures, and water, only water is normally limiting in dwellings. If the relative humidity of the air adjacent to the cold surface is less than 80%, then mould growth can be controlled. The relative humidity at the warmer centre of the room must be appreciably lower than this, especially if the external surfaces are poorly insulated. Ventilation exerts a critical role, and there is an optimum ventilation rate in any environment for a given heat and moisture input to control condensation. Too little ventilation will lead to a rise of the indoor vapour pressure, too much ventilation, to a drop. Cold indoor environments encourage occupants to drastically reduce ventilation rates, so enhancing the likelihood of condensation and hence increase health risks caused by growth of moulds and mites. While fungicides are sometimes used in the control of mould growth, the health risks introduced by the fungicides themselves also have be evaluated.

Thermal recommendations for temperate climates

Recommended standards of the thermal indoor microclimate in the COMECON countries have been given for sedentary occupations (Jokl, 1986). The indoor thermal radiation field is considered by using room temperature in terms of globe temperature. Attention is given to clothing insulation and air movement, floor surface temperature and temperature gradients. A distinction of the impact of changes on indoor comfort standards is made between optimal and

permissible conditions. The indoor thermal microclimate should be acceptable for the peripheral parts of the body, like the feet, as well as for the body core.

The International Standard ISO 7730-1984 (ISO, 1984) on moderate thermal environments sets an optimum indoor microclimate range (air temperature, radiant temperature and radiant symmetry) for people working at different metabolic rates wearing clothing of different insulation standard. The recommendations are based on sensory perception, and makes use of the operative temperature. The recommended comfort criteria from ISO 7730-1984 are:

Operative temperature 20-24 °C (22 + 2 °C)

Vertical temperature difference between air temperature at 1.1 m and at 0.1 m less than 3 °C

Floor surface temperature 19-26 °C , for floor heating systems 29 °C

Mean air velocity less than 0.15 m/s

Radiant temperature asymmetry (due to windows etc) <10 °C

Radiant temperature asymmetry from warm ceiling <5 °C.

The comfort zones recommended in specific countries in temperate climates are relatively narrowly defined for people working in airconditioned spaces. The 1983 ASHRAE standard 62 - 1983 for comfort of the population in air conditioning buildings in the USA, assumed clothing thermal insulation values of 0.9 clo in winter and 0.5 clo in summer. At 50% RH the indoor dry bulb temperature limits were set at: 22.8 °C to 26.1 °C for summer, and 20.0 °C to 23.9 °C for winter. The standard is valid for a maximum air velocity of 0.25 m/s in summer and 0.15 m/s in winter. For air conditioned buildings in the USA, humidity limits are now set in terms of vapour pressure (ASHRAE Standard 62 - 1981). The lower end is set to protect the respiratory mucosa from excessive dryness, and irritation. This evaporation is dependent on the vapour pressure difference between nasal and alveolar inspiratory air. The cleaner the air, the lower the humidity can be. The upper acceptable vapour pressure is related to the vapour pressure difference between the wetted skin surface and the air, which governs the rate of evaporation of sweat. The vapour pressures of the comfort zone are: at the upper end 14 mm Hg at 21.9 °C min and 25.3 °C max temperatures, and at the lower end 5 mm Hg at 22.6 °C min and 28.3 °C max temperatures. The comfort zone is formed by the quadrilateral joining these four points on the psychrometric chart. By including clothing insulation, a 80% thermal acceptability limit at the top end temperature of the comfort zone can be achieved with

a relative humidity of 60 to 80% and a air movement of 0.1 to 0.15 m/s with insulation of 1 clo at 22.6 °C, 0.5 clo at 25.5 °C, and no clothing at 28.0 °C .

Thermal recommendations for warm climates

Two points of view have prevailed internationally on the topic of indoor thermal comfort norms for people living in hot countries. One point of view is that there is a universal thermal comfort zone for man regardless of race or country (Fanger, 1972). The other point of view is that indoor thermal comfort norms are dependent on outdoor climate in each locality because of the natural adaptation and cultural and technical experience of the native people (Auliciems, 1983). People, used to living in hot countries are thermally comfortable at higher indoor air temperatures than people used to living in cooler countries. This viewpoint has gained international scientific support in recent years.

Mean thermal comfort represents the indoor condition in actual buildings when the greatest number of respondents are thermally neither too warm nor too cold. This condition is identified by statistical analysis of the subjective responses (Fanger, 1972). Studies on an international basis of group perceptual thermal responses derived from field studies inside buildings, show that the indoor air temperature required to achieve thermal comfort neutrality in a given season in actual buildings depends on the monthly means of outdoor daily dry bulb temperature found in that region (Humphreys, 1978; Auliciems, 1983).This implies that a constant global indoor thermal comfort temperature zone cannot be established. The practical results of thermal perceptual studies indoors in actual buildings indicate that some of the rigidities introduced by approaches based on climatic chambers, are overcomplex for the practical assessment of the thermal environments in buildings in overheated seasons. From the evaluation of systematic studies of neutral warmth temperatures in free running buildings in various parts of the world over a wide range of latitudes Humphreys (1978) stated that in free running buildings at a mean radiant temperature of within 2 °C of the air temperature the mean comfort temperature could be estimated within the range from 10 to 33 °C from the air temperature by a simple formula. The formula does not separate out quantitatively the effects of humidity and air movement. Auliciems (1983) suggested a formula for free running and conditioned buildings comparable to that by Humphrey (1978). The field studies showed that in summer the acceptable indoor comfort temperatures range from 19 °C for people native to cold temperate climates to 29.8 °C for people native to hot humid climates (Nicol, 1974). The summer clothing insulation standard and habits of native populations contribute to this range. Climatic

adaptation of people is of great practical significance.

Casual internal and external solar gains are implicit in the determination of the lowest outdoor monthly value that will enable a building to provide a thermally acceptable indoor climate without the heating system running in that month. Unheated buildings run with the temperature indoors a few degrees warmer than the shade temperature outdoors. For offices, the lowest value of the monthly mean air temperature, needed to achieve indoor comfort in summer, was 14.4 °C with comfort temperature indoors at 20.0 °C. Mechanical fans were in use in such hot outdoor climates, combining the effects of air movement and indoor air temperature. Buildings which are located in climates that are warm throughout the year, are likely to better designed for effective air movement from windows and doors than buildings located in climates with a strong cold season, and therefore have higher typical indoor rates of air movement. In locations with a cold season, designs are used to avoid excessive air losses, such as tightly closing the windows. One of the most important options for free running buildings is the option to increase rates of air movement to levels substantially higher than those normally found in air conditioned buildings, either using natural ventilation systems or mechanical fans.

Acceptable swings of indoor temperature

For air conditioned and also heated buildings, it is usual to specify an acceptable temperature control zone width. Auliciems (1983) suggested a zone of plus or minus 2 °C. In a free running building, the internal temperature will oscillate in an approximately sinusoidal mode, over the 24-h period. The amplitude depends on the thermal mass of the building. In summer in the temperate climate of the United Kingdom, a swing of 4 °C during working hours, around a mean temperature of 23 °C did not need major clothing adjustments (Building Research Establishment, BRE. With a daily mean indoor temperature of 25 °C., the maximum acceptable swing during office hours was as high as 8 °C, with 21 °C at the start of the working day after overnight cooling, and finishing the office day at 29 °C. This range was suggested as being acceptable, provided people can remove some clothing as the temperature rises.

In hot climates, when the temperature of a building in the free running state is within the discomfort zone for most of the day with people wearing the minimum of socially acceptable clothing, it seems inappropriate to suggest narrow temperature swings. Any big downward swing during the evening and night at such hot times of year is a more than welcome requirement.

The general issues of the health impacts of adverse thermal conditions outside the acceptable ranges have been systematically reviewed by Weihe (1987). Accepting the evidence of Humphries(1978) and

Auliciems (1983) on the range of mean comfort neutrality temperatures in the Tropics, resulting from combined autonomic and behavioral temperature regulation in different world climates, Weihe defined the range of thermal comfort neutrality acceptable without impacts on health as running from 17 °C as the lowest to 31 °C as the highest acceptable group neutrality temperature. He then listed symptoms of discomfort and health risks outside this range, with the cold effects on the left and the heat effects on the right (TABLE 2).

Table 2

Health effects of thermal microclimates lying outside the neutral
temperature zone.

←———————— Below 1°C		Above 31 °C ————————→	
Sudden heart death	Hypertension	Hypotension	Sudden heart death
	Hypothermia	Hyperthermia	Heart failure
Stroke	Respiratory infections	Tachycardia	Heat stroke
	Asthma	Heart insufficiency	
	Overeating	Inappetence	
	Tachycardia	Hypohydrosis	
	Reduced dexerity	Hydromeiosis	
	Indolence	Fatigue	
	Restlessness	Indolence	
	Sleepiness	Lethargy	
	Mental slowing	Increased irritability	
	Depression	Reduced learning capacity	
		Impaired memory	
		Depression	

In tropical climates most buildings will become
uncomfortably hot from time to time, even in relatively
temperate climates, for example, during a heat wave.
Through inadequate design, buildings may produce
indoor conditions which are incompatible with human
health. Some indoor thermal discomfort has to
accepted due to the dictates of economic necessity.
Under such circumstances, the design aim obviously
must be to limit both the frequency of occurrence of
severely overheated periods inside buildings, and also
their indoor intensity and duration. Man has developed
biologically to be able to cope thermally with known
natural hot outdoor climates. It is unfortunately both
possible and easy for environmentally ignorant
designers to design buildings whose indoor thermal
climates are far more severe than the surrounding
outdoor microclimates in the shade. This situation
seldom arises with traditional designs, which evolved in
harmony with the environment(Goromosov, 1968). It is
thus important, in the interest of safeguarding health,
to have an objective means available for deciding at
what level thermal conditions inside buildings have
become unacceptably hot for tolerable human
habitation. An idealized "healthy building" for cold and
hot climates is shown in FIGURE 2. The topic of
healthy building condition has received much less
attention than the study of thermal comfort in the
laboratory.

The rapidly progressing urbanization in countries
located in tropical climates will lead to heat
accumulation in urban centres with adverse effects
especially for elderly people (Weihe, 1986). The
present high life expectancy above 65 years of age in
temperate climates may never be reached if extended
outdoor heat stress hampers night cooling of
overheated dwellings. In free running overheated
buildings, the concept of the intensity-duration of

adverse indoor thermal exposure is very relevant. If the
discomfort condition lasts for a short period of the
daytime, the impacts are far less important for health,
than if the discomfort period extends over night.
International studies show that heat tolerance levels
depend on the length of hours of adverse exposure
during the diurnal cycle: "As long as there are an equal
number of cool night hours after a hot day for restful
sleep, it is possible to recover from daytime heat stress,
and if there are more cool hours at night, higher
daytime heat conditions can be tolerated. The balance
in the daily cycle of activity-fatigue-recovery is
disturbed, when recovery from fatigue is hampered by
heat during the physiological sleep period at night. The
diurnal variation between hot and cool hours during
the activity fatigue recovery cycle plays a major role in
the resistance of individuals with long term
cardiovascular diseases or exhaustion. When this is
disturbed for one or two days, in the event of a heat
wave, excess mortality increases"(Weihe, 1986). A daily
maximum air temperature of 35 °C has been suggested
as the critical temperature for heat aggravated death to
occur Weihe (1986). This value will be modified
depending on relative humidities. The 0.45 skin wetness
ratio has been associated with the appearance of some
heat stroke deaths in the USA (ASHRAE 1985).

COLD CLIMATE | WARM HUMID CLIMATE

NEEDS

TREES
FOR SHADE

HEATING

GOOD
INSULATION

17°C
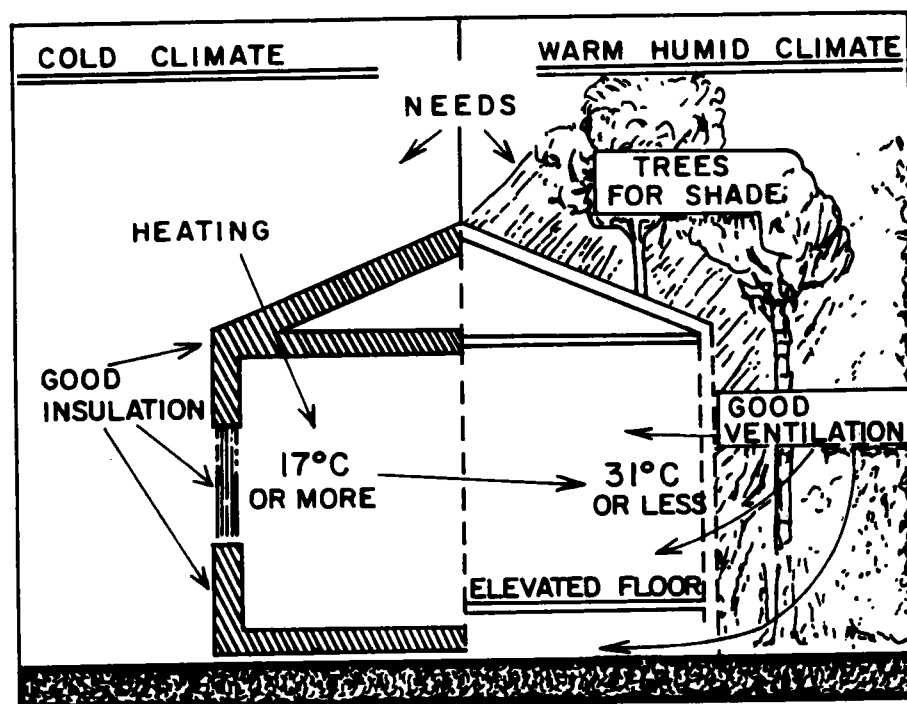OR MORE

31°C
OR LESS

GOOD
VENTILATION

ELEVATED FLOOR

Fig. 2:- A "Healthy Building" has to be designed and built in harmony with
the climatic conditions and the actual needs of its occupants.
(Source: World Meteorological Organization, Geneva).

Table 3

Tolerance limits for maximum indoor dry
bulb temperatures at various
humidities. Basis: Maximum acceptable skin
wetness ratio, 0.45, air movement <0.15 m/s.

Relative humidity	Dew point	Max dry bulb temp.
%	°C	°C
100	28	28
80	27	31
50	23	35
20	13	42

The tolerance temperature limits taking a typical
representative midday relative humidity of 50% are
given in Table 3. They are valid under the condition
that occupants are not exposed to the direct sun, and
the mean radiant temperature is not elevated more
than 2 °C above air temperature.

Relationship between indoor and outdoor microclimate

The indoor and the outdoor microclimates are closely
linked. The interface between the two is through the
building shell. The health, well-being, and productivity
of the occupants depends on the appropriate design of
this shell to aid the matching of indoor requirements to
the externally imposed outdoor microclimate. The
indoor conditions may be ameliorated by improving the
outdoor site microclimate, to better match indoor
needs at different seasons. The building design has to
relate appropriately to the outdoor microclimate, to
assure a better indoor microclimate. Sometimes
considerable positive operational savings can be
achieved by simple design changes, for example heating
cost reductions, and cooling cost reductions through
improved insulation. The strategic design decisions are
usually the critical factors in determining indoor
comfort and health. Fortunately the systematic study of
the ways of predicting the influence of town planning
decisions on outdoor microclimate and the
identification of the best ways of improving it by
appropriate urban design, has advanced considerably
over the past few decades. A range of measures to
bring about such outdoor microclimatic improvements
are available. The UN Agency with the lead role in
climatology and meteorology is the World
Meteorological Organization, WMO. WHO and UNEP
work closely with WMO in these fields of urban
climatology and building climatology. Urban
climatology deals with the issues of the impact of
human settlements on the natural climate, which lead
on, through the modified climates of specific urban
zones, to the eventual formation of the detailed
building site climate. A particularly important
document for assessing tropical urban microclimates is

the publication on the Technical Conference on Urban
Climatology held in Mexico City in 1984 (WMO,1986).
The normal sources of meteorological data for
bioclimatic analysis will be the national meteorological
services. Consultation with national meteorological
services is very advisable in assessing climatological
data. Advice may also be needed on urban
modifications, a topic well discussed in Conference on
Urban Climatology and its applications with special
regard to tropical areas (WMO, 1986), which is the key
international reference. The heat island effect can
introduce considerable temperature differences
between city centres and rural areas. These differences,
which may well exceed 5 °C, are greatest in the late
evening.

A particularly valuable new source of climatological
data are the Handbooks of Agrometeorological Data,
published by the Food and Agricultural Organisation,
Rome (FAO, 1984, 1985, 1987). Each volume contains
the following monthly statistics for a very large number
of sites in most regions of the world:

Monthly precipitation, mm.

Monthly average temp, °C

Monthly mean daily maximum temp., °C

Monthly mean daily minimum temp., °C

Monthly mean temperature day-time hours, °C

Monthly mean temperature night-time hours, °C

Monthly mean vapour pressure, mbar

*Monthly mean wind speed adjusted to 2 m above the
ground, m/s*

Monthly relative duration of bright sunshine, % possible.

Total (global) radiation, monthly mean daily values.

Potential evapotranspiration

In addition the rain fed crop growing seasons are
identified, information that can be of value in assessing
aspects of thermal performance affected by vegetation,
for example, variation of ground albedo with season,
periods when the trees may be in leaf.

The availability of day and night-time means of
temperature is a useful feature. Inside buildings,
substantial reductions in wind speed can be expected,
to about 1/3 to 1/2 the outside values, even with big
open windows giving cross ventilation. With single
sided ventilation, the indoor air velocities may drop to
around 1/10 of those found outside, or less.

Building climatology relates building design and

operation to site climate (Milbank and Petherbridge, 1974). Underlying both fields is the need to make human settlements more secure against natural disasters of climatic origin. We now also have to consider the impact of human settlements on the modification of the world's climate. Within the structure of current urbanism, heating buildings with fossil fuels and biomass, which discharges carbon dioxide, and cooling buildings with CFC refrigerants, have implications for the global warming and ozone destruction problems.

One critical feature of the climate of large cities important for human health, is the urban heat island effect (WMO, 1986). The outdoor microclimate of cities is often hotter than the surrounding countryside, and wind speeds lower, especially in the early hours of darkness. The centres of cities also heat and cool more slowly than the surrounding countryside, especially in still hot weather. This means the urban microclimate in very hot weather is often least favourable in the early evening in the period up to midnight, disturbing the early hours of sleep, first of children, then, later, of adults. This heat stress of the building up of heat islands, causing increasing morbidity and mortality, has led to discussion of cities as "death islands" (Weihe, 1986). The improvement of the urban outdoor thermal microclimate is thus an important objective for achieving a satisfactory regulation of indoor microclimates in towns. The aim is to minimize discomfort in hot weather, particularly during the night. Maximum use has to be made of simple natural cooling techniques.

Thermal operation of buildings

Four basic operational thermal responses to the outdoor thermal microclimate to meet the indoor thermal needs of occupants can be identified in building practice (Page, 1986a):

(1) Underheated season. The building is run with a heating system operational. The design aim is to make the building comfortable, with minimum energy expenditure for fuel. Positive resources are sunshine and thermal insulation.

(2) Free running building. The building is operating with the only energy inputs, other than casual internal heat gains, coming entirely from the natural outdoor environment. The design aim is to make the building comfortable using natural resources in the environment, the wind, sun, and long wave radiation.

(3) Overheated season with fan cooling. The building is running without either a cooling system or heating system operational, but with mechanical fans used to promote internal air movement. The design aim is to

keep the indoor air temperature down. Positive resources are shading and insulation.

(4) Overheated season with mechanical cooling. The building is running with a cooling or dehumidification system operational. Design aim to provide a comfortable environment for minimum energy expenditure. Positive resources are shading and insulation.

Indoor air quality problems are particularly liable to arise in the first and fourth modes of operation, because energy economy implies restricted fresh air ventilation (UNCHS, 1984). The free running state is a mode of operation, in which there are no internal energy inputs other than those from people and those needed for essential activities like cooking, lighting and recreation. In the free running state, the indoor thermal microclimate is strongly dominated by the impacts of the outdoor microclimate. If a free running building thermally responds to the outdoor microclimate in way that provides satisfactory indoor thermal comfort without creating the need to consume additional energy resources to provide that indoor thermal comfort, the outcome is obviously very satisfactory. It is usually possible, in most, but not in all climates, to meet this objective by appropriate building design for a limited time period. The satisfactory free running period of a building refers to such a period of the year during which the needs for comfort are satisfied. By improved design, it may be possible to prolong the duration of the satisfactory free running state to cover a longer period of the year.

As the indoor thermal microclimate is so closely affected by the outdoor thermal microclimate, in free running buildings the amelioration of the outdoor thermal microclimate is a vital factor influencing the amelioration of the indoor climate. The greater the ventilation rate, the more closely will the indoor temperature microclimate follow the outdoor temperature microclimate (ACGIH). In hot weather, the outdoor radiative environment makes a big impact, especially if the building is heavily glazed, and the windows are not adequately protected from the incoming solar energy. Shading is a key factor affecting the indoor microclimate. The indoor rates of air movement will depend on the amount of opening areas, opening type, as well as on the outdoor site wind conditions. The pattern of indoor air movement will be far from uniform. The relative humidity indoors under conditions of high ventilation will be very similar to that outdoors. If ventilation is restricted, indoor air movement will be reduced, unless fans are introduced, and the influence of the thermal storage properties of the building fabric will become far more dominant. If there are large solar gains, or other big internal heat gains, the daily mean indoor temperature will rise substantially above outdoor shade temperatures. Ventilation is the key factor in the indoor-outdoor temperature relationship. In some hot dry climates, it is

possible to restrict daytime ventilation in buildings with small solar heat gains, and achieve a cool indoor thermal microclimate by using thermal mass to damp the daily swing in indoor temperature. This option is not open in free running buildings in humid climates. The availability of adequate site wind flows in the outdoor climate is especially important in such humid conditions.

The unsatisfactory free running state in a building exists if indoor thermal comfort is not achieved. This situation may result from the extremes of natural climate, inadequate outdoor microclimatic design, or from technical inadequacies in building design, or, most commonly, from a combination of all three factors. This unsatisfactory state may be persistent across a particular season or be episodic, as during a heat wave. A decision, based on a statistical understanding of frequency of occurrence of unsatisfactory conditions, and their duration across the course of the year has then to be made as to whether heating or cooling systems should be introduced, and whether they are actually affordable, both in capital cost and in running cost terms. This is especially true of cooling. One has to accept that true thermal comfort indoors cannot be achieved for certain periods of the day during certain hot periods of the year. Mechanical cooling using air conditioning is not affordable in most areas with hot climates.

The relationship between the outdoor thermal microclimate and the indoor thermal microclimate in buildings operating in the free running state, is very dependent on detailed technical features of the design, such as thermal insulation and the size and positioning of windows (Givoni, 1981; Van Straaten, 1967). Particularly important is the thermal storage capacity of the building in determining hot weather building performance. Heavy buildings with restricted ventilation heat and cool more slowly than light-weight buildings. In heavy buildings with low ventilation rates, and well shaded windows, the 24-h daily mean temperatures indoors are typically about 2 °C above the mean daily outdoor shade temperature around the building. Typical temperature responses of heavyweight and lightweight buildings are illustrated in FIGURE 3. The daily swing of indoor temperature in heavy weight buildings is about 30 % of the external diurnal temperature range compared with about 80-90% in the case of lightweight buildings. If the windows are inappropriately orientated, for example in westerly directions, and large in size, appreciably higher daily mean temperatures will lead to larger diurnal temperature swings.

While solar energy in cold weather is a valuable heating resource, in hot weather it creates many problems. Equator facing windows give a good balance between winter gains and avoidance of excessive summer heat gains. A westerly exposure of windows creates the biggest problems. Westerly facades have a

poor balance between wanted winter gains and unwanted summer gains and are difficult to shade effectively. Additionally the radiation gains tend to coincide in time with the highest outdoor shade air temperatures. The summer heat gains are usually greater on surfaces facing east and west than on equator facing surfaces. An established rule in low latitude hot climates is to place the long axis of a building in east-west direction. A globally applicable method for assessing such gains quantitatively for different orientations at different latitudes between 40N and 40S has been developed by Page (UNCHS, 1989). Shading systems outside the glazing are considerably more effective in reducing indoor air temperatures than internal shading systems.

The effective use of simple natural cooling strategies in hot climate building design helps to avoid expensive mechanical cooling systems (UNCHS, 1984, 1989). The selection of solutions depends on the actual local climate. The seven key environmental techniques for achieving cooler buildings in overheated seasons and climates are:

(1) Increasing air movement using natural ventilation in those climates where increased indoor air movement improves indoor thermal comfort. Alternatively, in relatively closed buildings, providing internal fans to increase air movement in the room areas, where human activity is located. These techniques are of dominant importance in hot humid regions.

(2) Increasing building thermal mass and restricting daytime ventilation in climates where the humidities are low. To benefit fully from this mode of operation, the building must be operated in the closed mode during the heat of the day. Internal fans can be used to move the air inside the thermally closed building. This technique is particularly applicable in hot dry climates, where the diurnal range of outdoor temperature is large, and the need for fast air movement over the body to avoid a wet skin is low.

(3) Providing night-time structural cooling in those climates where heavy buildings are thermally acceptable. Such buildings should be thermally insulated on the outside of the thermal mass. They can operate with very restricted external ventilation during daytime hours, without creating thermal discomfort. The technique is particularly suitable in hot dry regions. Openings should be large. They should be protected with insulating shutters during the day and are used to flush the building with cold air during the night.

(4) Providing evaporative cooling in the incoming air flow paths (desert coolers) in hot dry climates to provide satisfactory rates of cooling without creating excessively humid building interiors. The technique is only applicable in regions with low wet bulb temperatures and requires the availability of water.
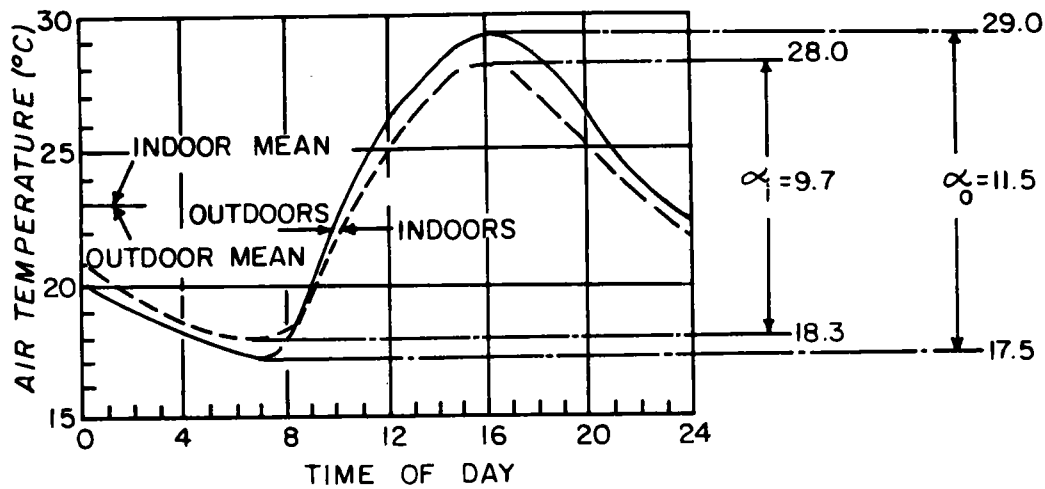
(a) STRUCTURE WITH UNINSULATED, LOW MASS WALLS AND
SUSPENDED WOODEN FLOOR.
AMPLITUDE RATIO, $\frac{\alpha_i}{\alpha_o} = 0.84$
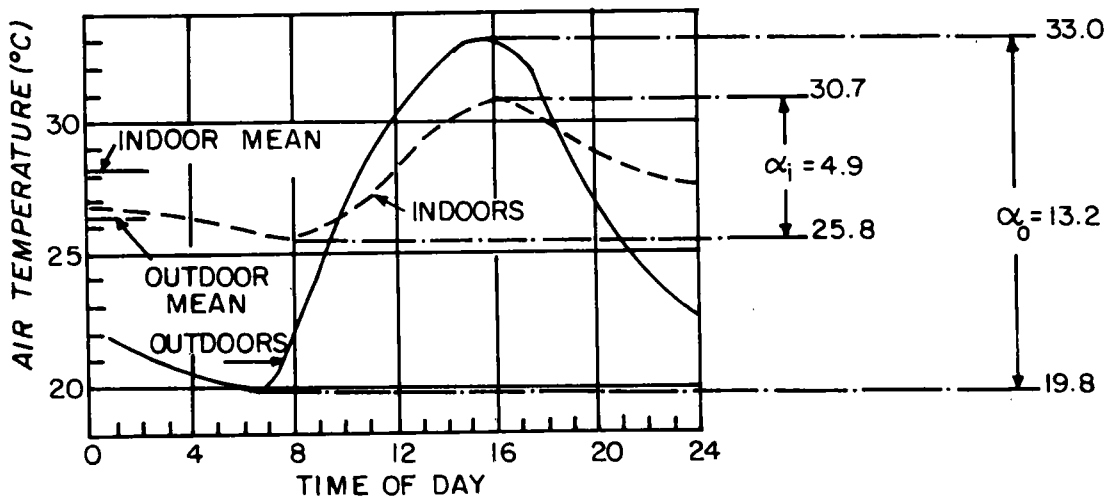
(b) STRUCTURE WITH 230mm MASSIVE EXTERNAL WALLS AND
MASSIVE CEILING.
AMPLITUDE RATIO, $\frac{\alpha_i}{\alpha_o} = 0.37$

Fig.3:- Examples of typical indoor/outdoor temperature curves and amplitude
ratios, indoor temperature range/outdoor temperature range, for two
structures of different thermal performance, operating under free
running conditions in hot sunny weather, windows shaded externally,
building orientation North-South. (Source:Wentzel et al., 1981).

α_i = difference between indoor daily minimum and maximum temperature
α_o = difference between outdoor daily minimum and maximum temperature

(5) Using thermal insulation and light coloured building exterior finishes to reduce heat flows through walls, and the roof, on which most solar energy impinges during the summer. Thermal insulation is an applicable technique in all climates. In humid climates light coloured external finishes are likely to lack durability, due to mould growth and fungal attack.

(6) Shading apertures to avoid excessive solar gains in hot weather. This is a mandatory process for satisfactory building design against hot conditions in all climates.

(7) Using evaporation of water from fountains to improve the microclimate in closed courtyards in areas where the health risks are acceptable, the water available, and the atmosphere dry enough.

In the case of heated and/or artificially cooled buildings, the indoor thermal microclimate is regulated, not only by the building structure itself interacting with the outdoor microclimate, but by additional indoor energy exchanges. In these situations, the external microclimate impacts on the capital and running costs. If these costs become too high for the energy and wealth available, the occupants will be forced to operate the thermal systems at the just affordable level to produce acceptable comfort. Such situations can lead to the compromising of health.

In the USSR the natural climatic conditions are valued as the key factor in the town planning. Successful solutions have to meet two basic objectives: (1) to protect the residents from the unfavourable impacts of the natural climate conditions, and (2) to ensure proper conservation and rational use of both the land and its natural resources. The effectiveness of any solution can be assessed in terms of the changes achieved in the physiological exposure of individuals to thermal stress in the outdoor environment and the contributions through improved hygiene to the health of the population through lowered atmospheric pollution. Amelioration of the outdoor environment can lead to indoor advantages such as reducing heating energy demands and heating energy costs.

In the USSR, a comprehensive factorial assessment of the background climatic conditions and local climatic conditions is made, involving both qualitative and quantitative criteria, complemented by the input of microclimatic data for the building area under consideration. Established standardized indices are used, and appropriate bioclimatic assessment criteria are applied. Assessment of background climatic conditions includes duration of different types of weather, appraised by bioclimatic types. The local climatic conditions are estimated, using an analysis of the main topographical features of the locality and are represented in the form of schematic charts of different scales. The matrix of typical climatic factors used in architectural planning of human settlements in the

USSR considers: temperature, direct radiation, cloudiness, wind, dust storms and fogs, precipitation, atmospheric pollution potential, and others. A set of general requirements is elaborated, covering planning, landscaping, building requirements, as well the overall improvements aimed at. These are stated both in terms of the bioclimatic requirements, such as thermal needs, protection from wind and sun, and urban ventilation as well as air quality requirements. The sources of information and analytic methods for assessing outdoor microclimate available to the planning teams, include bibliographic reference material, and the publications of research institutes. In addition, full scale observations may be instituted in various parts of the urban area. In establishing national planning norms, territories are combined according to their natural climatic conditions. The basic town planning requirements to ameliorate the natural climatic conditions through the processes of design, are formulated on the basis of the climatic features typical of each climatic region and its sub-regions. In the USSR, three basic climatic zones are identified in terms of town building requirements, the northern zone, the moderate climate zone, and the southern zone. In addition, are identified in The northern and the southern zone are divided into three sub-zones, the moderate zone into two sub-zones.

The microclimate of a specific built-up area can be characterized by the screen air temperatures, the humidity, and the rate of air movement, in addition to the radiation climate consisting of the two components: the solar radiation climate, and the thermal radiation climate. The formation of a specific outdoor microclimate around buildings is the consequence of the interactions between external climatic variables and specific features of the building project, like the number of stories, the length and orientation of the buildings, and the distance between them, the nature of the greenery in between, its height and density of planting, and very importantly the nature of the ground cover surfaces in and around the building complexes. Microclimatic assessments for specific climatic elements include graphical analytic methods, physical modelling, and full scale site observations. Microclimatic conditions are also assessed in terms of their impact on the thermal state of human beings outdoors. The heat balance equation for the human body is used to characterize the exchange of energy between the human organism and the outdoor environment under the impact of different meteorological conditions. Through the use of observations at fixed points, it becomes possible to obtain statistically reliable data on the departures of the microclimate from the natural background climate under different weather conditions. The fixed point observations are complemented by mobile observations carried out for "characteristic weather types". The number and duration of the microclimatic measurements needed are predetermined by the specific weather conditions found in different regions,

and, above all, by the stability of these conditions from day to day and from year to year.One of the obligatory requirements is comparison of the weather conditions found during the full-scale observations with the long term norms, including correlation of individual climatic factors with their long term average values recorded over many years. The microclimatic zoning of the city land area is based on a comprehensive analysis of the changes in the various meteorological elements, both in space and in time, within the urban area. The changes are expressed as deviations of the various climatic elements from the data supplied by the main meteorological station.

Natural climatic, local climatic and microclimatic conditions constitute the fundamental environmental basis for planning. This information is presented in the form of a "climatic passport" to aid architectural design and construction, and to formulate climatic and microclimatic requirements. The climatic passport of a town contains :

Analysis of local climate as predicted from the physical geographic features

Estimates of the climate from the standpoint of town construction

Analysis of the microclimates being formed under the planning and building proposals under the town development process.

In making up the climatic passport, the alteration of the climate under the impact of the local surface area treatment is excluded. Such aspects can best be considered later in the course of detailed architectural design. In a number of regions of the USSR, assessment of the climatic factors is made with regard to thermal comfort and air quality criteria based on physiological responses:

Acceptably low statistical occurrence of discomfort conditions in < 8%

Acceptably low statistical occurrence of wind velocities <4 m/s during winter months, and >5 m/s in summer months not being exceeded more than 20% of the time.

Summer values of the outdoor air temperature for comfort to lie within a range from 14 °C to 27 °C and of the relative humidity in the range 30%-70% RH; temperatures and relative humidities exceeding these limits are classified as discomfort range.

Annual precipitation rates above 800 mm are considered as causing discomfort.

The structure of the urban plan should provide for optimum airing of the city area by creating an interrelated network of highways, streets and squares, green areas and open water surfaces to act as a unified urban ventilation system. Transportation network should have an open structure, with special avenues or highways planned to run along the directions of the dominant favourable winds, at the same time avoiding running major transportation arteries in the directions from which strong cold winds blow in winter, or in drier desert areas, in the directions from which hot summer dust bearing winds blow. Town planning patterns of a predominantly closed type are used to minimize active dust transfer due to wind. In areas of overheating, an analysis of the overall energy balance at the different surface elements of the development is made.

In Europe and the USA planning of buildings begins with a small scale bioclimatic chart analysis with special reference to buildings operating in the free running state. Bioclimatic chart analysis is a tool for identifying, before the commencement of formal design, the basic strategic design options open to achieve appropriate thermal design goals on an all year round basis, taking proper account of outdoor microclimate. The aim of bioclimatic chart thermal analysis is to provide an analytic procedure that helps building designers select appropriate building design strategies to meet human thermal comfort needs indoors efficiently in any specified climatic region. The emphasis is on solutions for free running buildings operating without heating or mechanical airconditioning. The process essentially addresses typical relationships between outdoor thermal microclimate and indoor thermal microclimate.The different basic acceptable solutions compatible with the local climate then have to be developed within the context of the wider overall design objectives. The strategic aim of such analysis is to promote indoor thermal comfort and consequently improve human health and well-being at economically affordable levels of investment. An important ancillary aim in using bioclimatic chart thermal analysis in countries with fast development in tropical climates is to help designers maximize the length of the period of the year, during which the building can operate in the free running mode, and provide an acceptably comfortable and healthy indoor thermal microclimate for the occupants (UNCHS, 1984).
The aims of the analysis are: how to use best natural climatic resources and building thermal properties, and how to reduce and preferably eliminate thermal discomfort during the seasons when the unmodified free running building would otherwise be thermally unsatisfactory. If the free running building is always satisfactory, there is no need to consider heating systems or cooling systems in that climate, though use is always likely to made of solar heat energy and natural cooling in regulating the thermal responses of free running buildings.

Two types of bioclimatic charts are very commonly applied: the Olgyay chart (Olgyay, 1963) and the

Milne-Givoni chart a modification of the original Givoni chart (Givoni, 1981).

In the Olgyay chart the relative humidity is plotted on the x-axis and the dry bulb air temperature on the y-axis. The basic comfort zone is drawn onto the chart assuming still air conditions, and no net incident radiation on the body. The effects of air movement in making it possible to achieve thermal comfort at higher air temperatures, are allowed for by a set of 3 lines drawn above the still air comfort zone, for air speeds of 0.1 m/s, 0.4m/s, and 1 m/s, which is a fairly fast rate of indoor air movement. These lines indicate the upper end of the comfort zone for the indicated level of air movement for persons seated out of the sun. It is assumed, if air movement is being sought to promote indoor thermal comfort, then protection will be simultaneously sought from the direct sun, so the globe temperature and the air temperature are set the same. If there is underheating and there is a positive irradiation on the human body, then the acceptable air temperature level of the bottom of the still air comfort zone can be moved down to allow for the heating effect of the radiation on the human body. The irradiances on the chart go down to 800 W/m2 . However 800 W/m2 is very high level of direct beam irradiance on a vertical surface, especially after allowing for the glazing losses, so the practical lower comfort limit for people sitting in full direct sunlight indoors in still air is about 13 °C. The temperature band width of the still air comfort zone is 8 °C. This width is influenced by the fact at the bottom half of the zone, clothing insulation level is 1 clo, and at the top of the zone, the clothing insulation is 0.5 clo, so adjustment of clothing insulation to adapt to the thermal environment, sets up the wide comfort zone indicated by the chart. Such a wide zone of thermal comfort is not acceptable for a specific day, because, then, one is dealing with daily as opposed to a seasonal response. Olgyay's original chart was plotted for latitude 40 N. Olgyay suggested the bottom and top end of the comfort zone should be moved up by 0.42 °C for every 5 degree change of latitude towards the equator, with an upper limit for the top end of the comfort zone of 29.5 °C. The relative humidity limits for the thermal comfort zone are set on considerations other than direct thermal response. The preferred range is 30% to 65%.

The base of the Milne - Givoni bioclimatic chart (Milne and Givoni, 1979) shown in FIGURE 4 is a standard psychrometric chart widely used in standard engineering design, and normally easily available from the appropriate engineering institutions. Dry bulb temperature forms the x-axis and y-axis is the humidity ratio. The dew point scale is also formed on the y-axis. The standard charts also have plotted on them lines of equal relative humidity, and lines of equal wet bulb temperature. When the air is saturated, the dew point, the wet bulb temperature and the dry bulb temperature will be identical. To make a psychrometric charts

suitable for bioclimatic analysis, additional overlays have to be applied. The fundamental overlay is the thermal comfort zone between dry bulb temperatures of 20.0 to 26.7 °C. The acceptable range of relative humidities for still air is set between 20% and 80%, the lower end being the same as in the Olygay chart, but the upper limit being rather higher. The comfort zone was made up of two overlapping zones, a winter zone estimated for the 1 clo insulation level, lying between 20.0 to 24.4 °C, and a summer zone, estimated adopting a 0.5 clo insulation level with a still air, giving a summer comfort zone between 22.8 - 26.7 °C. Assuming that the maximum acceptable wet bulb temperature at a relative humidity of 80% for comfort under still air conditions is 21.1 °C, the top right hand corner of the comfort zone was cut back using the straight line joining the 21.1 °C wet bulb temperature at 80% RH to the point of interception of the 50% RH line with the 26.7°C vertical line.

The Milne-Givoni chart (Fig. 4) considers extensions of the comfort zone for the various practical natural cooling options. Three principle options for the overheated periods were identified:

Option 1. Natural ventilation producing air flow over the occupants, or blown fan flow over the occupants from overhead or side blowing fans. When the RH was 50% or below, it was considered this arrangement could extend the comfort zone to 32.2 °C. The bottom edge was set to run along the 20% RH line. The upper limit of comfort in terms of relative humidity was set at 98%, up to a limiting wet bulb temperature of 26.9 °C. The top right hand corner was cut out, using the line joining the 26.9 °C 98% RH point to the 32.2 °C 55% RH point. The Givoni natural ventilation overlay does not indicate the quantitative effects of changes in rate of air movement, unlike the Olygay chart. It does describe, however, a shift in the comfort zone due to air movement. The zone is realistic in relation to design for hot humid seasons, because dry bulb temperatures associated with very high relative humidities known by practical experience to be acceptable in the presence of good air movement, can lie within the comfort zone. This is an issue of considerable practical importance in the humid hot regions of the world. When achievable, lower indoor humidities are very desirable on grounds of skin wetness comfort.

Option 2. The two high thermal mass zones are based on building thermal performance considerations. The critical issue is by how much can the peak outdoor temperature be realistically reduced by the use of thermal mass in conjunction with reduced daytime ventilation. Givoni and Milne (1979) suggested two zones, one for high thermal mass without special night ventilation, the other for high thermal mass with night-time ventilation. A very heavy weight building was assumed. To construct the two overlays, it was also assumed that the diurnal range of the outdoor
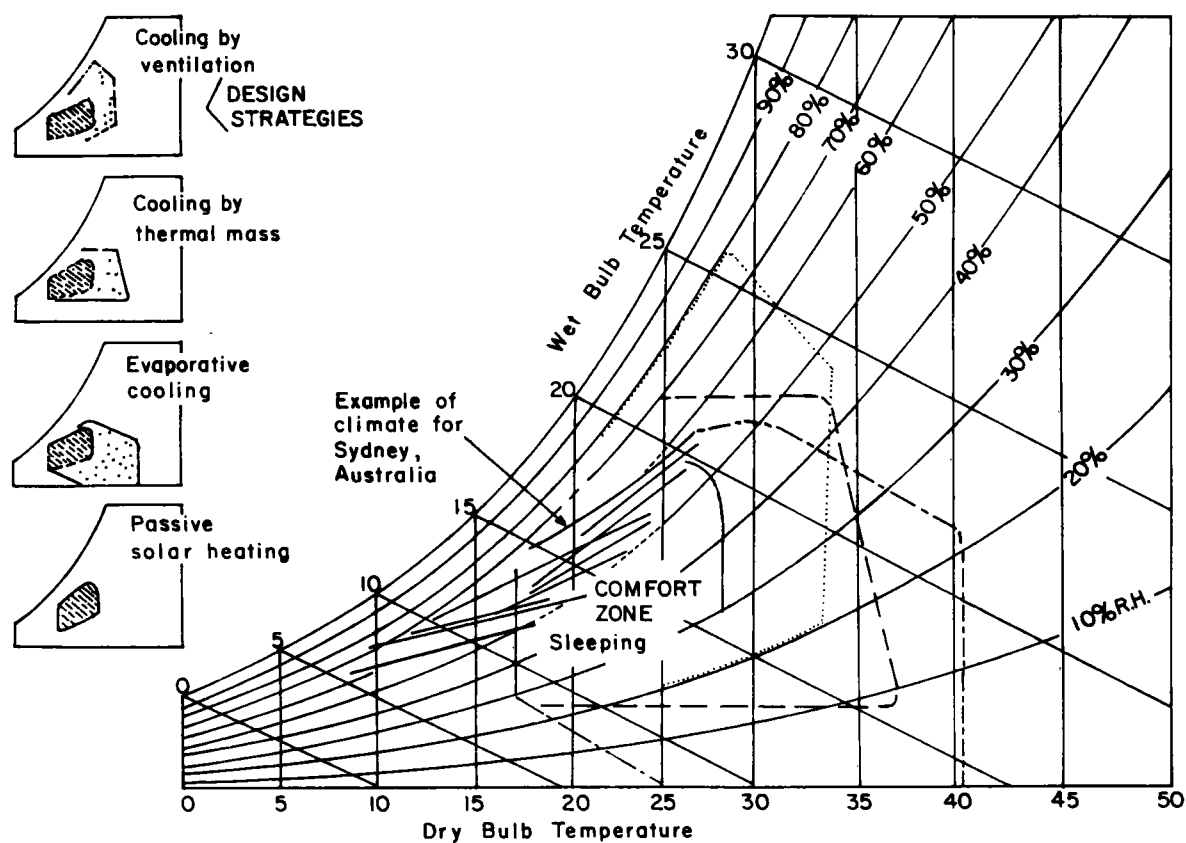
Fig. 4:- Example of the Milne-Givoni psychometric chart. (Source: Givoni, 1981 and Milne and Givoni, 1979).

temperature in a hot dry region was 18.9 °C and that, in the case of heavy mass alone, this situation would produce a peak indoor temperature equal to the daily mean outdoor temperature, i.e mass produces a temperature reduction of 9.4 °C. The humidity limits were set in terms of the dew point temperatures at the bottom and at the top of the comfort zone, the bottom limit being dew point temperature at -3.3 °C and the upper limit dew point temperature at 19.7 °C. In the case of the high mass with night-time ventilation design, it was assumed that the building would cool so much for the indoor maximum to nearly drop to the minimum outdoor temperature, a cooling of 16.4 °C below the maximum. The limits of the zones were established by adding these postulated reductions in dry bulb temperatures to the limiting dry bulb comfort temperatures at the right hand edge of the comfort zone. The upper limits of the temperature for 50% RH or below were set at 36.1 °C in the first case, and at 43.0 °C in the second case. Applying these same temperature differences at top apex of the comfort zone, the corresponding maximum temperatures are 33.3 °C and 41.1 °C. The full overlay zone consists of a parallelogram sitting on top of a rectangle. As the method makes specific assumptions about the actual diurnal range of outdoor temperature, and the extent the peak indoor temperatures can be reduced by thermal mass and by night ventilation, the recommended zone is both place specific, and building design orientated. This introduces some important limitations for generalized international use. In addition, the fundamental criticisms concerning achievable building performance in hot weather in free running buildings need to be addressed.

Option 3. The evaporative cooling zone was established by applying both technical and simultaneously physiological reasoning. In direct evaporative cooling, the cooling process proceeds along the wet bulb line. The water content of the air steadily rises, as the dry bulb temperature drops due to evaporation. It follows from the selection of the maximum acceptable wet bulb temperature for the comfort zone, that the upper limit of the wet bulb temperature acceptable is 21.7 °C. The technical consideration is that there are limits to the amount of cooling achievable with the volume of air that can be comfortably moved through the building. The upper temperature limit was set 13.9 °C above the maximum dry bulb comfort temperature acceptable at any given wet bulb temperature. So with a wet bulb temperature of 21.7 °C, the limit is 38.3 °C. At 50% RH or below, the upper dry bulb limit becomes 40.6 °C. The right hand scale of the psychrometric chart enables the amount of moisture to be added to each unit weight of air passing to be established.Having set up a locally acceptable chart, the next stage is to plot the local climatological data onto the chart.

As an example, Sydney, Australia, has a relatively humid climate, with about three months relatively cool at night, but not cool during the day. The mean temperatures are never particularly high, and hot weather comfort can be easily achieved by natural ventilation. The use of thermal mass with restricted daytime ventilation in hot weather offers no benefits in hot weather due to the high humidity, however the weight of the building will be useful in the cool season to store the heat of the day against the night. Passive solar heating should be able to meet the limited heating needs. Evaporative cooling is not an option open, due to the high summer humidities. The analytic process involves relatively simple climatic data adequate for bioclimatic analysis. There are three desirable inputs :

Mean daily maximum and minimum air temperatures for each month of the year, the mean monthly maximum, and the mean monthly minimum temperatures

The dew points, or vapour pressures, associated with the above temperatures.

The mean daytime and night time wind velocities either at standard height of 10 m, or at living levels, and the prevailing wind directions in the hot and in the cold season at different times of day.

Once the data is available, the next stage is to plot the monthly data onto the selected bioclimatic chart, so that the climatic implications for thermal design are identified. In the past, it has been usual to plot the monthly mean daily maximum and minimum values in a systematic manner that relates to the thermal comfort zones.

Air conditioning

Air conditioning systems attempt to closely regulate the indoor air temperature, rate of air movement and, also, simultaneously, the moisture content of the indoor air. The aim of air conditioning of spaces is to achieve indoor thermal comfort with good indoor air quality, independent of outdoor conditions. Indoor thermal microclimate design is normally carried out to design norms, which attempt to match the indoor thermal microclimate to be provided for the predicted seasonal thermal comfort needs of the majority of the occupants. These norms have to take into account clothing habits, and activity rates of the occupants in different types of space. There are four indoor thermal microclimate requirements:

(1) The range of indoor temperatures at living levels has to be appropriate to meet comfort desires

(2) The moisture content of the indoor air has to be both high enough to meet the respiratory needs of the building occupants, and low enough to avoid condensation and dampness

(3) Acceptable patterns of indoor air movement are required. Too fast a rate of air movement at occupied levels will lead to complaints about draughts. Too slow a rate of air injection may lead to poor mixing and pockets of poor air quality.

(4) The radiant environment, both short wave and long wave must be appropriate.

Window mounted cooling systems attempt primarily to regulate the indoor air temperature alone. In achieving some reduction of temperature, they may provide some limited reduction in the moisture environment through condensation on the cooling coils. In some situations, control of indoor humidity is the prime objective, using systems designed primarily to produce dehumidification of the incoming air rather than cooling of the indoor environment. The majority of air conditioning cooling plants installed over recent years have made use of refrigeration cycles based on chlorofluorocarbons (CFC's). CFC's were adopted partly because of the low human health risks of this thermodynamically very suitable refrigerant. The ASHRAE standard for 8-h exposure to CFC's is 1000 ppm. This is set at a level that is one tenth of the threshold value given in the ACGIH Threshold Limit Values, TLV, and Biological Exposure Indices (ACGIH, 1986-87). The phasing out of CFC's to secure the future of the atmospheric ozone layer may raise significant new indoor human health issues. The effects of the proposed alternative refrigerant gases on human health will require careful study, as well as their potential impacts on the atmospheric environment. Energy conscious building design to reduce cooling loads will not only enable more economic solutions for air conditioning, but will also reduce the rate of expansion of the amount of CFC's currently being discharged to the atmosphere from air conditioning and refrigeration plant. The new situation implies greater priority should be given to the development of natural cooling systems.

A well designed air conditioning system may cease to provide healthy indoor conditions, if the initial design specification are significantly changed such as by increased space occupation density. Building managers with day to day operational responsibility need to be informed of the relevant health issues. They may allow changes in building use that are unacceptable from the point of view of human health.

Experience in all countries indicates some problems of user dissatisfaction with air conditioning systems are very likely to occur in every scheme. In particular users complain very often that air conditioning systems fail to provide the required indoor air quality in practical operation. This is especially true in buildings that are poorly conceived in relation to the local climatic impacts, or where inadequate attention has been given to indoor air quality. There is an inherent danger that technical thermal specialists may overemphasize the potential benefits of airconditioning, and underestimate, ignore or minimize the risks of environmental complaints, which are likely to arise, when designs have not properly considered human health as well as comfort needs. In countries, design solutions that are not really compatible with user needs, are often determined on economic grounds because of the high inherent cost of air conditioning. One must make a distinction between initial design standards and standards in use. This is not just an issue of the plant working to specification, but also of the building being operated within design specification. There is often a tendency to increase building occupancy density to save money. New indoor pollution sources, for example equipment for reproducing engineering drawings, may be introduced without consideration as to whether the plant can handle the consequent pollution. Design engineers often get blamed for the faults of building management. Initial design solutions frequently are not flexible enough to cope with subsequent changes in building use.

Exemplary are the results of an investigation on the health and morbidity of office employees in administrative buildings in the USSR. Though the airconditioning systems provided the specified indoor thermal microclimate, 98.5% of the people complained they did not feel well, 71.5% were very tired, 64.5% felt sultriness, 19% had frequent headaches or felt the lack of fresh air in the room. Complaints in contemporary air conditioned buildings are a well established phenomenon world-wide, known as "Sick Building Syndrome"(Berglund and Lindvall, 1988; Sykes, 1988). The findings of numerous studies show that common complaints of people working in air conditioned and mechanically ventilated buildings are unlikely to be accidental. Current studies are examining the likely causes across a wide range of parameters characteristic of modern buildings.

A first key to health aspects of air conditioning design is its ventilation system outlined diagrammatically in FIGURE 5. The conditioned space is shut off from a direct air supply connection with the outside space by using a closed window system. Some infiltration and exfiltration through the fabric still occurs. The shutting off process in itself is often a cause of user conflict. People are used to regulating their own environment using openable windows. They have a tendency to object to loss of personal control of their indoor environments. This desire is especially strong if the indoor air quality is poor, or the indoor temperature too high. An appropriate ventilation system should supply at all times at least the minimum quantity of outside air needed for healthy ventilation. This outside ventilation air must also be properly distributed, so it is not short circuited to the air outlets or air exhausts, without first being delivered to room occupants. The thorough distribution of the outside ventilation air to the indoor environment is very important. The alternative to general exhaust direct to the outside air, which is otherwise very energy extravagant, is through
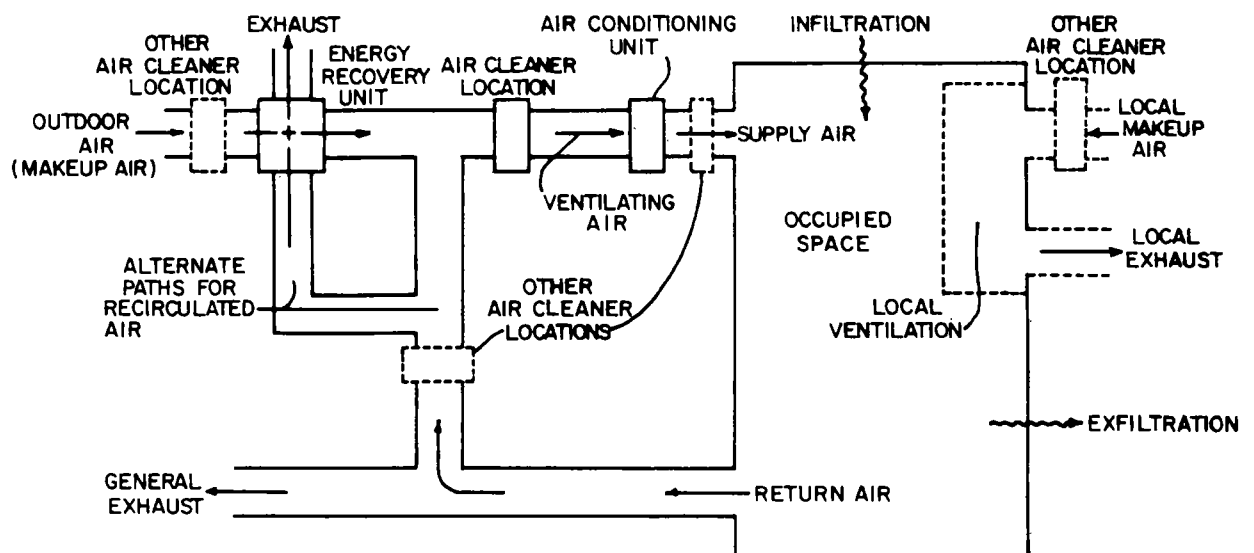
Fig. 5:- The ventilation system of a centrally air conditioned building.
(Source: ASHRAE Standard No. 62-1981).

an energy recovery unit, either a counter flow heat exchanger or heat exchange wheel.

In order to conserve expensively conditioned air, it has been normal practice to recirculate a significant proportion of the indoor air. The incoming fresh air is then often called the make-up air. The percentage recirculation of the total air supplied to the room describes the mixture quantitatively. The health norms for fresh make-up air supply amounts must always be given priority. The specification of a low percentage recirculation does not necessarily imply an adequate fresh air supply. The system should employ proper means of filtering out particulate matter in both components the fresh air from outside and the recirculated air from inside of the occupied space. An important source of indoor particulates is tobacco smoke. The air cleaning of unacceptable gaseous or vapourous matter is often needed, using activated aluminum or charcoal filters. If the air within the indoor space becomes contaminated by the chemicals, biological organisms and particulates such as tobacco smoke produced within that space, recirculation without filtration and air cleaning, will transfer the pollutants throughout the whole distribution system. There are a number of alternative air cleaner locations. Without air cleaning systems, a deterioration of indoor chemical air quality must result. The situation becomes worse as the percentage recirculation increases. Unfortunately there is strong evidence on a world wide scale that air conditioning design has grappled with the physics of the indoor environment much more successfully than with the changing chemistry of the indoor environment.

In conditioned rooms in the USSR with an air intake equal to 40 m3/h per person and an air change rate of 3.5 air changes per hour, subjects had a decreased speed in solving mathematical problems, an increase in the number of mistakes made, and a loss of vigilance. When the fresh air supply was increased to 60 m3/h per person, the capacity for mental work and sustained attention increased, and the subjects felt much better with the higher fresh air supply rate.

The second key factor for health in successful air conditioning design is the enhancement of the basic ability of the building fabric to regulate the varying impacts of the outdoor microclimate. This climatic control is achieved through a number of measures. Decisions about windows and glazing materials are very important. Shading system design is especially critical. Facade orientation strongly influences insolation. Facades facing north or south are easier to protect from excessive summer sun than east or west facades. Window sizes should not be excessive. People should be protected from having to sit in direct sunlight particularly in hot seasons. Air conditioning plants are basically designed to provide comfort for people sitting out of direct sunlight. The detailed architectural design inside the spaces makes a big impact on the success of

any air conditioned building. It is normally assumed in laying down such technical air conditioning specifications that the occupants will be properly protected from the direct rays of the sun. In practice many building designs do not provide this basic protection which is a frequent cause of many well founded complaints.

In a building with mechanical cooling, the indoor air temperature can be conditioned to be cooler than the outdoor air. The designer attempts to design a plant that enables the specified indoor needs to be met in the outdoor conditions that prevail. It is necessary in any climate to establish what range of indoor thermal microclimatic conditions are acceptable for the indoor activities envisaged in the building during each season. In a climate with an outside design temperature of 29 °C, an indoor summer design temperature of 23 °C may be very suitable; with an outside design temperature of 35 °C, an indoor summer design temperature of 27 °C may be more suitable. The appropriate specification for the indoor thermal environment is an issue of considerable significance, both for reasons of health and of operational economy. In the hot season, economy is achieved by setting the environmental temperatures towards the upper end of the comfort range, and in the winter towards the lower end of the comfort range. The comfort range can be widened by seasonal changes in clothing habits, physiological adaptation, and by seasonal air movement alterations. If the allowable indoor temperatures can be raised, a smaller plant can be installed, and less energy will be used in operation.

Some specifications for air conditioning systems have been based on the assumption there are universal thermal neutrality conditions, and that constant indoor temperatures are desirable throughout the year. For sedentary subjects dressed in light clothing with 0.6 clo insulation Fanger (1972) suggested that thermal neutrality with low rates of air movement is 23 °C world-wide. The COMECOM standards recommend an optimal globe temperature of 26.0+ 0.5 °C for summer compared with 20.8 °C in winter (Jokl, 1986). The range of acceptable globe temperature limits for summer were from 22.0 to 28.0 °C. Clothing adjustments are accepted as a means of widening the range. Globe temperatures in buildings in summer tend to stand slightly above air temperatures. The assumed rates of summer indoor air movement associated with this summer acceptability band, ranged between 0.15 m/s at 18 °C to 1.0 m/s at 28.0 °C. An alternative approach is that the locally required indoor comfort temperature in any region is a function of the long term mean climatic conditions to which people are habituated (Humphreys, 1976; Auliciems, 1982; Auliciems and de Dear, 1986). The climatically sensitive neutrality temperature values by Auliciems are about 1 °C higher than the values by Humphreys.

These sort of approaches tend to lead on the

specification of design conditions of air conditioned buildings for tropical climates of the type given in TABLE 4 drawn from UK international experience (CIBSE, 1986).

Table 4

Specification of Design Conditions of Air Conditioned Buildings (CIBSE 1986)

		Design Criteria		
Occupancy		Wet Resultant °C	Environmental Temperature °C	Relative Humidity %
Continuous	Optimum	23	24	52
	Maximum	24.5	25.5	60
		25.2	27	45
Transient				
Humid climate		24.6	25.5	70
		25.4	27	53
Arid Climate		27.1	29.5	45
		27.2	30	40

If the air velocity is 0.1 m/s, the dry resultant or operative temperature is given by the mean of the mean radiant temperature and the air temperature. If the room air speed is 0.5 m/s, then the indoor globe temperature should be raised by about 2 °C. Proportional adjustments should be made for other air velocities. The acceptable rates of indoor air movement in air conditioned spaces under winter conditions range from 0.15 m/s at 18.0 °C to 0.2 m/s at 23.5 °C desirable to control draught sensations (Jokl, 1986). It will be noted a transient factor for short term occupation of the space is incorporated in Table 4, and that this adjustment depends on the relative humidity. The corresponding US recommendations are given in Table 5.

Table 5

Operative temperatures recommended for thermal acceptability in the USA.

Air movement <= 0.15m/s, RH <= 50%. Optimal is the operative temperature that satisfies the greatest number of people at a given clothing and activity level. ASHRAE Standard 55-1981. Source 4.

Season	Typical Clothing	Operative Temperature Optimal °C	Range for 80% acceptability °C
Winter	Heavy slacks Long-sleeved shirt, Sweater	21.7	20.0 - 23.6
Summer	Light slacks Short sleeved shirt	24.4	22.8 - 26.1
	Minimal	27.2	26.0 - 29.0

The approach in the USA indicates the indoor design

temperature should vary from month to month to allow for the outdoor mean air temperature variation. This implies more sophisticated types of control equipment. Plant sizing normally proceeds by using statistical outdoor temperature data for the hottest month, and the desired indoor temperature. These data define the peak indoor outdoor temperature difference.

Some considerable economy can be achieved if some cyclical swing in temperature across the day is acceptable. Humphreys (1976) suggested the acceptable daily range was from -2 to + 2 °C. If wider temperature variations occur, provided rates of change in temperature with time are less than 2 °C/h and the peak to peak amplitudes are less than 10 °C about the neutral temperature, classical steady state comfort models can still be applied to assess the impacts. In a study of air conditioning in Australia, Auliciems and de Dear (1986) indicate that, with more appropriate variable control strategies, the outdoor indoor thermal gradients could be halved with similar energy savings in the warmer Australian places like Darwin and Brisbane. Accepting a diurnal swing in indoor temperature between 21.1 and 24.4 °C in a building with 15% recirculation, Shavit (18) estimated the saving in heating in Pittsburg was 37%, and in San Diego the saving in heating was 61%, and in cooling 93% (Shavit, 1977).

Norms for indoor humidity can be expressed in several different ways. Jokl (1986) suggested the an optimal range of vapour pressure with the high values at 1850 Pa in summer and 1636 Pa in winter, and the low values at 79.3 Pa in summer and 70.1 Pa in winter. The lower values are set to avoid the feeling of dryness of the mucosa. Once a design indoor temperature is

established, these limits can be immediately converted into relative humidities. At 20 °C, the acceptable range is from 30% to 80% RH for respiratory comfort and avoidance of sultriness, while, at 28 °C the acceptable range is from 18% to 50% RH. Practical engineering experience indicates a smaller desirable humidity range between 40% and 70% RH to avoid other problems, like eyes irritation, or surface condensation on cold spots. In winter, humidification is often needed to increase the indoor vapour pressure above the low values prevailing outdoors. In contrast, in humid summer weather, dehumidification may be required to avoid sultriness. Dehumidification is normally achieved by lowering the air temperature to the required dew point temperature by condensation on the dehumidification coils in the air conditioning plant, and then reheating the supply air to the required input temperature.

An important problem in air conditioning design for occupant comfort, is how to get the cooled air distributed, without causing unacceptable draughts. The bigger the internal heat load per unit floor area, the more heat has to be removed to ensure occupant comfort requirements are met. This additional heat can only be removed by lowering the inlet air supply temperature, or by increasing the inlet air flow rate. If the cool incoming air is not well mixed before it reaches occupants, unacceptable draughts may occur. Normally a 12 °C drop is considered to be the greatest acceptable temperature difference between the cold incoming air and the bulk room air for ceiling injection. Systems of air distribution that use smaller temperature differences are likely to give rise to fewer complaints due to cold air draughts. The increasing use of individual computer systems and word processors is tending to augment considerably the internal heat load in contemporary offices. It is becoming more difficult to remove such internally generated heat in low ceiling buildings without causing local draught problems from the supply air.

The commonest occupant complaint in air conditioned buildings is a feeling concerning lack of fresh air. It is often expressed as a desire to be able to open the enclosing windows. Experience indicates how important air quality standards are in air conditioned buildings. Attempts are often made to improve indoor air quality by reducing external air pollutants, using the processes of filtration to remove particulate matter in the incoming air, and using air cleaning equipment to remove gaseous components. Sometimes washing with water sprays is used to remove soluble gaseous components. The intended goal of improved indoor air quality, compared with outdoor air quality, is frequently not achieved in practice in air conditioned buildings. Indoor chemical pollution is usually more significant than outdoor air pollution because of the many indoor sources adversely influencing indoor air quality. Dirt is carried in by people on their clothes. Considerable amounts of dust, organic fibres etc. may become

lodged in various parts of air duct systems and then become either spasmodically dislodged, or continuously broken up into smaller pieces of more health damaging significance to respiratory system by the constant air movement. Additionally some pollutants are transformed chemically at the surface of the heating coils into less acceptable forms. Components located in the air supply ducts of buildings, like fibre glass sound absorbers may, over a period of time, start to break up, and feed fibres to the interior. Water droplets from cooling coils, humidifiers and from cooling towers may become contaminated with infective organisms growing in their water systems, and may cause serious infections like Legionnaires' disease (Oughton, 1987). There are also the problems caused by tobacco smoking. If the internal cleansing processes are not properly designed, internally generated chemical pollutants from people, from building materials and from furnishings may completely bypass the air cleaning system.

The issue of to what extent the indoor air quality can be satisfactorily controlled by air conditioning systems is crucial. Indoor particulates may have outdoor sources or indoor sources. Suspended particulate matter can be removed by filtration. Air filtration is a complex subject (Elmroth and Levin, 1983). While the theoretical aim may be to remove all suspended particulate matter, in practice it is relatively easy to remove the larger particles, but much more difficult to remove the more finely divided material (< 3 microns in diameter [1 micron = 10^{-6} metres]), which are usually much more damaging to the respiratory system. Air filter performance is often stated in terms of the percentage weight of overall incoming particulate matter removed. Such a figure does not give information about relative effectiveness of filtration at different particle sizes. Removing the bulk of the incoming particulate matter reduces interior soiling, but may still leave a large proportion of the health damaging respirable particulates in the incoming supply air. It is essential to start by deciding what particle sizes one particularly wants to take out on grounds of health and satisfactory plant performance. Air filters to remove fine particulates have a greater air flow resistance than those made to remove predominantly coarse particles. In operation, fine filters fill up more quickly with particulate material than course filters. As they fill up, the air flow resistance rises rapidly. This rise in flow resistance may cause a substantial fall in air supply flow rates. As a consequence, indoor environmental standards fall, especially air quality. Regular and effective maintenance of air filters is essential to avoid serious complaints in use. The practical problem is that such maintenance is often neglected. In countries without air filter industries filter availability depends on imports, which may simply not be obtainable or affordable. Electrostatic precipitators provide more effective fine particle removal, but at greater initial capital expense.

The amount and type of dirt in the outdoor air needs

consideration in setting plant standards and designing filtration plant. In many hot climates, the amount of dust in the outdoor air is considerable, and, unless plant and filter design is suitable, and filter maintenance adequate, the system may easily become aerodynamically blocked, giving very low air flow rates with poor thermal performance. The external particulates in hot dusty areas are mainly non respirable. A problem can be that the larger particles held on the filter medium can be broken up into smaller particles by the dynamic action of the air flow, and these broken pieces then may become released to the indoor air often in a more health damaging form. Insects caught in poorly maintained filters may disintegrate into smaller respirable elements in the buffeting air flow, and release allergens. Dust may be transformed in chemical nature within the system on the heating coils. Both the external parts and internal parts of filter system may become colonized by microorganisms. Adequate access for maintenance is very important. There should be appropriate access points for duct cleaning. Reliable long term performance in practical use of filters is more important than initial high performance.

The positioning of the filters in systems with air recirculation strongly influences the achievable indoor air quality. The particulates and adverse gases of internal origin must be systematically intercepted before they get back the central plant. In air conditioning systems with recirculation, the required additional air cleaning equipment should be placed between the room air extract points and the air conditioning plant (Fig. 5). The extract air path to the outside is not filtered before rejection. Without adequate maintenance, the theory and practice of filtration and air cleaning are very different. Equipment designed to apparently high standards may not produce the expected air quality in practical use. Gaseous pollutants will not be removed by filtration. They can only be removed by adsorption onto suitable substrates like activated charcoal, or, in certain suitable cases by solution, for example in water, or more rarely by other solvents. Filtration therefore does not resolve the issue of gaseous pollutants. Air cleaners may resolve it, but the chemical processes of removal have to be appropriate to the chemical nature of the gaseous pollutant. Air cleaner maintenance is also essential.

In view of the substantial practical difficulties with air quality aspects of air conditioning systems, and also the considerable energy running costs associated with their use, the high maintenance overheads and large capital investment required, one has to consider very carefully whether air conditioning in any particular climate will in fact confer the expected benefits for the large capital outlay required. Problems such as electric power brown outs and breakdowns have to be considered, also the quality of field maintenance achievable, including the availability of spare parts. If a facility may frequently be out of operation the building should be, in fact,

designed to cope with the plant system inoperable. Sealed windows can render buildings uninhabitable when failure occurs. It may be better to install key controlled opening windows, rather than permanently sealed windows.

One also has to balance the actual health benefits. Doubts grow concerning the necessity for air conditioning of buildings to increase labour productivity or improve the health of workers, even in the Tropics. However, in the reality of the market place, there is plenty of evidence that people in hot countries, especially in towns, strongly appreciate air conditioning, and acquire it as an amenity, especially for bedrooms, if they can afford it. The benefits of sounder sleep, relatively undisturbed by insects and external urban noise and the better security with closed windows at night are often cited in justification. The elimination of insects will protect against the transmission of insect-borne diseases. The need for mechanical cooling depends on the nature of the outdoor microclimate. In rural and suburban areas, the available wind flows may be adequate, and external noise levels may be low enough to allow naturally ventilated buildings to be designed to ensure a reasonable prospect of sound sleep. However, in hot humid climates, wind flows can be very low just at the time people are trying to go to sleep, so the benefits of intermittently operated unit air conditioners fitted in windows of bedrooms can be considerable in hot humid seasons, provided these conditioners are not in themselves too noisy. On more central urban sites, the urban heat island effect tends to raise outdoor temperatures, the differences being most pronounced in the early evening. In such situations, the evening wind flows are particularly low, because the sun is no longer driving the additional local circulation of air, as is the case in the heat of the day. The external social noise penetrating into naturally ventilated buildings tend to become more dominant in the evening, and is important for sleep patterns on central urban sites. The priority for residential unit conditioners is thus higher in such central area urban situations, especially in low rise buildings. It should be noted, on noisy sites, unit air conditioners need to be designed to reduce external noise transmission through the conditioner, as well as to be acceptably quiet in their own right.

Whenever some mechanical cooling is considered to be necessary it should be investigated first whether the seasonal or all year round cooling needs cannot be substantially reduced by appropriate building design, using the principles of correct orientation, appropriate window placing and shading design, and above all properly designed natural ventilation systems. The trends in the development of domestic air conditioning systems in the USA have been characterized by the employment of small relatively low capital cost and quiet unit air conditioners, which do not require strict air tightness of buildings.

Conclusions

This Chapter has dealt with the impact of thermal
microclimate on comfort and health within the range
from very cold to very hot. Emphasis has been placed
on hot climate conditions as these are the conditions
found in so many developing countries. Free-running
and air conditioning buildings have been treated
separately. Many of the detailed relationships between
indoor thermal microclimate and human health are still
poorly understood in epidemiological terms. Thermal
factors are of the greatest significance for human
health as a state of well-being. Considerable attention
must be directed to developing appropriate thermal
norms and standards for different areas of the world
that both relate to peoples' needs for the local climate,
and that are feasible to achieve within the resources of
the economy.

Chapter 3

Air Quality Environment

Introduction

The air of indoor spaces is influenced by the quality of various indoor pollutants, that are subsequently added internally, and the quality of the incoming outdoor air available at the face of the building. External pollution is discussed only in terms of its potential impacts indoors. The pollutant characteristics of the incoming air can be modified in the actual processes of artificial ventilation, for example by screening, filtration or by washing. The final indoor health impacts indoors are the resultant combination of indoor and outdoor air quality factors acting together within the interior. However it is usually the added indoor pollutants, which cause the greatest deterioration in indoor air quality.

There are many sources of indoor air pollution. Some volatile and particulate pollutants are emitted from the occupants themselves, others originate from other sources such as tobacco smoke, combustion products from cooking, heating and lighting, gaseous and particulate compounds from building materials and decorations, furnishings, aerosol sprays, insecticides and pesticides, nucleotides such as radon, live and dead microorganisms, and decay products from "low" organisms, such as moulds and fungi.

The concentration of an indoor air pollutant resulting from an pollution source of given strength is strongly influenced by the ventilation rate of air changes. The air change rate depends on the efficacy of the indoor-outdoor ventilation exchange system. The achievement of healthy indoor air quality in the presence of internal pollution sources requires both controlling indoor pollution sources and simultaneously providing adequate amounts of reasonably uncontaminated fresh air to replace contaminated indoor air. The extraction of indoor pollutants should be achieved as far as is possible by air flow patterns that avoid putting people in the path of polluted air flows from the polluting internal source to the external environment, for example, by providing effective chimneys set immediately above the fireplace for the removal of smoke from wood fires.

If environmental conditions, without or with support by administrative policy, fail to secure a satisfactory external quality in the external air, then the indoor air environment will be additionally affected by contaminants from outside. The achievement of healthy indoor air quality thus depends on (a) having a satisfactory environmental clean air policy to secure the availability of healthy outdoor air, (b) having a satisfactory building design, and (c) an indoor pollution control policy, supported by appropriate building ventilation standards, to use the clean outdoor air to secure a healthy indoor air environment. An adverse external thermal and noise climate may adversely affect natural ventilation needs, because occupants tend to value the indoor thermal and acoustical conditions higher than the air quality conditions, by keeping windows tightly closed in such situations.

There are a wide range of health problems related to indoor air quality to be resolved. Only some of the health aspects of indoor air quality are currently fully understood ,while new ones develop in the course modern living conditions. The key priority areas for improvement of indoor environmental air quality can be reasonably readily identified by using existing environmental health criteria (WHO-EHC).

Energy economy and indoor air quality standards

With shortage of fire wood, rising fuel prices, and increasing concern about the impact of carbon dioxide on global climate, the achievement of satisfactory indoor air quality takes on an increasingly important economic and health aspect. One key control route for improving indoor environmental air quality is through the reduction of indoor emission and adoption of better indoor air ventilation. With current practice, where high ventilation technology is available, this implies greater energy demands and further carbon dioxide increase. Ventilation to adequate standards in temperate climates may be achieved either by properly designed mechanical ventilation systems, or more normally, especially in hot climates, by the joint influences of natural wind and thermal buoyancy forces, set up by indoor outdoor temperature differences. Their effect depends on a pattern of suitably designed openings, to induce and facilitate the required exchanges of air. In airconditioned buildings, consuming energy for heating or cooling, these exchanges imply loss of either expensively heated or even more expensively cool air. With increasing energy prices and fuel wood shortages, there is a strong economic pressure, to keep indoor ventilation rates low (UNCHS, 1984).

Ventilation standards must be conceived primarily for air purity with respect to health, based on minimum

acceptable standards. There will be other standardizing pressures, emerging from those responsible for the control of energy economy, and global warming control. Such energy based maximum allowable standards may be in conflict with health standards, that state minimum acceptable ventilation norms set on health considerations. If energy based standards are in conflict with health needs, the priority should be given to the health requirements of the space occupants. In such situations, additional technologies must be sought for resolving the conflicts, like the use of counter flow heat exchangers to transfer heat from the exhaust air to the incoming fresh air.

Classification of indoor air pollutants

The contaminants of the indoor air may be categorized into 4 classes as follows. For each class and category examples are given:

(1) Gaseous matter
> Non-radioactive gases: CO, NOx, SO2
> Radioactive gases: Radon
> Vapours: CFC's, solvents

(2) Liquid matter
> Droplets from man such as sneezing
> other sources: cooking, washing etc

(3) Particulate matter
> Non-biological: dusts, smoke, fibres
> Biological: Pollens, moulds and slimes, algae, bacteria and epithelia, insect scales and components.

Contaminants are contained in droplets and attached to particles. Viable bacteria and viruses are carried in sneeze droplets. Pathogens attached to droplets and dust particles can be carried into the respiratory tract in the process of breathing. Particle and droplet sizes are very important in determining the movement patterns. Heavy particles tend to fall out and accumulate on horizontal surfaces, while light particles float and move in the ventilation flows. Processes like heated sources, walking and sweeping the floor, drafty openings, ducts and doorways can resuspend sedimented particles from the floor and other plain surfaces. Sedimented particles are removed by vacuum cleaning or wet cleaning.

A subjective detector of perception of chemical admixtures to the air is the human nose. The effectiveness depends on the smell sensitivity of the individual based on the function of the olfactory system. The nose provides a warning signal of the presence of pleasant or unpleasant odours and unpleasant or adverse chemical pollutants in the air, like ammonia, sulphur dioxide, and hydrogen sulphide. Odourless toxic gases, like carbon dioxide, carbon monoxide and nitrous oxides cannot be detected by human sensory systems. There are many chemical substances in the indoor air without direct adverse effects for health, but are nevertheless perceived to smell unpleasant, or to be irritable, like body odours, substances outgassed from paint, furniture, and building materials. The smell stimulus is sharpest when there is a step change in the chemical environment, such as entering a tobacco smoke enriched or a freshly painted room from the fresh air. With continued exposure, the smell sensation becomes dulled as the olfactory system adapts. Recent experience has indicated considerable smell dissatisfaction with novel building, insulation, and surface treatment materials, which have replaced or are tried to replace traditional building materials and furnishings (Fanger, 1988). In the USSR the presence of odour is one of the criteria used for the regulation of the use of polymers. The symptoms tend to show up as an ill defined set of adverse sensations and unspecific complaint reactions by a significant percentage of the occupants to the indoor environment. One of the negative effects of many polymers is their unpleasant odour, which is not only the cause of discomfort, but which may also cause cardiovascular disturbances, and initiate asthmatic attacks. The occupants have a reaction which might be described as a sense of lack of well-being. Such spaces fall into the group designated as "Sick Buildings". There are many unidentified and subjectively undetectable causes of such ill health to the quality of air in closed spaces (Berglund, Lindvall, 1988; Sykes, 1988)). The verification and diagnosis is often difficult. An aggressive antipathy may develop towards the indoor environment, which may have quite significant effects on work performance, and building user satisfaction. The designers often are not aware of the quality of materials recommended by them in buildings, which in their view were designed to high environmental standards. These adverse reactions, when investigated, are sometimes found to be due to the use of materials inside the spaces and not solely a failure to provide the right thermal and moisture environment. In a significant proportion of the cases, although the basic thermal design objectives have been reached, there are still significant complaints. The feeling of lack of fresh air is often mentioned, even though the air change rates are quite high by conventional standards. The syndrome of complaints of occupants in modern and well insulated spaces has become very widespread, under different names, in countries in temperate climates with industries specialized in the production of building and furnishing materials.

This serious problem has developed partly through a failure of designers and manufacturers to analyse the fate of their products under varying indoor climate conditions. There has been a failure to recognize the odour perceptual implications of the changing chemical nature of the indoor built environment, particularly the increasing impact of outgassing polymeric materials. In this respect, one must note that the basic ventilation

standards for ordinary rooms, for example those developed in the USA, were based on the perception of human body odours and on the perception of tobacco smoke, before the smelly, and chemically detectable smell-less, indoor substances in buildings became more dominant.

The standards based on odour perception need to be revised for a far wider range of indoor odour pollutants than was previously recognized. In Denmark, Fanger et al. (1988) are now extending the perceptual approach to a wide range of building odours, using the noses of a large panel of judges to assess the perceptual smell characteristics of rooms on initial entry. These studies are being used to define perceptual ventilation standards for people, to be used to control the odours emitted by different building materials and furnishings to acceptable levels. The required ventilation for a particular smell source is established by comparing these needs with the basic air change requirements based on acceptable control of human body odours in enclosed spaces. On the basis of these studies the ventilation criteria presently adopted in many environments are far too low to avoid adverse smells in modern furnished environments.

Criteria for odour perception, based on a feeling of smell related well-being can cover only one aspect of indoor air quality. It is not enough to meet the perceptual odour criteria alone. An unknown number of odourless gases and pollutants with possible or significant implications for the maintenance of health need detection by chemical and biological methods (Meyer, 1983).

Action of indoor air pollutants

Many pollutants act in small concentrations over long periods of time. The volume of air passing through the human respiratory system over a year is very large. Breathing at rest typically 500 ml per breath, the air volume is 6 l/min, 360 l/h, and 8640 l/day. Even if only a very small proportion of the contaminants in the inhaled air are permanently retained, the intensive exposure of the respiratory system is appreciable. Some air contaminants cause immediate toxic reactions, for example carbon monoxide; other contaminants act as irritant of the mucous membranes of the nose, the respiratory tract, the conjunctiva, and of the skin. Some contaminants may have simultaneous toxic and irritant effects such as tobacco smoke. Many gaseous contaminants in the inspired air will pass directly to the alveoli of the lungs from where they pass through the membranes into the blood stream to reach the blood cells. The nasal and bronchial membranes have to fulfil a effective clearing of particles impinging onto them, of binding and transporting them and with expectorating secretion of mucous bound irritants. There are some

particles such as asbestos fibres which are not expectorated but incorporated in fibrous tissues. The position of first impaction of the particles on the various surfaces of the respiratory air flow system depends on particle size and shape. Particles >10 micro metres in size will be retained within the nose region, particles <10 to >5 micro m within the upper respiratory tract, and smaller particles will pass down into the alveolar space, of which those <1 micro m will be exhaled again. The various sections of the respiratory tract physically may be looked upon as a very complex droplet and particle impact size separating system. The physics of particles that penetrate the lungs is very important. Very small smoke particles (<0.5 micro m) may be cumulatively retained in the bulk of the lung tissue, causing chronic irritation that may lead on to chronic diseases of the lung and vascular system. The contact of the membranes with smoke contaminants also increases the risks of lung cancer.

Indoor air acts as medium for the distribution of allergens and the transmittance of airborne microorganisms between occupants. Two main pathways are through the transfer of droplets sneezed out, and through dust particles carrying bacteria. Distances and air flow patterns between persons emitting droplets such as patients in hospitals rooms is important for the control of cross infection by airborne microorganisms. Cleaning practice is an important factor in controlling the whirl up of the contaminated dust particles settled on the floor.

Concentration of pollutants and duration of exposure

Exposure to air quality hazards has to be assessed as a combination of concentration of the causal agent, and the duration of the time of exposure to it. In setting indoor air quality standards for dwellings, one has to recognize the length of time of the day spent by various persons within the spaces. These times differ over a wide range according to function of the space, activities, occupation, age, sex, and mobility from a few minutes to 24 hours. Indoor air quality standards have to consider this wide range of exposure time, but should be set high enough to allow for the typically long durations of potential exposure. Some indoor activities may produce severe pollution, like cooking over wood burning stoves. But such situations of high emission rates of pollutants and exposure to them last only for a portion of the day. Women cooking over open wood or charcoal fires, are particularly exposed to smoky air and so are liable to suffer poor respiratory health in dwellings with improper ventilation, even in rural areas with little outdoor pollution (Smith et al, 1983). Where the indoor pollution is strongly influenced by outdoor pollution, indoor pollution patterns tend to follow the outdoor daily and seasonal variations. Some outdoor pollutants, such as smoke, increase in the cold season, and decrease in the hot season. Other pollutants, like

surface level ozone increase around mid-day in the summer season, and decrease in the winter, when the sun is low. Characteristic seasonal and diurnal patterns of pollution exist for the natural emission of pollen and other plant allergens, and artificial emission of traffic pollutants, reaching peaks at the morning and afternoon rush hours. Extremes of indoor and outdoor pollution tend to be episodic. When such outdoor episodes occur over several days due to weather conditions such as inversion, they inevitably affect the indoor air of dwellings. Then there is no protection of the occupants, with possible effects on morbidity and mortality.

Persons with existing acute and chronic respiratory ailments and those with particularly sensitive respiratory organs such as infants and small children are particularly affected by extreme episodic air quality events. Recovery from respiratory disease is often much slower in environments of low air quality, especially if airborne irritants are present to reinforce the irritation. The recovery of young children from respiratory infections has been demonstrated to be adversely affected by the smoking habits of the parents. Good air quality is also especially important for spaces where gymnastics and vigourous physical exercise is carried out. Many pollutants impair lung function by increasing airways resistance, and, for healthy subjects, this factor becomes far more critical, when their physiological work rates become higher.

The primary health aim in indoor air quality control must be to avoid or reduce adding adverse substances to the indoor air. If adverse admixtures are added indoors, which is always in conflict with health needs, the consequent distribution of the pollutants within the living space may be far from uniform. Vertical gradients of pollution may occur. For example, with unflued stoves, the indoor smoke plume may fan out under the ceiling. The sampling of indoor air quality has to take account of spatial variations of indoor air pollution, flow, turbulence and diffusion mixing of air pockets and to relate these variations to the spatial pattern of the human activities in the space. The indoor pollution climate cannot be described adequately by a single measurement, as there is a complex indoor pollution microclimate to consider. It is useful to distinguish between point sources of pollution, like individual burners on a cooker, and area sources, like a polymeric wall covering.

Unfortunately the addition of some unhealthy admixtures from indoor sources may be currently unavoidable for cultural and developmental reasons, and depends on the availability of resources. The use of open wood burning cooking stoves is the only choice in areas totally lacking alternative energy supply infrastructures. In such circumstances, exposure mitigation strategies such as measures for improved ventilation offer the only option for health protection. The concentration of adverse substances in the indoor

air will be highest at those specific places, where the internal pollution generating sources are located, for example, in the region of the cooking stove. An important aim for health protection in such circumstances, is to attempt to extract such adverse pollutants as close as possible to the point of their indoor generation, before mixing with the distant indoor air. It also is desirable to site people at rest and during activities in the paths of the clean air flows or flow patterns, and to avoid the polluted air flows. This can only be done effectively if the structure of the indoor air quality microclimate is understood.

Outdoor air quality

Though most of the more serious indoor air quality problems arise from internal causes, it is still necessary to consider the impact of the outdoor air quality on the indoor air quality, as the outdoor environment is the sole source for fresh air for ventilation. The key outdoor factors potentially impacting on indoor air quality, are:

Flora and fauna, as sources of allergens.
Agricultural, animal, and food production activities

Building operating dust and dirt.

Chimneys discharge from burning in houses and factories and incinerators

Transport systems, road, air, rail, water based motor traffic pollutants

Mining, chemical and metallic industrial activity

Power generation from fossil fuels such as oil and coal, often the predominant cause of urban smoke

Waste disposal dumps

Airborne dusts raised by wind from parched ground surfaces, storage, building and construction sites, fields, and desert areas.

The list can be extended and will never be complete as there are innumerable sources for the production, generation, emission, distribution and transport of gaseous and particulate matter in the outdoor air.

The atmospheric pollution in densely populated urban areas is of great significance for indoor air quality. To improve the practical use of data in relation to the protection of human health, the WHO and UNEP have set up the Global Environment Monitoring System (GEMS, 1987). This is the collective effort to monitor the world environment for the preservation of essential natural resources, and to promote the exchange of information. The GEMS Air monitoring project was begun in 1973. It has gradually increased in size to about 50 countries and approximately 170 measuring

sites. The GEMS Air monitoring stations are in the urban areas, where pollution levels are the highest and most threaten human health. The cities for the GEMS project were selected to provide as broad a global coverage as possible, representative of different climatic conditions, levels of development, and pollution situations.

In the initial stages of the programme only two air pollutants were measured, sulphur dioxide and suspended particulate matter. The combustion of coal, wood, petrol and oil, and various industrial and human activities, give rise to these pollutants. Suspended particulate matter also arises from other human activities such as dust raised by vehicular traffic, from construction sites and work in the fields. More recently, nitrogen dioxide and lead, have been added, but few results are yet available. This programme is enabling the World Health Organisation to get a much clearer global picture of outdoor pollution levels and their ups and downs in key urban areas. The data accumulated in the network can be used to assess the outdoor air quality in urban areas throughout the world and also to investigate trends in air pollution levels. Two summarizing technical reports "Urban Air Pollution" are available, covering the period 1973-1980 (GEMS, 1984), and the period 1981-1985 (GEMS, 1987a). The health related issues are specifically discussed in the Report on Global Pollution and Health (GEMS, 1987b). Useful summaries of the GEMS work have summarized by Bennett et al.(1985) and de Koning et al. (1986). Methods suitable for measuring air pollutants have been selected (WHO, 1976). For the measurement of the level of particulate pollutants two basic types of methods are used in the GEMS urban air pollution programme. The gravimetric methods measure the weight of particulate matter per unit volume of air. The smoke shade method measures the darkness of the particulate stain left on the filter paper after filtering of air. A calibration curve relating the density of the filter stain to the weight of smoke particles deposited on the filter paper has been established for "standard urban smoke".

The findings of the GEMS programme serve to demonstrate comparative outdoor pollution levels. Outdoor air pollution levels are constantly fluctuating with weather and with primary pollution outputs. It is desirable to use statistical methods of data presentation that preserve the nature of the variations found by observation. Special plots are often used, plotting the observed concentrations logarithmically on the Y-axis against the cumulative Gaussian normal frequency distribution on the X-axis. This statistical process enables straight line log-normal cumulative frequency distribution plots to be obtained. Sulphur dioxide data for Tokyo and Zagreb are presented in this form in FIGURE 6.

The 50% cumulative frequency level is representative of the annual average levels, while the 98% cumulative frequency level is considered statistically representative of extreme conditions. In 1973 the 50% SO2 value for Tokyo city centre commercial sites was estimated as 69 micro g/m3 (microgrammes per cubic metre), and for Zagreb as 170 micro g/m3. By 1980, these 50% levels had been reduced to 53 micro g, and 80 micro g respectively. The 98% SO2 levels were of course much higher, 140 micro g/m3 in Tokyo in 1973, falling to 79 micro g/m3 in 1980, and for Zagreb, 600 micro g/m3 in 1973 falling to 260 micro g/m3 in 1980. For other purposes data are presented in the monthly means (FIGURE 7).

A very sharp annual variation about winter existed for Zagreb, whereas there was little annual variation in Tokyo. The differences between city centre and suburban sites is evident. These data illustrate that a city centre commercial site can be more polluted with sulphur dioxide than a city centre industrial site. The range of annual means and the composite mean for sulphur dioxide in a number of cities across the world is shown in FIGURE 8.

The acceptable limits for sulphur dioxide as defined in WHO-EHC 8 are the two horizontal lines included on the diagram.

Examples for the annual range of suspended particulate matter are presented in FIGURE 9a and for the annual range of smoke in FIGURE 9b for a range of cities with a composite average for each city. The exposure limits for suspended particulate and smoke are inserted (WHO-EHC 8).

Guidelines to limit the outdoor exposure of the general public to sulphur dioxide and particulate levels have been drawn up in WHO-EHC 8 Sulphur Oxides and Suspended Particulate Matter. For annual average concentrations relevant to long term effects, the guideline values are 40- 60 micro g/m3, for sulphur dioxide and smoke, and 60 to 90 micro g/m3 for gravimetrically determined suspended particulate levels. Exposure effect relationships to smoke and to sulphur dioxide are set out in tables: TABLE 6 for effects of short term exposures, and TABLE 7 for the effects of long term exposure. The results from the studies were based on different methods of measuring sulphur oxides and particulate matter. Guidelines for exposure limits consistent with the protection of public health are given in TABLE 8.

Using average concentrations taken from 1975 to 1980 (GEMS, 1984) the data shows most sites in the GEMS network are below or within the Guideline values. About one quarter of the sites are above the upper guideline for sulphur dioxide (FIGURE 8). A somewhat greater proportion, just over 40% of all sites, is above the upper guideline for suspended particulate matter, including smoke (FIGURE 9a, b). City centre,
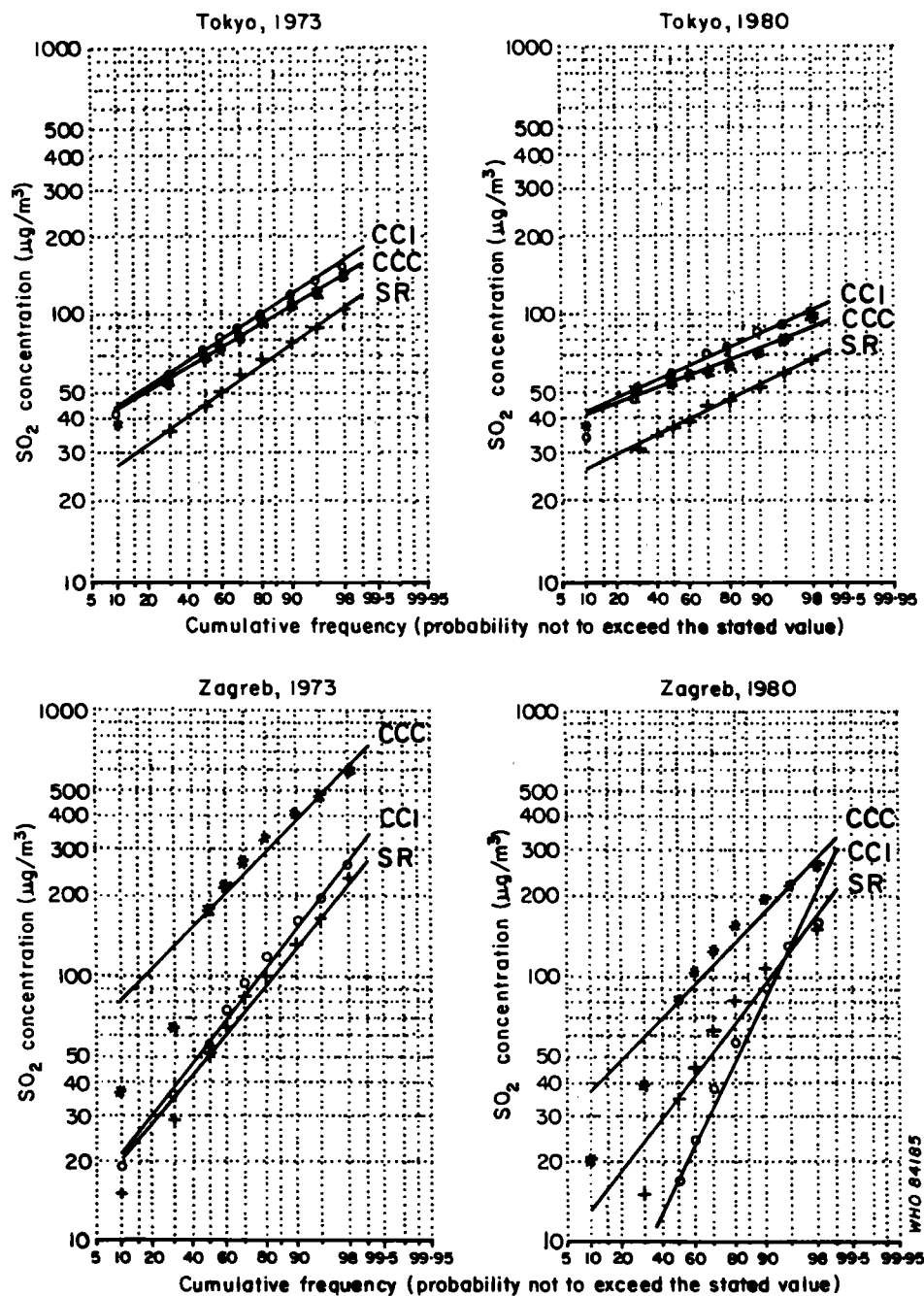
Fig.6 :- Cumulative frequency distributions of daily SO_2 concentrations in Tokyo and Zagreb at city-centre commercial (CCC), city-centre industrial (CCI), and suburban residential (SR) sites.
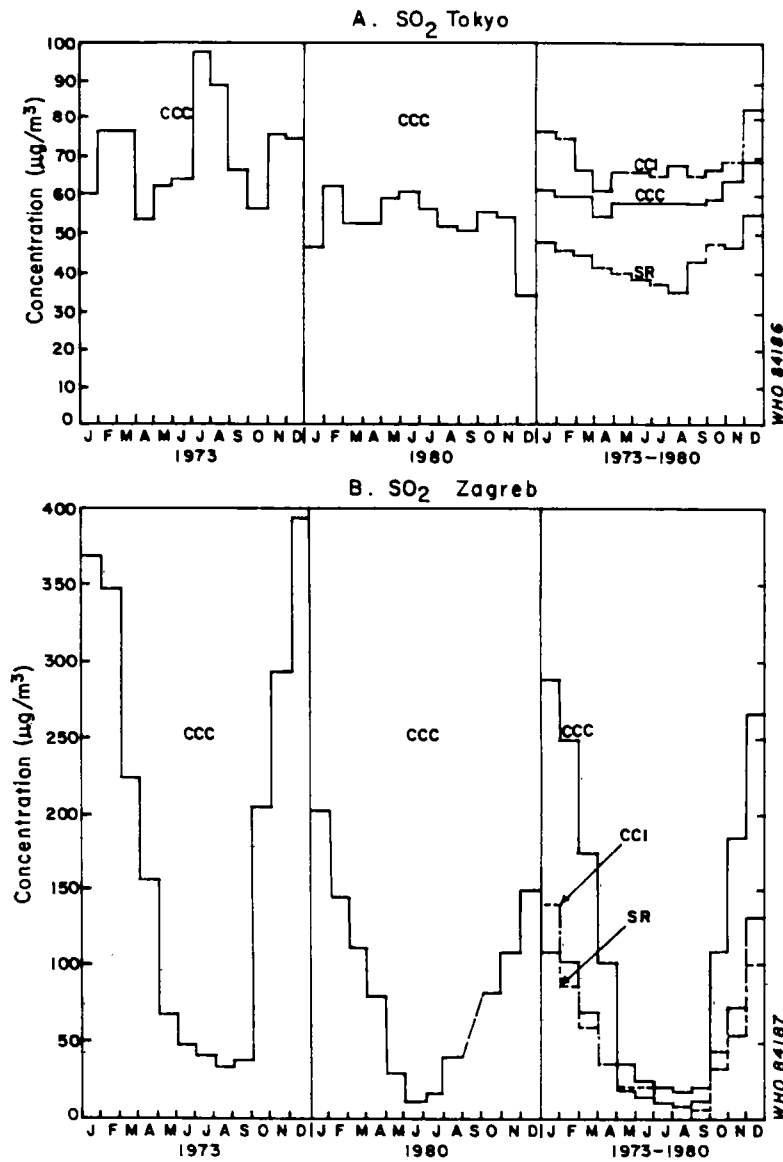
A. SO₂ Tokyo

B. SO₂ Zagreb

Fig.7 :- Monthly variations of mean SO₂ concentrations in Tokyo (A)
and Zagreb (B) at city-centre commercial (CCC), city centre
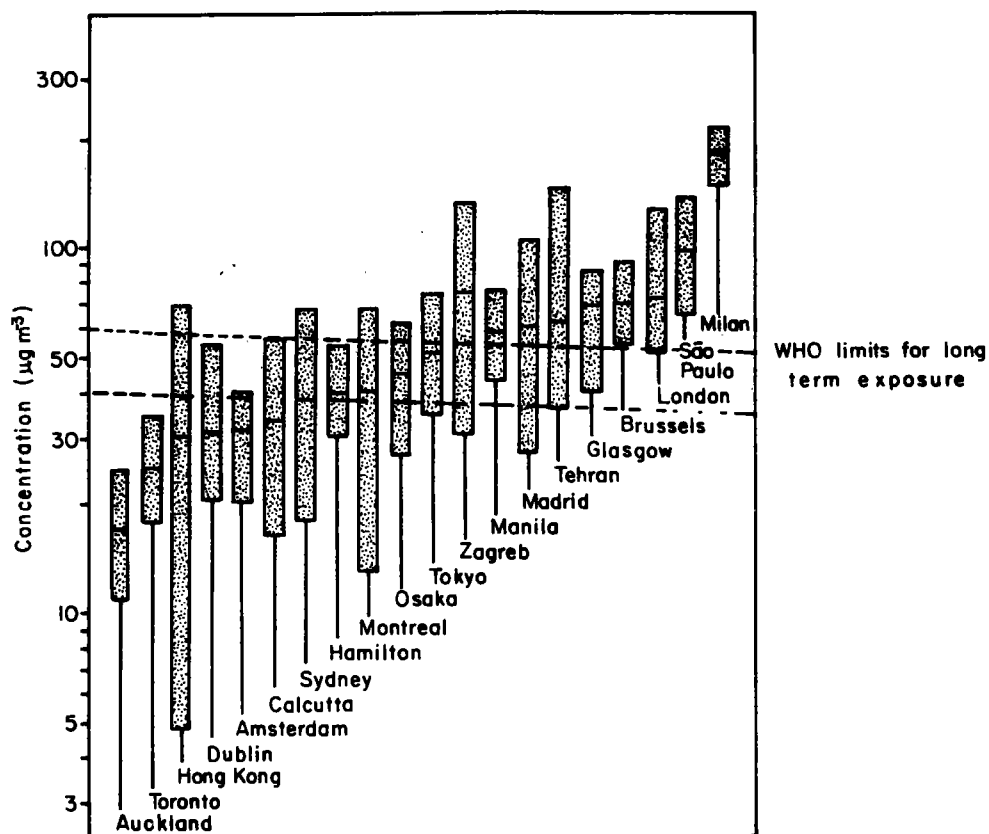industrial (CCI), and suburban residential (SR) sites.(Source:
GEMS, 1984).

Fig. 8:- Range of annual averages of sulphur dioxide and composite average in cities 1976-1980 (GEMS, 1984) compared with WHO upper guidelines (WHO-EHC 8). (Source: Bennet et al., 1985).
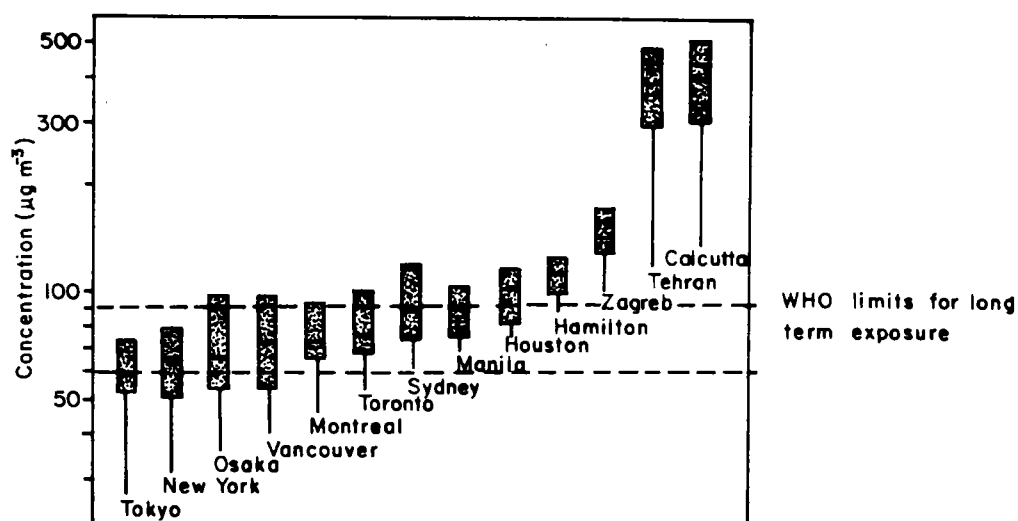
Fig.9a:-Range of annual averages of *suspended particulate matter* and composite averages in cities 1976-80 (GEMS,1984) compared with WHO upper guidelines (WHO-EHC 8).(Source: Bennet et al., 1985).
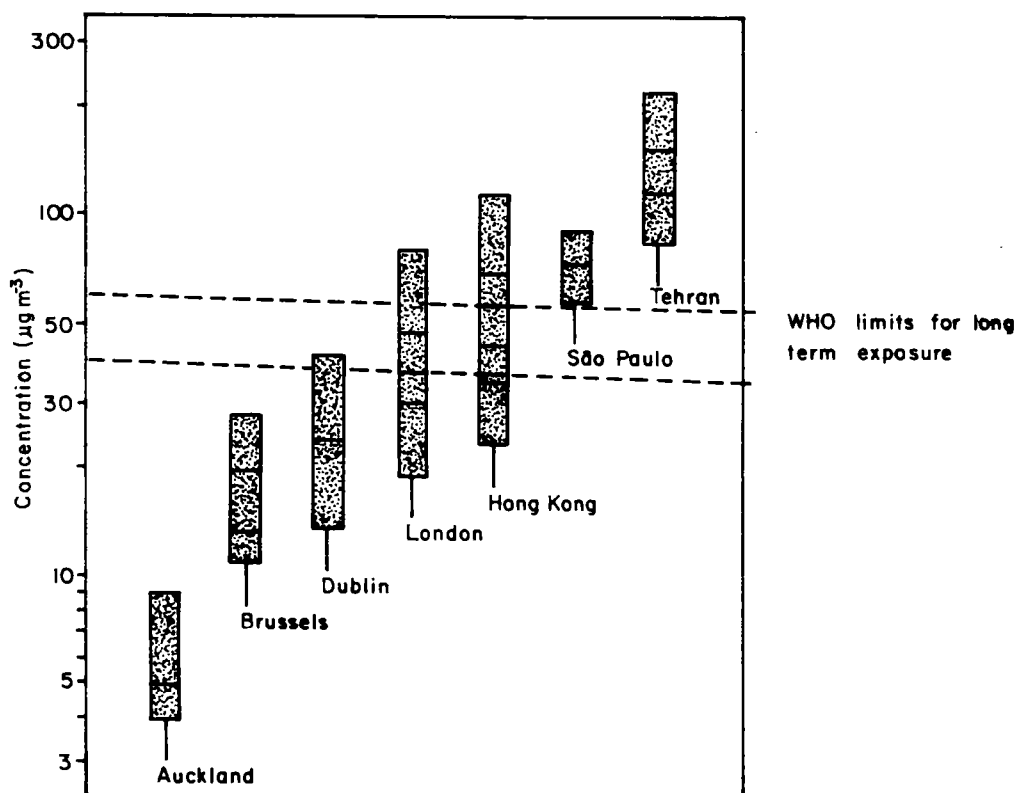

Fig.9b:-Range of annual averages of *smoke* and composite averages in cities 1976-80 (GEMS,1984) compared with WHO upper guidelines (WHO-EHC 8).(Source: Bennet et al., 1985).

Table 6

Expected effects of air pollutants on health in selected segments of the populations: effects of short-term exposures (a).

Expected effects	24-h mean concentration (ug/m3)	
	Sulfur dioxide	Smoke
Excess mortality among the elderly or the chronically sick	500	500
Worsening of the condition of patients with existing respiratory disease	250	250

(a) Concentrations of sulfur dioxide and smoke as meansured by OECD or British daily smoke/sulfur dioxide method (Ministry of Technology, UK, 1966; Organisation for Economic Cooperation and Development,1965). These values may have to be adjusted in terms of measurements made by other procedures.

Table 7

Expected effects of air pollutants on health in selected segments of the population: effects of long-term exposures

Expected effects	Annual mean concentration (ug/m3)	
	Sulfur dioxide	Smoke
Increased respiratory symptoms among samples of the general population (adults and children) and increased frequencies of respiratory illness among children	100	100

(a) Concentrations of sulfur dioxide and smoke as measured by OECD or British daily smoke/sulfur dioxide method (Ministry of Technology, UK, 1966; Organisation for Economic Cooperation and Development, 1965). These values may have to be adjusted in terms of measurements made by other procedures.

Table 8

Guidelines for exposure limits consistent with the protection of public health (a).

	Concentration (ug/m3)	
	Sulfur dioxide	Smoke
24-h mean	100-150	100-150
Annual arithmetic mean	40-60	40-60

(a) Values for sulfur dioxide and smoke as measured by OECD or British daily smoke/sulfur dioxide method (Ministry of Technology, UK, 1966; Organisation for Economic Cooperation and Development, 1965). Adjustments may be necessary where measurements are made by other methods.

industrial and commercial sites are more frequently above the upper guideline, and suburban residential sites are below the lower guideline value (FIGURE 6).

For limiting acute effects from short term exposure from these air pollutants, the guideline value applied to the 98th percentile of the daily averages are 100-150 micro g/m3 for sulphur dioxide and smoke and 150-230 micro g/m3 for suspended particulate matter, SPM. The upper guidelines are exceeded by nearly one third of all sites for SO2 and by nearly one half the sites for SPM. Residential sites are more frequently below the guideline values than are commercial or industrial sites.

Air pollution from traffic (WHO-EHC 7)

Vehicle engines are a major source of urban air pollution. These sources, in many situations at present, move along traffic arteries in large numbers often in close proximity to residential buildings (Hotherhall and Salter). The principle of environmental separation of noxious polluting activities from clean areas is broken often in the evolving urban traffic situations. Dwellings adjacent to traffic thoroughfares, are frequently exposed to the emissions from densely occupied traffic lanes as powerfully polluting line sources. The output of pollutants depends on the quality and amount of motor vehicles, and the conditions of operation of the traffic. Traffic congestion causes pollution levels to rise. More pollution is produced per unit road length when climbing hills than on the even level. Temperature also exerts an influence on engine operating efficiency. The consequent dispersal of the pollutants after emission depends on the ventilation at street level. Open streets enable a better wind flow to be achieved to disperse local pollution concentrations than is possible in canyon type streets. Wind flow directions are of significant importance. In canyon streets, the wind flows above the roof top level, leaving the pollution trapped below. Roads sited in areas with low wind speeds tend to produce higher pollution concentrations than roads more exposed to wind. Stationary traffic produces little air turbulence compared with fast moving traffic, so the worst conditions for the primary pollutant accumulation occur with near stationary traffic on still days in canyon type streets. In more exposed positions, primary pollution concentrations are normally highest at exhaust level close to the traffic lane and fall off both with increase of height and increase of distance from the traffic lane.

Consequent to initial emission, the primary pollutants may react to form other products (WHO-EHC 4 Oxides of Nitrogen). Oxides of nitrogen, NOx, are produced in high temperature combustion processes. Important outdoor sources are electric power stations, and internal combustion engines. These oxides will penetrate indoors from outdoors and are often complemented from strong indoor sources, like gas combustion appliances. Nitrous oxides tend to be oxidized to nitrogen dioxide. Annual mean NO2 outdoor concentrations in urban areas are typically in the range 20-90 micro g/m3 (WHO-EHC 4). Data for shorter averaging periods show considerable variations, depending on meteorological and seasonal conditions, and on the proximity and nature of local sources of pollution. Generally the highest monthly means of NO2 levels in large urban areas are about 60-110 micro g/m3, and the highest daily means 130-400 micro g/m3. Typical peak hourly values are 240-850 micro g/m3.

Solar radiation promotes photochemical reactions leading to the formation of oxidants as secondary pollution products, especially ozone(Newell and Selkirk, 1988). The general mixture, if produced in the presence of sunlight, is usually named smog, of which the Los Angeles type smog with its adverse effect for health has become well known. Trapping of pollutants due to vertical inversions of temperature aggravates the problem. The formation of photochemical oxidants from traffic exhaust fumes and the consequent health impacts of photochemical oxidants are discussed in detail in WHO-EHC 7 Photochemical Oxidants. A typical diurnal cycle of oxidants in an urban situation is shown in FIGURE 10.

The oxidant concentrations are highest around noon and the early afternoon, when there are most high energy photons available to promote the photochemical reactions. The nitrogen dioxide levels typically peak slightly earlier. As soon as the photochemical generation rate falls, the concentration simultaneously declines. In large cities with strong sunshine and dense traffic, photochemical air pollution is a daylight phenomenon with maximum 1-h ozone concentrations sometimes as high as 300-800 micro g/m3 during midday. Such peak concentrations are preceded by nitrogen dioxide peaks and accompanied by concurrent rises in peroxyacetylnitrate concentrations. In contrast to oxides of sulphur and smoke, ozone exposures are always intermittent, the peak concentrations rarely lasting for more than 2-3 hours. Seasonal variations in the number of days in the month with 1-h oxidant concentrations equalled or exceeded 200 micro g/m3 in the mid latitude sunny climate of Los Angeles, and the high latitude cloudy climate of Delft.

Ground level ozone reacts aggressively as a powerful oxidant with many materials. Photochemical oxidants can produce strong eye irritation. Impacts of increasing concentrations of ozone and other oxidants on health as summarized in WHO-EHC 7 are:

some effects on the respiratory function of healthy human subjects might occur with an exposure to ozone level of 200 micro g/m3 for 2 hours.

1-h ambient oxidant levels in the range of about 200-500 micro g/m3 may affect lung function in children, increase the frequency of asthma attacks, cause more
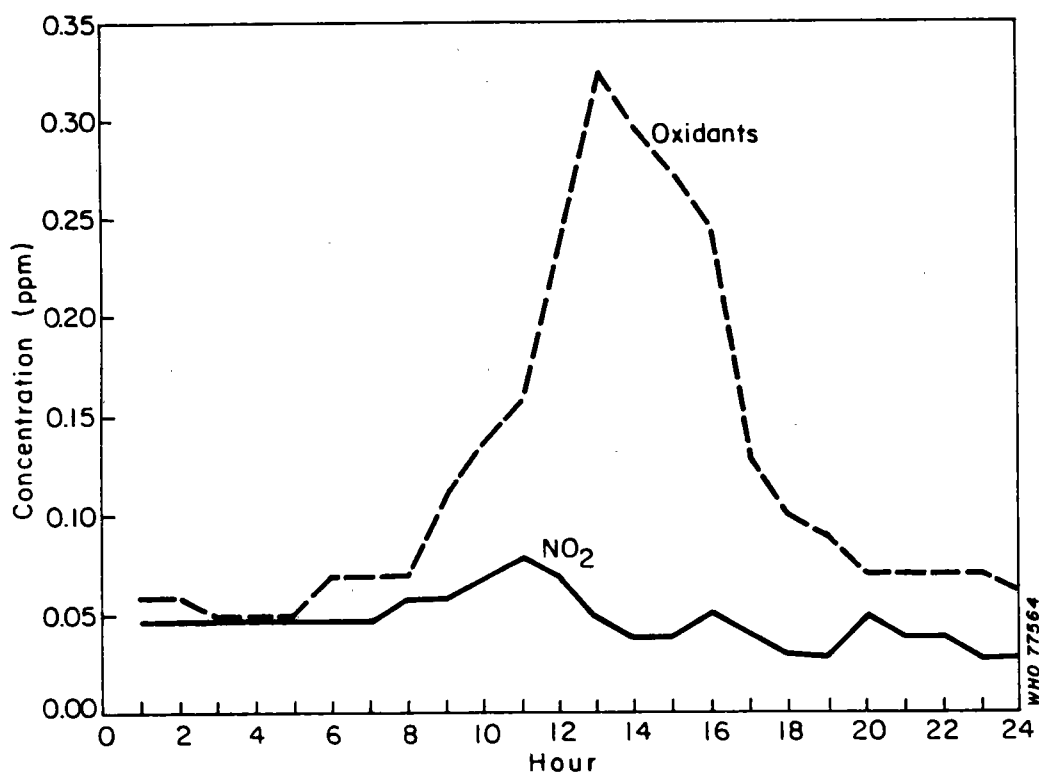
Fig. 10:- Daily variations in oxidant and nitrogen dioxide concentrations, 18 May 1974, Chiba, Japan. Nitrogen dioxide, 1 ppm = 188 $\mu g/m^3$; oxidants, 1 ppm = 2000 $\mu g/m^3$ (Environment Agency, 1975a).

frequent eye irritation, and reduce athletic performance.

1-h oxidant levels within the range of 400- 1400 micro g/m3 may exert additional stress on patients with chronic pulmonary disease.

air way resistance may be increased in healthy human subjects following exposure to ozone levels of 700-800 micro g/m3 for two hours.

An 1-h exposure to outdoor ozone levels of 100-200 micro g/m3 can be used as the upper permissible level for the protection of public health (WHO-EHC 7). The environmental planning issues that arise in photochemical oxidant control are complex, especially in built up zones covering large areas. The control of outdoor emissions of both oxides of nitrogen and hydrocarbon emissions are needed. This implies changes both in engine design and in exhaust design. Better spatial separation of traffic routes from residential areas and planning to improve air flow at street levels will help to cut down nitrous oxide emissions.

Lead (WHO-EHC 3)

Lead tetraethyl for many years has been added to petrol to give improved performance in internal combustion engines. The exhausted lead has caused significant toxic effects on people in urban areas, especially in residential areas adjacent to major routes. High ambient lead levels are thought to have an especially deleterious effect on the mental development of young children. After the introduction of control measures the concentration of lead in blood in children has declined from approximately 600 micro g lead/l blood in the 1960's to 250 micro g/l in 1988 (Davis and Svendsgaard, 1987). The lead is discharged from the vehicle to the air in a finely divided form. Some of it settles close to the road, and when such fine dust is stirred by passing traffic and carried by the wind, it may enter the indoor environment. The concentrations of lead in the blood of children living in buildings at different distances from main traffic roads, was found to be higher of children from poor families living in badly overcrowded conditions than of children from better off families in better locations (WHO-EHC 3). In the USA lead poisoning among young children was associated with poor families living in deteriorating old property, painted earlier with lead paint. Water intake increases in summer, and, if the water supply were lead contaminated, this would produce a seasonal variation in intake. Children playing close to traffic routes in dry conditions in summer could imply more lead ingestion from the ground lead contaminated dirt by nearby traffic routes.

In recent years, there has been strong international pressure to lower the lead content of petroleum fuels. Legislative measures to achieve this goal have been passed in many countries. While the lead content is lower, this gain is sometimes still not enough to offset by the continual rise in the number of petrol driven vehicles, so planning to separate occupied buildings from traffic routes, especially residential buildings which are occupied for the greatest proportion of the year, remains a priority to achieve acceptable outdoor air quality in areas where leaded petrol is in extensive use. Recent national policy is a move to lead free petrol, a conversion process that requires time and legislation. According to GEMS (1984) the lowest lead levels in residents were found in Tokyo, a city which petrol has been virtually lead free since 1976. The median lead levels in Japan fell from 210 micro g/l in 1967 to 60 micro g/l in 1981. In contrast, petrol in Mexico City contained the highest lead content of all the cities studied, and people from that city had over four times as greater levels of lead in blood than people in Tokyo. The WHO-EHC 3 considers 200 micro g lead/l as the level at which biochemical changes in the blood start occurring. Changes in enzyme activities may occur at even lower levels. Effects on the nervous system are expected to occur at 400-500 micro g/l. While the average concentrations found in the GEMS biological monitoring programme were below the no effect level, some individual exposures at a few of the locations were actually in excess of the "no-effect" level. For example, in Bangalore, India, and in Mexico City, 10% of the population sampled had exposure levels higher than 300 micro g/l.

Carbon monoxide (WHO-EHC 13)

Gasoline motor vehicles are the principal outdoor source of carbon monoxide close to human settlements. Carbon monoxide results from incomplete combustion of carbon in the fuels. The patterns of external carbon monoxide concentrations follow in cyclic variation the patterns of motor traffic flow (FIGURE 11). Carbon monoxide concentrations in the outdoor air vary considerably, not only between urban areas, but within cities as well. The maximum 8-h mean concentrations measured at more than 200 measuring stations in the USA in 1973, ranged from less than 10 mg/m3 to 58 mg/m3 with most of the values being less than 30 mg/m3. One hour concentrations may rise to 90 mg/m3 at adversely located central urban sites. Annual average concentrations of carbon monoxide in most locations fall well below 10 mg/m3.

Outdoor pollution control

Responsibility for the overall control of outdoor air quality rests with the groups in any economy responsible for urban environmental planning and control. A key principle is making effective use of environmental zoning to separate noxious activities from other areas. Chimney height and chimney location policy is critical. Environmental impact analysis provides an important technique for assessing risks in
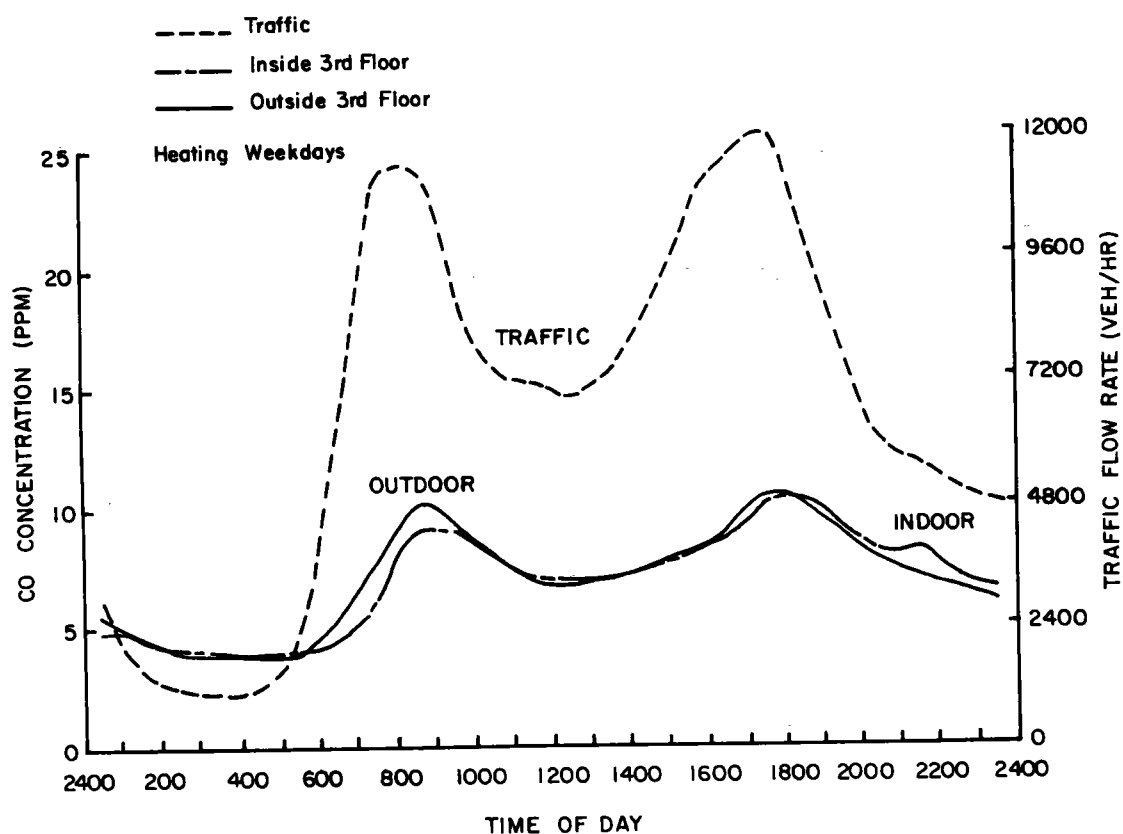
Fig. 11:- Mean diurnal concentration of carbon monoxide in the air in
Wiesbaden, FRG. Carbon monoxide 1 ppm = 1145 μg/m^3.
(Source: WHO - EHC 13).

urban development. It is essential to avoid locating residential construction in the plume space of a major pollution source such as a power station with an unsuitably low chimney. The urban environmental problems cannot be resolved at site level, but logical use of the site can mitigate problems, for example siting fresh air intakes well away from traffic fume exhausts.

The primary planning principle always is to reduce pollution production at source, either by converting the pollution product into a more acceptable form e.g. converting the unburnt or partially carbon to carbon dioxide, or by eliminating or reducing the pollutant emission from the process, for example sulphur removal from fuels or of lead tetraethyl in petro, or by alteration of the process, for example reduction of the production of oxides of nitrogen by changes in car engine combustion technology.

The second planning principle is safe dispersal of unavoidable pollutants by correct choice of discharge location, and discharge height in relation to pollution power of the source, using appropriate emission standards acceptable for human health to determine the suitability of any proposals. This requires a knowledge of the directional characteristics of the local weather.

The third principle is appropriate spatial separation of environmentally incompatible activities, including the use of the prevailing wind flows to channel pollution away from sensitive areas for as great a proportion of the year as possible. The three dimensional nature of the pollution flow patterns must be related to the three dimensional nature of the terrain to perceive adverse relationships, like the plume from a large industrial chimney located in the valley **floor** running out to strike a housing development located on the valley side sited above the level of that chimney. Wind speed and wind direction are always a critical environmental factor in planning outdoor air quality control. At a finer scale level, the pollution flow from one building directly to another should be avoided. Temperature inversions may cause pollutants to be trapped below them for several days, and pollutant concentrations then may increase cumulatively for days on end to reach very unhealthy levels, unless there is some effective administrative intervention to order an instant reduction in the production of the pollutants. This can only be done if there are appropriate legislative powers enabling such interventions to take place.

Indoor concentrations of outdoor air pollutants

Ventilation transfers outdoor pollutants from outside indoors. It is useful to be able to make some assessment of the probable indoor levels of the various external polluting constituents when they are transferred to the indoor environment through the processes of ventilation. In the example of New York

City in FIGURE 12 there is clear evidence of a close relationship between traffic levels, and outdoor and indoor concentrations of carbon monoxide as a function of time of day (WHO-EHC 13 Carbon Monoxide). With windows wide open indoor pollution levels and outdoor levels will be very similar. With more restricted levels of air exchange, chemical factors indoors exert dynamically a greater influence through the processes like surface absorption on building materials and furniture. Indoor chemical reactions also may proceed between internal and external pollutants, for example internally generated ammonia interacting with incoming externally generated sulphur dioxide, to produce ammonium sulphate (WHO-EHC 54 Ammonia). Suspended particulate matter and sulphur dioxide are especially common adverse outdoor urban pollutants. In the absence of indoor sources, indoor concentrations of these two pollutants is lower than outdoors WHO-EHC 8). Sulphur dioxide as a gas, can readily diffuse onto walls and other surface materials. There is also evidence that the gas is most effectively absorbed onto walls, curtains, carpets, other soft furnishings, clothing, and it reacts with ammonia from the indoor air. As a result, where these abound, concentrations of sulphur dioxide are with the doors and windows closed only of the order of 20% to about 35% of those outdoors. In offices and other buildings containing less absorbing material, concentrations may be 40- 50% of those outside.

The amount of suspended particulate matter indoors is normally around 50 to 90% of those outdoors (WHO-EHC 8). Some particles impinge on the crack walls and are retained in the process of entering the room through cracks. The larger particles are preferentially removed by settlement in the stiller air conditions, which prevail indoors. A considerable fraction of the suspended particulate matter can be removed through air filtration. Normally some additional particulate matter will be added in the interior, through the furnishings, and through tobacco smoking. The consequent indoor concentrations depend on the ventilation rate. Some incoming gases like carbon monoxide are relatively inert, and so are little absorbed (WHO-EHC 13). The CO concentrations indoors and out of doors are then very similar.

Only limited information appears to be available on the relationship between NO2 levels outdoors and indoors in the absence of internal polluting sources. Assuming certain relationships in the chemical affinities of sulphur dioxide and nitrogen dioxide, absorption on fabrics and furnishings is expected. Nitrogen dioxide levels were reported to be lower indoors, except in rooms where gas appliances were in use (Benarie and Nonat, 1978). As ozone is so reactive, ozone concentrations indoors will always be lower than those found outdoors.

There is often a high concentration of small acidic droplets in outdoor fog in polluted urban regions.
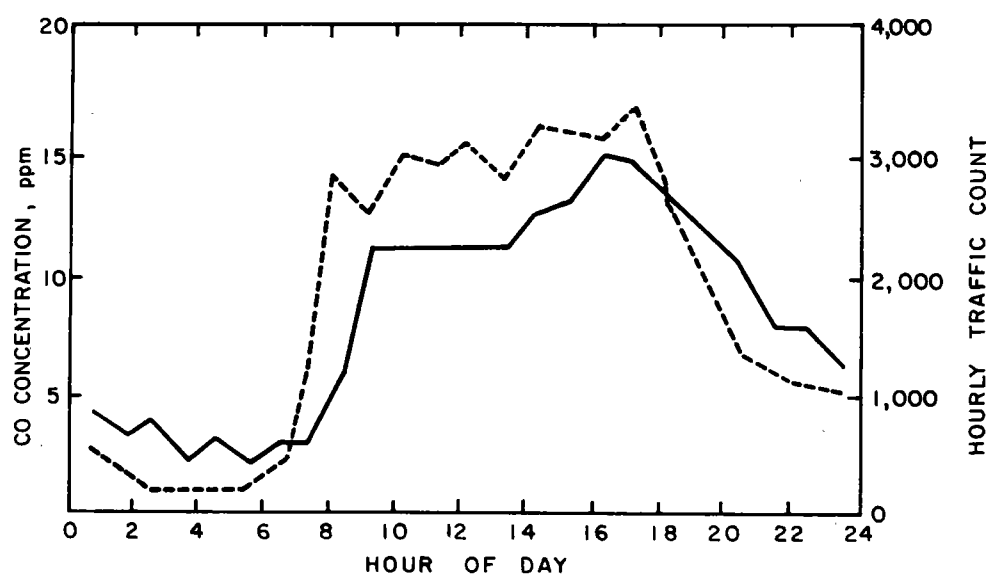
Fig.12:-Indoor-outdoor carbon monoxide concentrations in New York. Carbon monoxide 1 ppm=1145 μg/m^3.(Source: Lee, 1972 quoted in WHO-EHC 13).

Gaseous acidic pollutants discharged into the atmosphere tend to be absorbed into the water droplets. The partition of SO_2 in the atmospheric air between the gaseous and the liquid phase depends on the droplet radius. Because of their large surface to mass ratio, small droplets tend to absorb most sulphur dioxide, which then is rapidly oxidized to form sulphuric acid. The acidity of small droplets in a polluted fog thus can be high. When they are inhaled into the respiratory tract and impact, the localized irritation of the upper respiratory tract due to the droplets can be very severe. In a heated dwelling, mists and fogs normally evaporate, and the chemical residues contained in them become particulates. The evaporation of the majority of the highly acidic aerosol droplets in the heated indoor environment helps eliminate this adverse health factor. With acidic foggy outdoor conditions, it is healthier to stay in a heated interior.

Indoor pollutants

There are a very wide range of potential indoor air pollution sources, the effects of which may impinge on human health, in some cases very seriously. The list below covers the key factors:

Tobacco smoking
Domestic animals
Building materials, including insulation materials and adhesives
Surface finishes, paints
Furniture
Combustion systems for heating and cooking
Cleaning materials, sanitary and cosmetic facilities
Pesticides
Emanations of gases from the ground

The indoor pollution source may be a point source, like a cooking stove or fireplace, or an area source like a carpet with an unsuitable plastic backing. Local extraction of pollutants at the point of generation is useful in the first case, but not applicable in the second case. Combustion systems, especially wood fuel cooking stoves and tobacco smoking, are traditionally the most serious indoor pollution sources (De Koning et al. 1985). Changes in the chemical nature of the building materials in common use is throwing up more and more chemical pollutants. Man himself discharges gaseous and particulate matter from his body which contribute to the pollutants the indoor environment.

Toxic products resulting from internal human biological processes, play an important role in the formation of the indoor residential air quality environment, especially if ventilation is restricted. In specialized studies in the USSR, using gas chromatography and mass spectrometry, about 400 different chemical compounds have been identified in rooms occupied by people. The air sampling procedure is to collect samples in a living room at heights 1.5 m and 0.8 m from the floor level, with the windows closed before airing after the nights sleep, after half an hours airing, and then after one hours burning of all gas burners, normally 4 burners. The volume of air exhausted through the extract air duct is measured at the same time. Under normal conditions of occupancy of residential and public buildings, accumulations of such specific substances, in non-air tight environments do not reach unpleasantly irritating or unacceptably toxic levels. However, even relatively low concentrations of a such great number of substances in conjunction may have a negative influence on man's well being and his capacity for work. In the USSR detectable substances are divided into four classes according to the strength of their biohazard effect.

One fifth of the identified substances falls in the class of very noxious substances. Their indoor concentrations depends on the ventilation rate. In a dwelling without ventilation, the concentrations of dimethylamine and hydrogen sulphide in the air exceeded the maximum permissible concentration values. Substances such as carbon dioxide, carbon monoxide and ammonia were also measured at concentrations equal to or above the highest permissible concentrations. All other substances, although at concentrations one tenth lower than the highest permissible concentrations, or less, when considered in isolation, but taken together, produced a poor air quality microclimate, which had a negative effect on intellectual work, even after only two to four hours indoors. The mean outdoor atmospheric concentration of CO_2 in urban areas may reach 0.07%. The principle source of carbon dioxide within spaces is the respiration of its occupants. A carbon dioxide concentration of 0.1% has a marked, even harmful effect on the regulation of respiration and blood circulation. Concentrations of more than 0.10- 0.15% CO_2 may cause giddiness (WHO, 1968). Carbon dioxide is an important indicator for indoor ventilation standards. High levels indicate insufficient ventilation on physiological grounds. While CO_2 levels as high as 1.0% by volume are tolerated in special situations like submarines, it is normally agreed that 0.5% by volume is the upper acceptable limit for 8-h occupation. At higher concentrations >0.5% CO_2, the changes in the acid-base balance of people may have general effects (Schaefer et al., 1964). A minimum acceptable ventilation standard for mechanically ventilated and air conditioned buildings on the basis of carbon dioxide levels, is given in the 1981 ASHRAE Guide (ASHRAE, 1985). This standard indicates an absolute minimum air supply rate of 2.5 l air/s per person.

Since a man engaged in light work exhales about 22.6 l of CO_2/h, the minimum volume of fresh air required per person to ensure a CO_2 concentration not exceeding 0.25% by volume compared to 2.5 l/m3 - considering 0.03% or 0.3 l/m3 normal, would be 22.6/(2.5- 0.3) = 10.3 CO_2 m3 /h or 2.85 l/s/person,

as the just tolerable minimum. For a more reasonable maximum acceptable concentration of 0.1%, the required volume of fresh air would be 32 m3/h or 8.9 l/s/ person to allow for the effects of breathing alone. Further reducing the carbon dioxide level to 0.05%, which is half the level at which the effects described above were observed, gives an increase to 22.6/(0.5- .0.3) = 113 m3/h or 31 litres/s/person. This figure is appreciably higher than allowed for in current ventilation practice. Assuming a typical air space per person of 25-30 m3, it represents about 4 fresh air changes per hour. If additional carbon dioxide is added indoors by combustion of fuels, in appliances without satisfactory flues, additional amounts of fresh air will be needed to meet these standards.

Ammonia is present in residential buildings mainly from human sources, for example from babies napkins and toilets. The health impacts are discussed in detail in WHO-EHC 54 Ammonia. The reactions between sulphur dioxide and ammonia indoors are discussed in WHO-EHC 8. Indoor combustion systems used for cooking and for heating are frequently the cause of severe indoor pollution. The principle fuels used are wood, charcoal, coal and coke, natural gas, propane, and kerosene. An important basic distinction can be made between flued systems and unflued systems. On health grounds, a very strong preference must be expressed for flued systems. The combustion products are carbon monoxide, carbon dioxide, water vapour, oxides of nitrogen, sulphur dioxide, formaldehyde, and smoke, the constituents of which will depend on the nature of the fuel, and the conditions of combustion (NRC, 1981). Charcoal, having few volatiles, can produce considerable amounts of carbon monoxide, but as there is little smell from volatiles, and as carbon monoxide is completely odourless, people can suffer from the toxic effects without realizing it. In addition to suspended particulate matter in smoke, particularly under poor combustion conditions considerable amounts of polycyclic organic matter, POM, may be emitted from wood fires. Up to 50 times as much benzo-a-pyrene may be emitted compared with oil. Benzo-a-pyrene is known to be a carcinogen.

Wood fuel indoors is causing most current concern on grounds of health, particularly in rural areas in tropical climates, where much cooking is carried out over wood fires with no flues (De Koning et al., 1984). In hot humid climates with no cold season, it may be possible to locate the cooking fireplace in the open air with a small sheltering roof overhead to keep off the rain. Cooks in villages appear to spend about 2.4 h/day cooking. The amount of pollutants produced depends on the temperatures of combustion, on the wetness, as well as on the type of wood giving rise to seasonal variations in wood smoke concentration. Smoke densities up to 5000 micro g/m3, aldehydes up to 3.80 ppm, and CO levels up to 150 ppm were recorded in Papua, New Guinea in the damp cool climate of highland areas (Cleary and Blackburn, 1968). There is

a strong gradient in smoke concentration the closer the person gets to the fire. Women are particularly exposed during the cooking process, and so are their young children if they are carrying them on their back during work. The smoke tends to rise, and, depending on the quality of the dwelling, may diffuse through the roof. During the preparation of meals, the average levels of CO concentrations were reported to be over 1000 mg/m3 with peak levels as high as 3400 mg/m3 in traditional thatched buildings in Nigeria, where fuelwood was used for cooking (Sofoluwe, 1968). These figures may be compared with a recommended time weighted maximum average exposure of 55 mg/m3 for periods of exposure not exceeding 30 min, to keep carbohaemoglobin levels within 2.5%-3% in non smoking populations, as set out in WHO-EHC 13 on Carbon Monoxide.

Smoke repels insects, reduces their activity, and helps preserve thatched roofs by fumigation. But this result is achieved at a cost in human respiratory health. In areas without electricity, wood may be burned to provide light as well. In colder seasons it may also be burned to keep warm. With little fuel available, occupants group in close proximity to the fire in cool weather, again increasing the exposure to the combustion products. Many attempts have been made to improve the efficiency of wood stoves, but many have failed because safeguarding health was seldom in the development program. The adoption of a chimney is the most important step forward environmentally. The cooking appliance causes the main problems in indoor air pollution. The dangers must increase if ventilation has to be restricted for reasons of cold. The reduction of pollution connected with cooking is an important environmental health problem of the future elsewhere in the world. Measurements of indoor pollution from burning biomass in tropical areas under village burning situations almost always exceed, sometimes grossly, occupational and community air quality standards that have been set in temperate climates by nations with a high standard of living (WHO, EFP/84.64). Special concern about the effects of CO on the health women consists for three reasons:

1. Women generally have less haemoglobin in reserve than men, so the negative aspects of CO may occur at lower doses than with men.

2. During pregnancy there is an additional demand on a womanŗs haemoglobin, making them more sensitive to CO.

3. There is evidence from women who smoke, that CO exposures can affect the unborn child.

In the GEMS Human Exposure Assessment Location project (GEMS, 1987c) it was found that most mothers and children under five years of age stay about 50% of the time near the fire. The mean 24-h concentrations of respirable suspended particles, RSP, and nitrogen

dioxide in houses with open fires for cooking and free ventilation in Kenya was 1400 micro g/m3/h, which was 20 times higher than the indoor RSP levels from cigarette smoke in Dutch homes. During the seven hours per day during which the fire was burning, levels were estimated to reach 3000-4000 micro g/m3/h and in the evening peak levels up to 36000 micro g/m3/h were observed. Under these conditions, it was hard to remain in the kitchen for more than a few minutes, because of the discomfort caused by the dense smoke. There is no doubt that the problem of wood fuel combustion is a very serious health issue in some parts of the world. Chronic obstructive pulmonary disease and right heart failure are very common among people in rural areas relying strongly on biomass. The disease is induced by inhaled emissions from biomass fuels. If duration of daily exposure increases it may progress from subacute to chronic inflammation of the respiratory epithelium, often with recurrent superimposed infection such as pneumonia. Chronic bronchitis and emphysema lead eventually to respiratory and to heart failure.

The centralized supply of energy for space heating of urban dwellings and rural settlements definitely increases the well-being of people compared with combustion of gas and other fuels indoors within the dwelling space. Findings of numerous studies conducted by hygienists show that the indoor climate of dwellings using the indoor combustion of gas deteriorates through the pollution of the air environment by diverse chemical compounds. Typical concentrations of different chemical agents in air of kitchens with gas cooking in the USSR were: Carbon monoxide 15.00 mg/m3, formaldehyde 0.037 mg/m3, nitrous oxide 0.62 mg/ m3, nitrogen dioxide 0.44 mg/m3, and benzene 0.07 mg/ m3. Increased concentrations of these chemical compounds were detected not only in kitchens, but also in other rooms of the apartments. During cooking, the temperature of the air in the kitchen increased by 3-6 °C, and the humidity by 10-15%. With the gas burners turned off, the levels of carbon monoxide and other chemical substances decreased over 1.5- 2.5 hours to original background levels. Investigations showed that the lung performance and the functional state of the central nervous system were reduced after exposure to gas combustion products. The number of visits of children to local polyclinics, and the duration of illnesses were definitely increased among the group of children in houses heated by indoor combustion of gas. The exposure to oxides of nitrogen in residential houses with gas fired appliances is usually underestimated; the recent expansion in the use of natural gas has increased this exposure (WHO-EHC 4). Air samples from houses with gas fired domestic appliances such as space heaters, boilers, and cookers contained concentrations of up to 2000 micro g NO2/m3 at breathing height in the immediate vicinity of cookers .The concentration of nitrogen dioxide measured in Japan in a normally ventilated room with an oil fired

stove ranged from 380 to 1700 micro g/m3 depending on the type of stove, and with a gas fired stove from 750 to 940 micro g/m3.

The health effects of oxides of nitrogen are discussed in detail in WHO-EHC 4 on Oxides of Nitrogen. There have been difficulties in assessing the precise health impacts of nitrogen oxides, because these gases are always present with other combustion gases. Nitrous oxide has been found to be markedly less toxic than nitrogen dioxide. Nitrogen dioxide interferes with the lung's ability to remove inhaled deposited particles efficiently, by altering the phagocytic, enzymatic, and functional processes of the alveolar macrophages and of the ciliated epithelial cells. The lowest NO2 level at which adverse health effects with short term exposure concentration can be expected to occur has been set at 940 micro g/m3. By adopting a minimum safety factor of 3-5, a maximum 1-h exposure to 190-320 micro g NO2/m3 should not be exceeded more than once per month. Information on the effects of long term exposure to nitrogen dioxide in man is lacking.

The health impacts of carbon monoxide are reviewed in detail in WHO-EHC 13 Carbon Monoxide. Tobacco smoking is the commonest source of carbon monoxide pollution in indoor air for the general population. Blood carboxyhaemoglobin levels of office workers in London were 1.3% for non smokers compared with 6.2% for smokers. Blood samples from 29000 donors in the USA gave mean values of 1.39% for non smokers and 5.57% for smokers (Wakeham,1976). The human respiratory system is the primary flue for its combustion products. The smoke then becomes generally distributed within the room. Improved ventilation can only mitigate the concentration of pollutants from smoking. Before carbon monoxide reaches significant general levels in the room air, the irritation from other constituents of tobacco smoke becomes unacceptable, if not intolerable. Susceptible persons suffer eye irritation, coughing and possible nausea from aldehydes, nitrogen dioxide, and suspended small particulates. Another important CO-source is incomplete combustion of carbon in fuels burnt indoors, and this usually increases the concentration of carbon monoxide in the indoor air. Risks exist with all combustion appliances, if they are not properly maintained, especially in situations where ventilation air flows are strongly restricted. Particular attention must be given to the efficient venting of flue gases to the exterior. In some indoor situations cases of acute and even fatal CO-poisoning are not uncommon.

WHO-EHC 13 indicates a maximum acceptable carboxyhaemglobin level of 2.5-3.0% in the blood as the upper limit for the protection of the health of the general population, including those with impaired health. As it is now widely planned to reduce ventilation rates in the interest of energy economy, vigourous efforts are required to curtail smoking, especially in public places. Certain spaces, where

smoking is admitted, should be provided with special exhaust ventilation or air cleaning systems.

Building materials and indoor air quality

The majority of traditional building materials produces very few indoor air quality problems. Some by their chemical nature actually contributed to the reduction of external pollution impacts, i.e. the reduction of sulphur dioxide levels by absorption on gypsum plaster and lime paint. One important exception was lead based paints. Continuing advances in the chemical industry have thrown up a wide range of new materials. The public health impacts of these new materials are frequently not appreciated by those who manufacture, specify or use them. One evident trend is towards the greater use of factory made insulating materials, which may be fibrous or porous in their nature. They tend to break up slowly in use, adding fibres and dust to the indoor air. The other evident trend is towards the extensive use of polymeric materials in buildings. One feature of such manufactured materials is the outgassing of solvent compounds. Such emissions may continue for very long periods after building completion. An increasingly wide range of solvents is being used in buildings in decorative materials and adhesives. Public health regulations for the chemical control of building, insulation, decorating, and furnishing materials are presently incomplete.
The effects of asbestos and other mineral fibres, used for wall insulation and roofing, are described in WHO-EHC 53 Asbestos and other Natural Mineral Fibres, and WHO-EHC 77 Man-made Mineral Fibres. Small particles of fibres of lung-going sizes have been identified in indoor air. A subsequently clearing of the fibres from the lung is insufficient, because of their shape and aspect ratio, and they are insoluble.
Retained fibres in the lung and surrounding tissues can lead on to asbestosis, a special kind of pulmonary fibrosis in man with a carcinogenic effect. The latent period before neoplasm develops may be up to 20 years. The risk of incidence of bronchial carcinoma is doubled in the case of inhalation of asbestos particles with associated tobacco smoking. An increased incidence of pleural and peritoneal mesotheliomas has been recorded in West Germany, Great Britain, USA, and South Africa. The annual death rate linked with asbestos in the USA is said to be about 8200 people, while in the Federal Republic of Germany the death rate is about 1000 people per year. A typical concentration of asbestos in the urban air in the FRG is about 10000 fibres/m3.

The extraction of asbestos and its consequent manufacture into a variety of building products has become a very important issue in indoor health control. The relative cheapness of asbestos has opened up the possibility of using it as roofing material and as reinforcing additive to many traditional building materials, like cement and gypsum. Asbestos cement pipes are extensively used for water supply. Asbestos

has found wide use as thermal insulation material and in fire prevention measures in buildings, either in the form of boards or sprayed on surfaces with suitable binders. It stands up well to very high temperatures. It has been used even as a fibrous acoustic absorption material. Sometimes it has been applied in air handling ducts. Many of these applications occurred before the dangers of asbestos in the environment were fully appreciated. An important reappraisal of the use of asbestos in building is now taking place. More precautions are introduced to control operative exposure. The widespread application of asbestos products in the building and civil engineering industries requires a number of sanitary improvements. Wherever the means are available extensive steps to safe removal of asbestos from unsafe building applications are now taken for the health of its occupants. The major asbestos uses in the period from 1977 to 1983 in the USA has declined drastically (WHO-EHC 53). The international situation is complicated by the fact that quite a number of countries and organizations do not want to tackle the problem, justifying their position in terms of the economic benefits of large scale employment and cheap cost of the asbestos based product.

The concentration of polymers in the indoor air has received particular attention in the USSR, where about 100 types of polymers are used in building construction and civil engineering. Polymers are mostly used as floor and wall coverings, heat insulation, sealing and finishing wall and partition joints, window and door frames, and as components of prefabricated buildings. There are sound economic reasons for the increasingly broad application of polymers in the construction of residential and public buildings. The results of many studies show that virtually all polymeric materials are the sources of the migration of various agents hazardous to human health into the indoor air of residential dwellings (Bokov, 1977). Polyvinylchloride polymeric materials, PVC, the most widely used type of polymers utilized for finishing of modern public buildings, give off into the indoor air environment such compounds as dibutylphthalate, diacetylphthalate, vinyl chloride, mesethylene, pseudocumene, toluene, ethyl benzene, cyclohexanol, xylol, butyl alcohol and other hydrocarbons. Wood particle boards consolidated in phenol methylene oxide and in carbamide oxide matrixes, pollute indoor air by emitting phenol, methylene oxide, and ammonia. Mats of man made chemical fibre may give off rather high concentrations of styrene, isophene, and anhydride sulphide. Glass reinforced plastic materials based on various compounds, using in building and civil engineering for sound proofing and thermal insulation, emit considerable quantities of acetone, meta-acrylic acid, toluene, butanol and formaldehyde, phenol, and styrene. In addition, volatile compounds are emitted from clothes and shoes. The intensity of emission of volatile compounds by polymers, and their indoor concentration, depend upon the amount of polymer

used, and the indoor temperature and air humidity. The temperature is the most important factor influencing the intensity of emission of noxious agents from polymeric materials. A similar dependence has been found for humidity. The rate of emission increases with increases of both surface and of air temperature. Apart from this, the concentration of chemical agents is directly proportional to the air exchange rate between indoors and outside. The problems thus become more acute in hot and hot humid climates (Anderson et al. 1975; Bokov, 1977).

Chemical compounds emitted by polymers produce an aggressive odour, which causes discomfort, asthmatic attacks, and cardiovascular complaints. Cases of contact allergy have been reported. Hydroperoxides, phthalic anhydrides, styrene, benzene, chloroprene, carbon bisulphide have gonadotropic effects and disturb the ovario-menstrual cycle. Benzene, phenol, and chlorpropane display teratogenic and embryogenic effects. Epoxy resins, butadienestyrene rubber and chloroprene latexes have shown mutagenic, gonadotoxic and sensitizing effects on human health. Epidemiological investigations in the USSR indicated a higher incidence of morbidity caused by colds, allergies, vegetative "dysregulation" and hypertension among people inside buildings where a great amount of polymeric materials is incorporated in their construction.

Criteria for assessing the harmfulness of the use of polymeric materials in buildings have been developed in the USSR. Recommendations in the 1970ŗs favored the total absence of emissions of toxic volatile substances from polymers into the environment, or, with good ventilation practice, some limited emissions of the toxic volatile chemicals from polymers. Permissible emission rates have now been established in the USSR for about one hundred chemical compounds emitted by polymeric materials. Any specific volatile polymer emitted into the indoor environment of residential and public buildings, should not exceed recommended highest permissible concentrations, HPC. The sum of the ratios of the actual concentrations to the highest permissible concentrations for each compound, summed over all toxic compounds, should not exceed a limit value. A special calculation method was developed. Limits are set for each material for the rate of emission of noxious substances into the environment at the time of completion of manufacture or soon after. The health risk criteria applied in the USSR are:

Polymeric building materials should not emit any specific odour in the indoor environment by the time the residents move in to occupy a building.

Polymeric building materials should not emit, into the internal environment, compounds in such concentrations that would have a negative impact on the human organism, taking due regard of the combined action of all the agents emitted. The highest permissible concentration of each noxious substances built up in the indoor air, is taken as one of the criteria for the health evaluation of polymeric building materials.

Polymeric materials should not degrade the overall indoor microclimate, i.e adversely influence temperature, humidity, and light indoor environments.

One of the most important factors which determine the health suitability of polymeric materials in indoor environments is the length of time people spend in the indoor space and the activities in which they are engaged while they are in that space. Different types of building have their own specific occupancy activity profiles which should be taken into account in deciding the extent to which it is healthy to use certain polymeric materials in construction. For example, in selecting polymeric materials for use in sports halls, it is necessary to take into consideration the high physical activity rates of athletes, since their elevated metabolic rate, increased activity of their cardiovascular system, and their central nervous system, and greater rate of respiration, result in an increased rate of intake of volatile substances exceeding the functional adaptive mechanisms of humans.

The chemical problems with the quality of indoor air as described for the USSR have emerged in every country where modern materials are used for building and furnishing residential and office rooms. Much attention is now devoted to foamed insulants releasing formaldehyde. A special concern met in hot climates is the emanation of pentachlorophenol from timber impregnated to protect it from termites. Timber exposed to the direct rays of the sun can become very hot, and heavy outgassing to the interior can occur.

There is a growing recognition that architects and engineers must be better trained in building material selection from a chemical pollution point of view, and pay greater regard to the potential impact of buildings materials on indoor air quality. It is also recognized that the building materials production industries must be better regulated from the point of view of controlling noxious pollutants from their products in practical use. Interior design has tended to be treated very much as aesthetic issue in the past.

Pesticides and other contaminants

Pesticides are very widely used indoors in dwellings in tropical countries. The health impacts of pesticides are very important. All vector control measures involving the use of pesticides and repellents are potentially hazardous to the population. The risks are minimal. The community must be aware that they exist, and they should be instructed in simple precautions that are necessary to reduce exposure. This is especially important with increasing community participation in

vector control (WHO, 1982, 1985).

Detailed publications on specific insecticides and pesticides compiled by the WHO are:

WHO-EHC 9: DDT and its Derivatives.
WHO-EHC 11: Mycotoxins
WHO-EHC 34: Chlordane
WHO-EHC 38: Heptachlor
WHO-EHC 63: Organophosphorus Insecticides
WHO-EHC 64: Carbamate Pesticides
WHO-EHC 76: Thiocarbamate Pesticides.
WHO-EHC 78: Dithiocarbamate Pesticides.

A large number of contaminants to the indoor air may be identified in the category of consumer products. Products include furniture polishes, deodorant sprays, hair sprays, disinfectant sprays, window cleaners, oven cleaners and chemical air fresheners. The propellants include chlorinated fluorocarbons (CFC's), now being phased out, nitrous oxide, methylene chloride, vinyl chloride, butane and propane. Cleaning agents and surface maintenance agents such as waxes, polishes, bleaches can all add undesirable chemical components.

There is also the problem of residential indoor air contamination by industrial processes associated with craft activities and hobbies. Ozone can be produced indoors by photocopiers, laser printers, electrostatic air cleaners, and other high-voltage electrical equipment. Photocopiers, other types of copying machines, copy papers are also potential sources of irritating hydrocarbon compounds. Organic solvents and ammonia from carpet shampooing have been associated with eye, nose, throat and skin irritation. While the ventilation is reduced or shut off, high concentrations of irritants can accumulate in rooms that only slowly dissipate when ventilation is restored (NRC, 1987). Where home and workplace may be combined, the risks to health can become quite serious and very difficult to deal with. Health education of the general public is very important in these areas, including better product labelling indicating the risks and how to reduce them. Where a particular type of commercial craft is widely carried out in a community, it may be possible to make progress through a community health care educational programme, which identifies the specific hazards and then indicates, in a practical way, how best to reduce them.

Microorganisms, parasites and insects

Viable microorganisms and parasites may reach the indoor air from both outdoors and indoors sources (Wells, 1955). Sources are man, animals, pets, rodents, insects, plants, vegetables, fruits, fluids, and many materials providing conditions for growth. In agricultural communities, working animals may be housed in indoors in the same buildings with people. Sweeping can transfer settled microorganisms into the room air. Favourable microhabitats for mites can form

in carpets and other furnishings. Condensation due to excessive moisture combined with poor heating and poor insulation can be very serious in cold damp climates creating habitats for mould and fungi growth, which can become a powerful source of spores, acting as allergens. The impacts can be reduced by identifying and eliminating favourable microhabitats for unwanted species and by improved cleanliness. Reducing breeding opportunities for the larvae of insects, in particular of the anopheles species in and around houses, is essential in malaria control. This is of special importance in humid tropical areas, Attempts to exclude insects by UV screening or electrical traps are often made.

The control of cross infection by airborne bacteria and viruses depends on distance between people and the volume of indoor air per occupant. The transfer of pathogens causing infections follows a direct air path from an infected person to an uninfected person nearby. The separation of people into separate rooms for sleeping helps reduce cross infection, while overcrowding through increased proximity, promotes it. Good health, promoted by indoor air of good quality, implies that the organism with its particularly exposed respiratory system will be prepared to resist effectively airborne infection risks. Organs such as the respiratory system irritated, inflamed, or permanently damaged by chronic exposure to polluted air of poor quality, will be more vulnerable to infection, and will recover more slowly. In the past, there has been a tendency to view ventilation hygiene as solely controlling the bacterial transfer process. Ventilation hygiene has two functions: reducing or washing out viable microorganisms and allergens, and cleaning the air of substances which may or will facilitate the susceptibility of the organism to infections. The latter has received less prominence in health studies, and this is the area where most educational effort is now needed.

Radon and radon daughters (WHO-EHC 25)

In recent years much attention has been devoted to the accumulation of radon gas in indoor air. Radon is gassed out of building materials such as concrete as a decay product of radium. The short lived radioactive decay products of radon are called radon daughters. Radon has four short lived daughters, each with a half-life of less than 30 min. They mostly become attached to airborne particulates, and, if inhaled, they are partly deposited on the human respiratory tract. The radiation doses received by people with the inhalation of the alpha particle emitting radon daughters in the air, constitute the main part of the natural radiation dose to man. The radiation dose caused by radon itself is minor by comparison with that by radon daughters. The main sources of radon emission are building materials. Radium concentrations in building materials vary considerably. Some materials, such as aerated concrete made with alum shale and phospho-gypsum from sedimentary ores contain significantly higher

radium concentrations than others. Materials with a low radon emissions are wood, natural gypsum, sand and river gravel. Radon also is associated with water supplies and natural gas supplies. The other important source of radon is the ground. Some soils emit much more radon than others. The soil radon exhalation rate may be several orders of magnitude higher in areas of natural uranium deposits, phosphate related land, waste products from the uranium industry, and waste products from alum production from radium rich alum shales.

The health issues of radon are described in WHO-EHC 25 on Selected Radionuclides and in WHO-EURO (1979). The levels of radon and radon daughters in indoor air depend on the source levels and on the dilution in the air. The indoor levels are normally higher than outdoors. Ventilation rates exert an important influence on the accumulation. Reduced ventilation may cause radon released from building materials or seeping up through the soil below to build up in enclosed spaces. Even with identical ventilation rates radon concentrations can vary considerably inside buildings. The precautions to be taken against radon pollution include avoidance of sites with adverse soil emanations, placing barriers between highly emitting soils and ground floors, and selective elimination of building materials with a high radium content. Before any action is taken, it is necessary to establish whether a serious problem in fact exists. This is often a highly regional issue within a national territory. Present United States Health Guidelines (Budnitz et al. 1980) set the maximum permissible concentration below 4 nCi/m3. Air change rates above half an air change per hour are typically needed to keep radon concentrations below this limit. Special precautions have to taken to prevent the radon seeping up. If mechanical ventilation is available, ventilation rates can be stepped up, to improve radon control, and yet keep energy economy, by using an air to air heat exchanger to recover heat in the outgoing exhaust air (Nazaroff et al. 1981). The problems caused by radon are likely to be far outweighed by more pressing problems like adverse health effects due to wood burning, and tobacco smoking. However some general geological enquiries would not be out of place to ensure that special hazards have not been overlooked in specific places, and that acceptably safe sources are being used as mineral inputs to the building materials industries. Certainly improving indoor ventilation rates to meet the other chemical hazards will make a significant downward impact on indoor air concentrations of radon, and hence its damaging daughter products.

Ventilation norms

It is essential to ensure the appropriate ventilation or air exchange rate to secure the indoor air quality required for health. Ventilation norms may be stated in two main ways. If the density of occupancy and activities are known, the ventilation requirement can be expressed in terms of the litres/s of fresh air per person. If the density of occupancy is not known, it is usual to work in terms of air changes per hour, i.e the hourly air supply divided by the room volume. If the room volume per person is known, one can convert from one measure to the other. Often a density of occupation is implied in situations where norms are stated in air change rates.

It is not possible to ensure minimum ventilation standards at any stated level of air exchange in naturally ventilated buildings. It is only possible to ensure that effective means for achieving an environmentally acceptable natural ventilation supply with appropriate seasonal ventilation controls, easily operable by building occupants, are available. Natural ventilation standards are often defined in terms of openable areas per unit floor area, for example opening area to be 5% of total floor area. In cold weather, in the interest of thermal comfort, the occupants are likely to give a low priority to ventilation. They may even accept risks to try to stay warm. In a closed building, the rate of air exchange will depend on wind speed and on outdoor-indoor air temperature differences, as well as on the general tightness of the building when closed. Recent trends have been towards tighter buildings in the interest of energy economy. Typical air change rates have tended to fall from about one air change per hour in older type fairly 'loose' buildings to 0.25 air changes per hour, or even lower, in highly energy efficient domestic buildings. Such air exchange rates may be too low to secure adequate air quality, especially if aggressive indoor chemical pollutants may accumulate. If indoor pollution of the air environment is appreciable, then this developing situation must give rise to serious health concern. Very air tight buildings imply, as a mandatory complement, mechanical ventilation systems to ensure minimum safe ventilation standards are actually met in cold weather (ACGIH). Internal rooms are unacceptable on hygiene grounds in naturally ventilated buildings, and local extract mechanical ventilation must be provided to draw air from the surrounding naturally ventilated spaces. It is important for the building industry to provide the technical means by which the building occupants can regulate their ventilation effectively and easily. In this respect, the details of standard window frames are very important.

Outdoor air supply rates for air conditioned spaces have been adopted by the Chartered Institution of Building Services Engineers for the UK (CIBSE, 1986). Two levels a recommended and a minimum level are given. Tobacco smoking is used as an important indicator. The exact ventilation rate numbers vary from country to country. The corresponding standards for the USA are set out in ASHRAE Standards No.62-1981 and 62-1983 (ASHRAE, 1981,1983), ACGIH and NRC (1987), a report on assessing and improving existing air conditioning systems, where air quality problems are being encountered.

There has been a tendency in recent years to recommend an increasing rate of air intake. In Denmark, Fanger (1988) and Fanger et al.(1988), observed, in offices with 25 l/s/person fresh air supply, which is far above the value normally provided, substantial dissatisfaction with the air quality. There were complaints about stale, stuffy and unacceptable air. Analysis of the complaints showed 20% was perceived as indoor air pollution produced by materials, 42% was produced by the ventilation plant itself, 25% was produced by smoking, and only 13% was produced by the occupants. The normal assumption in airconditioning is that the plant itself is producing no pollution.

The recommended air exchange rates for residential buildings from a range of international sources are summarized in TABLE 9. There are no great differences in the values recommended by different authors, but a tendency towards increased air rates may be noticed. The International Energy Agency commissioned a review of building air tightness and ventilation standards covering practice in Denmark, Norway, Sweden, Belgium, Netherlands, Switzerland, United Kingdom, West Germany, Canada, USA and New Zealand (Thomson). It is written from an energy conservation point of view, and illustrates the energy minimalist approach to ventilation norms rather the health related approach.

The minimum required air change rates for rooms of different purposes in the USSR are marginal standards. Even if they are observed, it does not mean that adequate removal of chemical pollutants from the indoor environment will be achieved. The required rate of air intake and extract should be defined separately for residential and for different types of public buildings, considering the types and amounts of polymeric material used, the air space per person, the number of people in that air space, their activity, and the length of time of staying in that environment.

Attempts are sometimes made in hygiene practice to force some permanent ventilation by air bricks and by other forms of permanent ventilator. It is fairly common practice for occupants to block such openings to secure greater warmth in cold weather. This is particularly true if the openings are located so as to cause direct draughts over people's bodies. Such openings should either be set high, or placed behind radiators on the external wall, so some preheating occurs. Chimneys provide an important means for securing some permanent ventilation, as well as for removing fumes from the fire, but the flue size must be large enough to match the output of the appliance it serves. Adequate inlet air to feed the appliance with combustion oxygen also must be allowed to filter in. Permanent ventilation openings in the glazing, set high in the fenestration, are often found to be the best way of securing this minimum permanent air requirement for combustion. Openings in the glazing are much less

likely to be blocked up by occupants, because the blocking looses daylight, and is also unsightly. People also associate windows with natural ventilation. An important trend in some southern climates has been to set balanced flue devices in the external wall. The inlet combustion air is taken in and the flue gases exhausted at the outside face of the wall. The heat transfer to the interior is achieved without any combustion taking place within the curtilage of the indoor air space.

A critical problem affecting ventilation standards throughout the year, especially at night, is personal security, especially on ground floor rooms. Secure ventilation systems are much more likely to be used during night-time, than insecure ventilation systems. There are many hazards in addition to the risk of direct entry, which can be controlled by bars, like fishing for possessions through outside windows using poles. If some secure ventilation can be provided, say at a high level in the room, it is much more likely to be used in urban areas, where these security risks are greatest. As so much depends on the sensible actions of the part of the occupants, health care education on toxic risks and how to control them and on good ventilation practice guidelines for health.

Conclusions

This Chapter has endeavored to explain the scientific basis of indoor environmental air quality control, and its impacts on health and well-being. The results of the Global Environmental Monitoring Programme, GEMS, will provide useful data for the future assessment of urban health risks indoors, due to polluted outdoor urban air. The chemical hazards presented by modern building materials, especially polymers, of tobacco smoking and associated indoor combustion, including pollution from burning of biomass have been outlined. Extensive reference has been made the WHO Environmental Health Criteria documents, WHO-EHC, to enable more detailed health considerations to be followed up, as required, in a more specialized way. Practical guidance has been provided on minimum ventilation standards, and on natural ventilation design to protect people from adverse indoor pollution. The priorities for action on the improvement of indoor air quality in the interest of human welfare and better health in different climates and areas must be based on local analysis of the relative importance of the problems being encountered.

Physicians and hygienists may need to seek greater help from chemists and toxicologists to assist in the complex task of measuring indoor air pollution quantitatively. The training of architects, building engineers and builders, on chemical and other aspects of indoor air quality control for improved health within buildings, is generally inadequate in most parts of the world, and needs substantial improvement. In view of the widespread occurrence of complaints in tight and airconditioned buildings, designated as sick building

Table 9

Recommended air exchange rates for residential buildings with plenum exhaust ventilation, drawn from various sources.

Source and country	Building space	Air exchange rate cubic metres/hour
L. Leclere floor area France	Living room	30 up to 15 sq.m.
		60 > 15 sq.m. floor area
J. Rydberg Scandanavia	Living room	45
	Kitchen	80
	Bathroom	60
Kh. Zarivaiskaia USSR	Residential	45-60
W. Kruger FRG	Living room	15-25
	Kitchen	50
	Kitchen (short purge)	200
	Bathroom	60
	Lavatory	30
P. Jardinier J. Simont France	One room apartment	
	Living room	60
	Kitchen	30
	Bathroom	30
	Lavatory	15
	Two room apartment	
	Living room	70
	Bathroom	45
	Lavatory	15
	Three room apartment	
	Living room	80
	Bathroom	60
	Lavatory	15
G. Ende FRG	Hotel rooms Floor area, 15 sq.m. per person	30-40 (ceiling >4m.)
		40-60 (ceiling < 4m).
CN & R 1-71 USSR	Residential buildings	
	Living room	3 per sq.m. floor area per person
	Kitchens with gas supplied	60 two burner stove 75 three burner stove 90 four burner stove
	Bathroom	25
	Lavatory	25
M.T. Dmitrieva et al, USSR	Kitchens with elect. cooking	84 two heater stove 126 three heater stove

syndrome, and communicable diseases like
Legionnaires' disease, heating and air conditioning
engineers may need help and advice from medical
specialists. The interrelationships between town
planning decision making and urban air quality
management are still poorly perceived. The urban
environmental planning must be of adequate
competence to ensure healthy outdoor air available for
ventilation purposes at building facades. Importance
must be attached in building design to drawing air
from the less polluted points in the external
microclimate. The building materials supply industries
may need to be better regulated chemically. Some
vigilance may be needed in the case of imported
materials to ensure that dumping of environmentally
unsatisfactory building materials does not occur. Above
all better education of the whole community on the
importance of good indoor air quality for health is
needed. People need to know and understand the
various ways of reducing the indoor environmental
health risks caused by the various indoor activities
which produce an unhealthy indoor air quality. They
must be helped to understand the positive actions that
they can undertake under their own personal control.
The building design must help them achieve that
control simply and easily.

Chapter 4

Noise Environment

Introduction

About 40% of the population in industrialized countries suffer from noise of which one third are exposed to noise levels that are damaging to their health. The population exposure to noise tends to be most widespread and severe in large cities (ASTM, 1979). A lot of the indoor noise comes from the ambient external environment, especially from ground based transportation and air traffic. Growing urbanization and technical progress are linked with the intrusion of noise into every part of life of urban man. An almost similar situation is likely to develop everywhere in the near future in countries with growing industries and motor car traffic. In low latitude countries, the situation tends to become even more intolerable due to the conflicting needs for outdoor fresh air in generous amounts to stay acceptably cool indoors and desire for the closure of building facades to keep out external noise. The solutions lie in better planning and in improved noise control. The fight against noise has become, for most central and local governments, a pivotal point in urban ecological policy. Their actions cannot be not successful without the cooperation of every citizen.

The loud blows from a steam hammer or the rumbles of mechanical looms, once symbols of industrial activity, are now expressions of uncontrolled developments with negative effects for health. Under the conditions of modern life, artificial voluntarily and involuntarily produced noise is everywhere. It irritates, disrupts daily life, induces aggressiveness, reduces physical and mental performance, interferes with sleep and rest of people, it alters every day behavior, and causes feelings of discomfort, headaches and other complaints. The type of exceedingly loud and continual noise has become a risk factor for health. The various aspects of the influence of noise on man are compiled in Burns (1968) and WHO-EHC 12 (1980) Noise.

Physical and physiological characteristics of sound

The term "noise" describes any unpleasant or undesirable sound or combination of sounds, which interfere with positively wanted sound signals like speech and music, disturb silence, reduce efficiency and have irritating and harmful effects on the organism. Sound as a physical phenomenon is a mechanical vibration of an elastic medium within the range of audible frequencies. Sound, as a physiological phenomenon, as perceived by the hearing organ, when exposed to sound waves, is a sensation of full or temporary overt awareness. What a person hears is first of all determined by the sound intensity and the sound tonal pitch. The sound intensity, which causes the sensation of loudness of a sound depends on the sound pressure. Compared with the atmospheric pressure, the sound pressure is extremely low. Normal conversation creates a sound pressure which is less than one millionth of the atmospheric pressure.

The tonal pitch depends on the frequency of vibration of the sound pressure. The number of vibrations per second of the sound pressure is the sound frequency. The unit of sound frequency is the Hertz (Hz). 1 Hertz is 1 vibration/s. In a 1000 Hz or 1 kHz tone there are 1000 vibrations of sound pressure per second. The higher the frequency of the tone, the higher is the perceived pitch. Man can receive sound up to 18 even 20 kHz. The perception range is high for young persons and narrows with age beginning in the upper frequency band. The fall off in hearing sensitivity at low frequencies is shown in FIGURE 13.

In normal life, pure tones of only one frequency are rare. Most frequently one is hearing a mixture of loud and of quiet sounds of high and low frequency. This combination of sounds, when unwanted, is called noise.A region in space, where sound waves can be detected, is called a sound field. The physical state of the vibrating environment in the sound field, or the change in the mean condition, caused by the presence of sound waves, is characterized by the sound pressure (p). Sound pressure is the difference between the value of the impact pressure and the mean pressure, which is observed in the environment in the absence of a sound field (Beranek, 1971). Sound pressures can change within a wide range from 2.104 to 2.10-5 N/m2, the ratio between these values being 109 N/m2. The absolute values of quantities which vary so much, are very difficult to use. In technical acoustics, the sound pressure is measured in relative logarithmic terms; the units are decibels. Sound pressure levels in typical living and working situations are given in TABLE 10.

Classification of types of noise source

The majority of noises in the hearing range contain sounds of almost all frequencies. They differ in the distributions of sound pressure levels in different frequency bands, and their patterns of change with time. Noises, having an effect on man, are classified by their spectral nature and their time characteristics. Depending on the nature of the spectrum, noises are
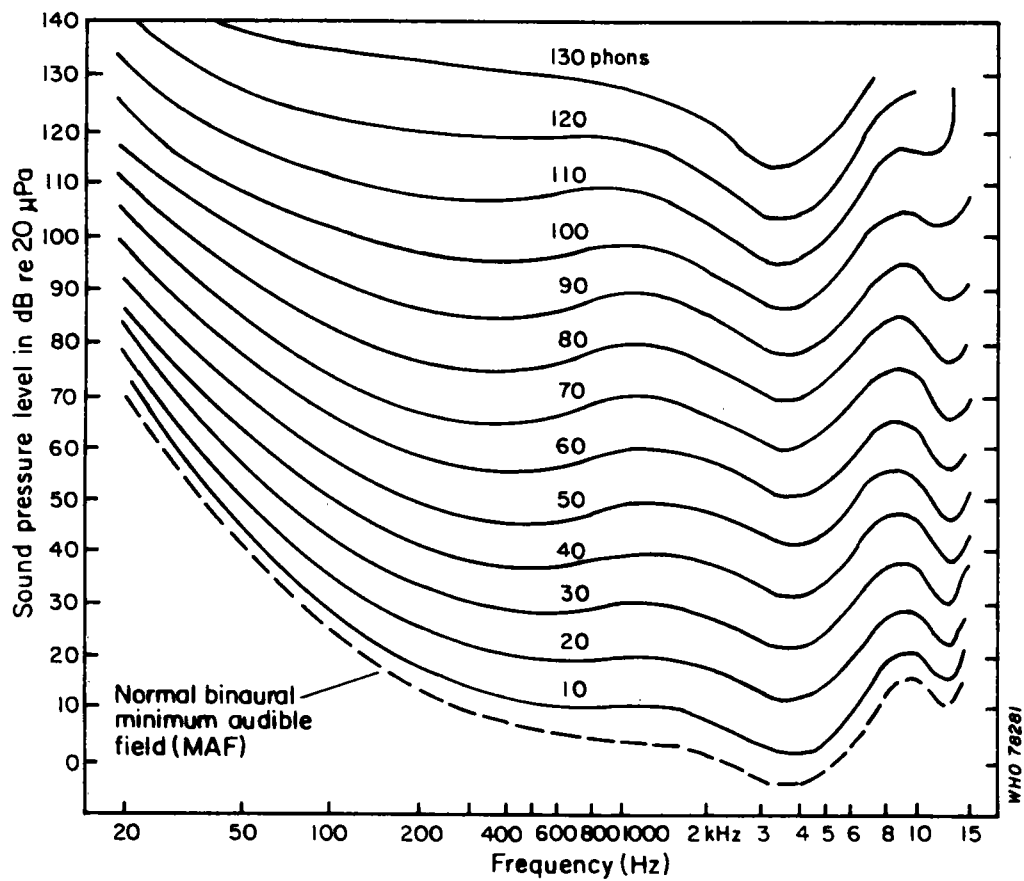
Fig. 13:- Normal equal-loudness contours for pure tones (From: Robinson and Dadson, 1956).

Table 10

Sound pressure levels of typical noises. Source USSR authors

Type of noise	Level of sound pressure (dBA)
Threshold of hearing	0
Quiet countryside	20
Quiet bedroom	25
Living room	40
Conversation of average loudness	60
Working typewriter	65-70
Main street	85-90
Weaving shop	90-95
Pop group show	100
Jet plane take-off at 100 m	125
Jet engine at 25 m	140

divided into wideband noise, with a continuous spectrum of over one octave wide, and tonal noise, with a spectrum that includes audible discrete tones. Noise tonality is measured in one-third octave bands using a discriminating level difference of 10 dB between that band and the neighbouring band. Noises can be broken down into low frequency noise with the maximum sound pressure level below 300 Hz, medium frequency noise with the maximum sound pressure level in the 300-800 Hz frequency band, and high frequency noise, with the maximum sound pressure level above the 800 Hz octave band.

Depending on time variable characteristics, noises can be divided into constant noises and variable noises. In constant noises the sound level changes less than 5 dB; in variable noises the sound level changes more than 5 dB in time. Typical constant noises are noise from continuously working, pumping and ventilation plant, and operational industrial equipment, like air blowers, compressors, and testing equipment. Noises which vary in time can be divided into:

- unstable in time, the level of variable noise is constantly changing in time,

- intermittent noise, consisting of peaks lasting longer than 1 second before the increased sound pressure drops back to the background level, and

- impulse noise, which consists of one or more pulses, following one another rapidly at intervals shorter than one second.

Variable noises, which change in time, are usually evaluated using the equivalent continuous sound level of a variable noise over a total observation period in seconds. Examples for variable noise are motor traffic noise, for intermittent noise refrigeration plant switching on and off, and for impulse noises working cycles of industrial equipment such as pneumatic hammers, press forging equipment, and lift door slamming.

Noise evaluation procedures

The selection of appropriate noise evaluation procedures depends firstly on the character of the noise to be assessed. Constant noise is measured as the sound pressure levels in decibels (dB) in octave bands with geometric mean frequencies of 63, 125, 250, 500, 1000, 2000, 4000 and 8000 Hz.

Man is most sensitive to noise in the range 1000 to 4000 Hz. Lower pitched tones below 1000 Hz, and higher pitched tones above 4000 Hz, are perceived as relatively quieter than medium frequency tones. This frequency dependence of the sensitivity of the human ear to noise can be allowed for in noise evaluation by weighting the energy according to frequency. This is done by incorporating frequency weighting filters (evaluating contours) into the sound pressure level meter. There are three widely used standard weighting functions incorporated in precision sound level metre scales A, B and C. On some measuring instruments a D-scale weighting is also incorporated. The weighting curves used for the A-, B-, and C- scales are shown in FIGURE 14. The most widely accepted weighting scale for practical environmental noise evaluation is the A-scale. **Levels measuring on the A contour are called sound levels and are marked as dBA.** This scale roughly characterizes the frequency response of the perception of noise unpleasantness or loudness by the human ear. To measure variable noises, which change with time, as well as to make a rough evaluation of constant noises, noise control inspectors usually use sound levels, as measured by sound level meters, which include the A weighting frequency response compensation circuits, to decide about noise suppression measures.

It is essential to have appropriate acoustic measurement equipment available to assess outdoor and indoor noise environments. Such equipment should conform with agreed international standards. Facilities for its proper calibration are also needed. Acoustical standardization internationally is the responsibility of the International Standards Organisation (ISO). Agreed measurement techniques are also needed to ensure comparable measurement results are achievable. Noise measurement procedures require that the background noise should be at least 8-10 dBA lower than the measured noise. In measuring variable noise, only one measurement point is selected as the most typical location for the site. Measurements are taken during the period of the most intensive operation of the variable noise source. The duration of the measurements must depend on the pattern of level variations in time, but in any case should not be shorter than 30 minutes. Constant noises are measured over a period of 2 to 5 min, and if the difference between the results exceeds 3 dB, then the measurements are repeated.

Measurements of constant noise inside buildings are taken at least three places. This is also done at the noise source location in the neighbouring building. The level used for checking conformity with norms, is the highest sound level out of the three sets of measurements. This issue becomes very important in the enforcement of legal norms. A considerable number of ISO standards for noise measurement in different situations have been published. The basic value of the noise level used in the ISO documents is the equivalent sound pressure level measured within a period of time. Most countries have followed the ISO recommended practices norms for allowable noise levels, set out in ISO (1966-1971). These earlier
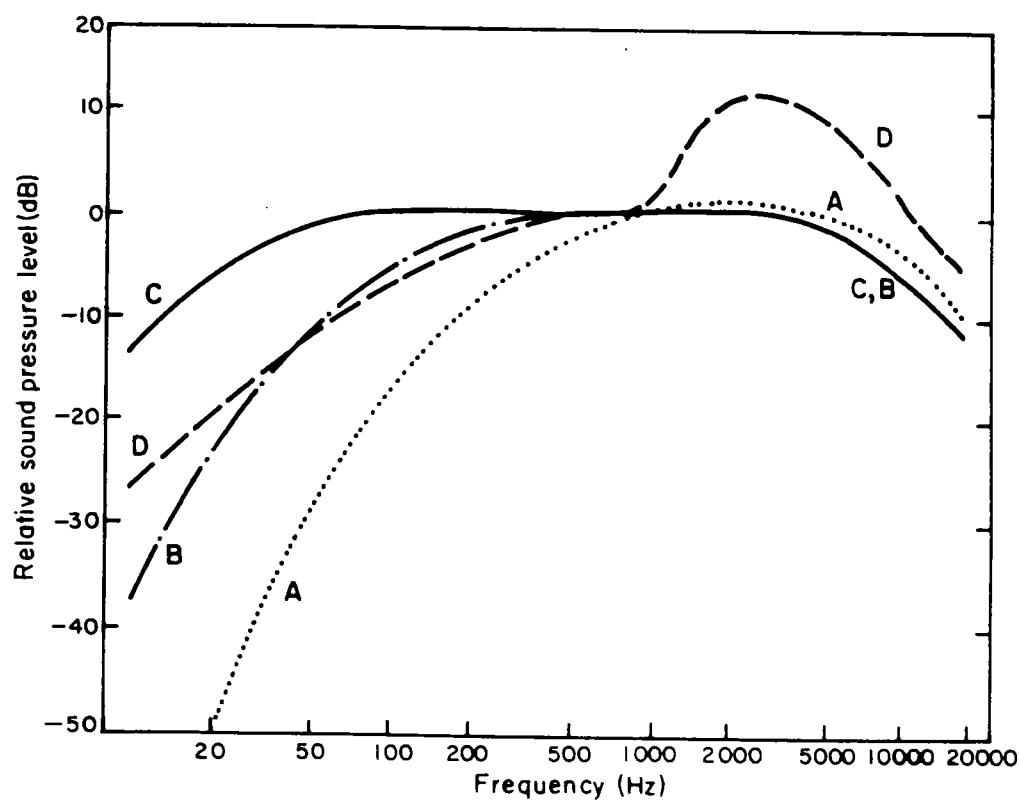
WHO 78282

Fig.14:- Standard A, B, C, and D filter characteristics for sound level
meters (IEC, 1973a, 1973b).

recommendations have been replaced by a series of revised standards. ISO should be consulted for an up to date list of international acoustic standards.

Effects of noise

Man has accustomed himself to the acoustic background of the natural environment during the long process of his evolution. In recent times considerable modifications in the noise environments of man have taken place. These usually depend on the location of the residential district, the nature of the noise and the time of day. As a side product of many inventions man has created noise sources, whose total emissive power increases annually. Man lives surrounded by sounds and noises created by the civilization in which he lives. Some of these sounds are needed and useful signals, motor car horns, loudspeaker systems at railway stations, some are associated with entertainment, for example pop-concerts, spectator participation in sport, radio and television, some are the unwanted by-product of useful systems, like road traffic, air traffic, electric transformer noise, and industrial production noise. Of primarily concern is noise in the indoor environment that is considered to be disturbing, bothering, irritating or even harmful to human health. Unfortunately a large proportion of the indoor noise is often outdoor noise penetrating to the interior. This is especially so in large cities. Reactions of different people to noise depend not only on the physical characteristics of noise, but also on a number of other factors such as activity, position, previous experience, emotional attitude to the noise source, status in society and others. In order to prevent noise from irritating people excessively and especially from disturbing their sleep, many countries have established norms.

The adverse influence of noise on man ranges from simple subjective irritation to serious objective pathological disorders in the hearing organ itself, in the central nervous system and in the cardiovascular system.

The adverse influences of audible sound on man are:

- Damage to the hearing function, causing a temporary or permanent loss of hearing

- Disruption of the ability to transmit and perceive wanted sounds, for example the hindrance of speech

- Irritability, anxiety, distraction from routine work, and sleep disorders

- Changes in the physiological responses to stress signals

- Deterioration in physical and mental

performance capacity.

Research on the influence of noise on people has many goals. A great number of studies in different countries have been carried out to identify permitted upper limits of unfavourable noise influences on the human organism. While in residential indoor situations, pathological damage to the noise perception organs does not occur, the study of pathogenic factors and noise damage mechanisms and adaptation processes is of considerable interest in the evolution of norms for permitted noise levels in the indoor environment.

Most indoor noise is not at a high enough level to cause pathological damage, and the human response to urban noise is typically a subjective response. The initial indicators of an unfavourable noise impact are complaints from people about irritability, anxiety and sleep disorders. Based on questionnaire studies on the influence of irritating traffic noise in the USSR, the number of noise complaints by the people and the noise levels in areas adjoining highways is directly correlated. The complaint level exceeded 85% at an equivalent sound level of 75-80 dBA, 64-70% at 65-70 dBA, was 50% at 60-65 dBA, and fell to about 33% at 55 dBA. At an equivalent noise level of 50 dBA, the complaint level was only 5%. For residential areas noise levels of 50 dBA are acceptable though complaints of sleep disorders are still encountered at equivalent noise levels as low as 35 dBA.

Objective physiological laboratory or field studies are directed towards detecting the actual functional state of the human hearing capacity, and the recording of responses within the body systems and organs. Investigations of noise influence are based on the hearing of man at the threshold level. First unaffected threshold levels are established by testing subject in a sound-shielded environment of 25-30 dBA. Subjects are subsequently exposed to higher sound levels and, if effects of the noise are recorded, the time to recover is measured. At levels of around 65 dBA traffic noise, there was a temporary hearing loss of more than 10 dBA in the lower frequency ranges. This loss correlated with the shape of the low frequency spectrum of traffic noise. A traffic equivalent noise level of 80 dBA led to a hearing impairment of 17-25 dBA over a wide range of low, medium and high frequencies. People living in houses near city highways, commonly complain of difficulties in speech perception due to baffling of the sounds of speech by traffic noise. At levels exceeding 70 dBA, speech audibility in human communication is seriously hampered. Listeners cannot discriminate between 20-50% of the words presented to their ears.

Urban noise can cause an overstrain of the central nervous system. The stimulus response time can be shortened or prolonged. In subjects in a quiet apartment of 40 dBA, the response time light stimulus was about 158 ms and to a sound stimulus 153 ms. The

latency time increases by about 30-50 ms during periods of rest in residential areas exposed to noise, indicating an inhibitory effect on the function of the brain. Noise levels exceeding 60 dBA result in the decline of vigilance, reduced mental performances such as information transmission speed and short term memory, and change of mood.

Overstrain to noise is revealed by changes of pulse rate and blood pressure as hypotension and hypertension. In subjects studied in the USSR exposed to air traffic noise in the laboratory at 80-90 dbA and in the field over 2- to 4-h periods, there was a pronounced decrease in heart rate. The arterial blood pressure was unstable with fluctuations of 20-30 mm Hg. Rheoencephalography showed cerebral vascular hypertension and a diminished brain blood supply.

Noise affects the regulation of the endocrine system, the metabolism, and the function of the gastrointestinal tract. This is expressed by slight deviations in adaptive responses and longer rehabilitation time in those functions even at relatively low noise levels. Noise is a particularly intolerable stimulus during night time. Because of noise, people find it difficult to fall asleep, their sleep is shallow, and they wake up frequently. They are poorly rested in the morning. The impact of increased noise levels on sleep of people in the city of Moscow is shown in TABLE 11. The sleep was normal at noise levels below 30-35 dBA. It was considerably disturbed at 40 dBA. The falling asleep period extends to over one hour, and the depth of sleep drops to around 60% at 50 dBA. Other investigations in the USSR indicated that women and elderly people living in noisy areas complain more often than the young about irritation, sleep disorders, headaches and heart pains. independent of the physiological decline of hearing capacity. Special attention should be given to pre-school children and children at school in residential areas exposed constantly to traffic noise as well as to exhaust gases. Children are more sensitive to noise than adults, through they respond differently than old people.

Noise Sources

The most widespread sources of external noise in cities are road traffic, trucks, trams, buses and trolley buses, railway transport system including open sections of the underground system, and civil aviation planes. Complaints about traffic noise make up about 60% of all complaints about noise in cities. Contemporary cities are overloaded with road traffic. The level of resultant traffic noise is determined by intensity, speed and nature of the traffic stream. Typical traffic streams on the main roads of large and medium size cities consist of 1500 to 1800 vehicles per hour. Traffic is heaviest on the streets of administrative and cultural centres of cities, and on roads which connect residential and industrial areas. In highly industrialized cities and in new cities under construction, the biggest part of the traffic stream may be heavy traffic, typical figures in the USSR being 63 to 89%.

Systematic acoustic analysis has allowed the establishment of the main relationships between traffic conditions on city transportation routes and the resulting noise levels (Schultz, 1982). Use of these relationships makes it possible to evaluate the expected noisiness of city streets and road networks in the future. The noise characteristics of surface traffic are usually assessed using the equivalent sound level at 7.5 m distance off the axis of the near-side traffic lane. Typical equivalent sound levels are 69-83 dBA. Prediction methods for estimating expected noise levels from road traffic have been worked out in different countries (WHO-EURO, 1986). TABLE 12 lists the values that are used in the Soviet Union for the approximate evaluation of traffic noise characteristics of streets according to their function. The sound level from passenger, freight and electric trains is typically 90-93 dbA at 50-60 km/h. In tackling the problems of noise abatement within housing estates, certain externally located noise sources, though usually less intensive than industrial noise, but more widely spread must be considered. Typical noise characteristics of noise sources in residential areas in the USSR (GOST, 1982) in 1979 are given in TABLE 13. Values were measured at 1 m distance from the boundary of service yards, shops, public catering service establishments, and sports ground.

Noise propagation

As noise spreads in the open air, its level abates as the distance from the noise source increases. A number of physical phenomena are responsible for the noise reduction (Piercy and Embleton, 1979). The main factors are:

- Damping due the geometric expansion of the area over which the acoustic energy is distributed with increase of distance from the source.

- Damping due to noise screening by obstructions (barriers) placed between the noise source and the receiving point.

- Damping due sound absorption in the air.

- Damping due to sound absorption at the ground surface.

Noise propagation is also affected by the atmospheric conditions prevailing, vertical gradients of wind and temperature especially, also humidity. Disregarding the sound absorption in the air, the sound level created by a point source as well as a line source such as a stream of continuous traffic along a road, in a homogeneous

Table 11

Sleep indicators of people exposed to different night time noise conditions in Moscow. Source USSR authors

Equivalent noise level dBA	Falling asleep time min.	Maximum time of quiet time intervals min.	Duration of quiet sleep as % of total sleep time, %	Activity Factor
35	14 – 20	90 – 115	70 – 82	0.05 – 0.09
40	25 – 30	65 – 77	63 – 66	0.09 – 0.18
50	47 – 63	61 – 73	58 – 62	0.14 – 0.35

Table 12

Traffic noise levels on road with various traffic densities in the USSR. Source USSR authors

Category of streets and roads	Number of lanes both directions	Noise level dBA
Highways	6	86
	8	87
Continuous traffic	6	84
	8	85
Controlled traffic	4	81
	6	82
Low standard roads	4	81
	6	82
Residential area	2	73
	4	75
Service roads	2	79

Table 13

Characteristics of outdoor noise sources located inside residential estates in the USSR in 1977. Source USSR authors

Noise source	Equivalent sound level dBA
Garbage removal truck in operation	71
Loading and unloading goods	70
Children playing	74
Children in swimming pool	76
Football	75
Volley ball	74
Basketball	66
Hockey	65
Tennis	61
Table tennis	68

atmosphere in the absence of obstructions at distance can be calculated. In the case where there is an obstruction or barrier between the noise source and the receiving point, an area of sound shadow forms, which provides additional sound abatement due the screening effect. The barrier may be artificial or natural, e.g a long building, a wall, earth bank, or a natural hill. The barrier must not have air gaps in it. The noise screening effect is most noticeable at high frequencies. The noise screening efficiency can be calculated in a number of ways. The most widely used method is that by Maekawa (1968). It is sensible to put the screening barrier as close as possible to the outdoor noise source. Typically, barriers can give a noise abatement of 5 to 15 dBA in equivalent noise levels. Buildings may act as barriers (FIGURE 15). The noise level difference between the back of the small building close to the highway and the front is more than 15 dBA. Noise barriers may take many forms as FIGURE 16 shows, but the planning land use factors associated always need careful thought.

As the sound energy propagates in the atmosphere, some of the energy is transformed into thermal energy due to a number of molecular processes in the air. The damping of sound levels due to sound absorption by the air can be calculated considering a damping factor and the distance between the noise source and receiving point. The atmospheric sound damping factor is strongly dependent on the relative humidity, and on the sound frequency. It greatly increases at high frequencies. In practice, damping due to air absorption for urban noise, is regarded as being insignificant within <100 m distance (Piercy and Embleton, 1979). The ground surface sound damping should be considered only in the case where the noise source and point of observation are situated close to the surface, and the intervening surface is covered with grass, soft soil or scattered vegetation. Usually, the noise absorption by such ground surfaces does not exceed 4-6 dBA, while with a sound reflecting ground surface noise levels increases of 2-3 dBA may occur. If a 3-5m high shelter belt lies across the propagation path, the incident sound energy is partially reflected, partially dispersed, and partially absorbed by the foliage. The noise absorption for shelterbelts does not normally exceed 0.08 dBA/ m shelterbelt width. Shelterbelts of less than 25 m width are of little practical value. Climatic factors, in particular wind and temperature, can be very effective for outdoor sound propagation above the ground, especially at >50 m distance from the noise source (Larsson et al., 1979). Vertical wind and temperature gradients cause changes in direction of the of sound waves propagation. Such sound refraction leads to sound shadowing and sound amplification effects.

The availability of theoretical modelling techniques for estimating outdoor noise at the outside face of buildings of different types in their existing locations enables current noise situations to be investigated theoretically, and problem areas to be identified. It enables to explore quantitatively the available technical options for effective noise abatement. Checks to be made of the consequences of future planned developments for the health of the inhabitants in advance of their construction. Techniques developed in the USSR (GOST, 1977,1982) are very similar to those in other countries(WHO-EUR 1986). The methods for reducing the urban noise consist in keeping down the noise at its sources, in planning and architectural design, and in construction and internal sound damping.

The primary means of reducing external urban noise is through the reduction of transport noise (CEC, 1980.) Various administrative measures can be applied within existing city areas, like redistribution of through traffic on bypass roads, ban of trucks and heavy noisy buses and motorcars within city centre limits, and speed restrictions at various times of day for specified routes. This is opposed by the trend towards higher engine capacities, larger vehicles, and the continual growth of traffic through the promotion of transport. Efficient are town planning measures which improve the noise control of the general layouts of towns, and in more detail residential and other building construction planning for noise control, providing special noise reducing devices to reduce noise penetration or isolate the noise at its source by absorption and reflection. Advantage of noise shelterbelts can be made using topography and green spaces, earth banks, and walls as sound screens along main traffic roads. In planning, the area in city districts should be divided into functional zones with quiet places for pre- school and school children as far away as possible from noise sources like highways, parking lots, garages and large transformer substations. Zones adjoining noise sources can be reserved for administration, service and trading buildings, shops and stores, which can tolerate higher noise levels (Jenkins et al. 1976). If there is a necessity to locate a residential area at the boundary of a city centre district, specially designed noise preventive dwellings must be placed along traffic highways. This requires dwellings with enhanced external noise insulation and noise attenuated ventilation systems. Main windows should be facing away from the sound source and sealed. Industrial plants, often the main source of numerous ambient noises in adjacent or nearby residential areas should be centralized in one area away from the town centre.

Any particular method for the protection of residential areas from industrial noise should consider the characteristics of the sound sources and the permissible noise level norms at the receiving check points located within the adjoining residential zone. Typical sound levels inside heavy industrial plant and power stations range from 80 up to 110 dBA. Noise sources of industrial enterprises include workshops emitting noise through window, doors, ventilation apertures and other openings, including roof ventilators and roof lights,
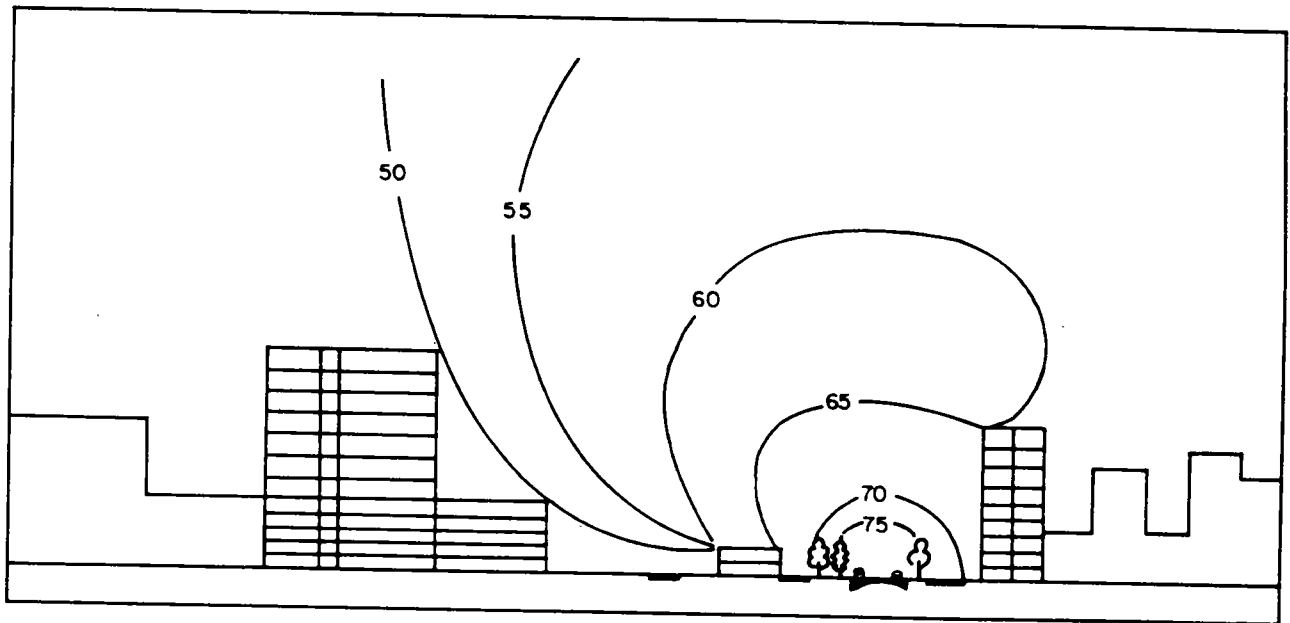
Fig. 15:- Noise propagation from a highway in a residential area. Buildings immediately adjacent to highways need sound proofing. Units Equivalent A weighted noise levels.
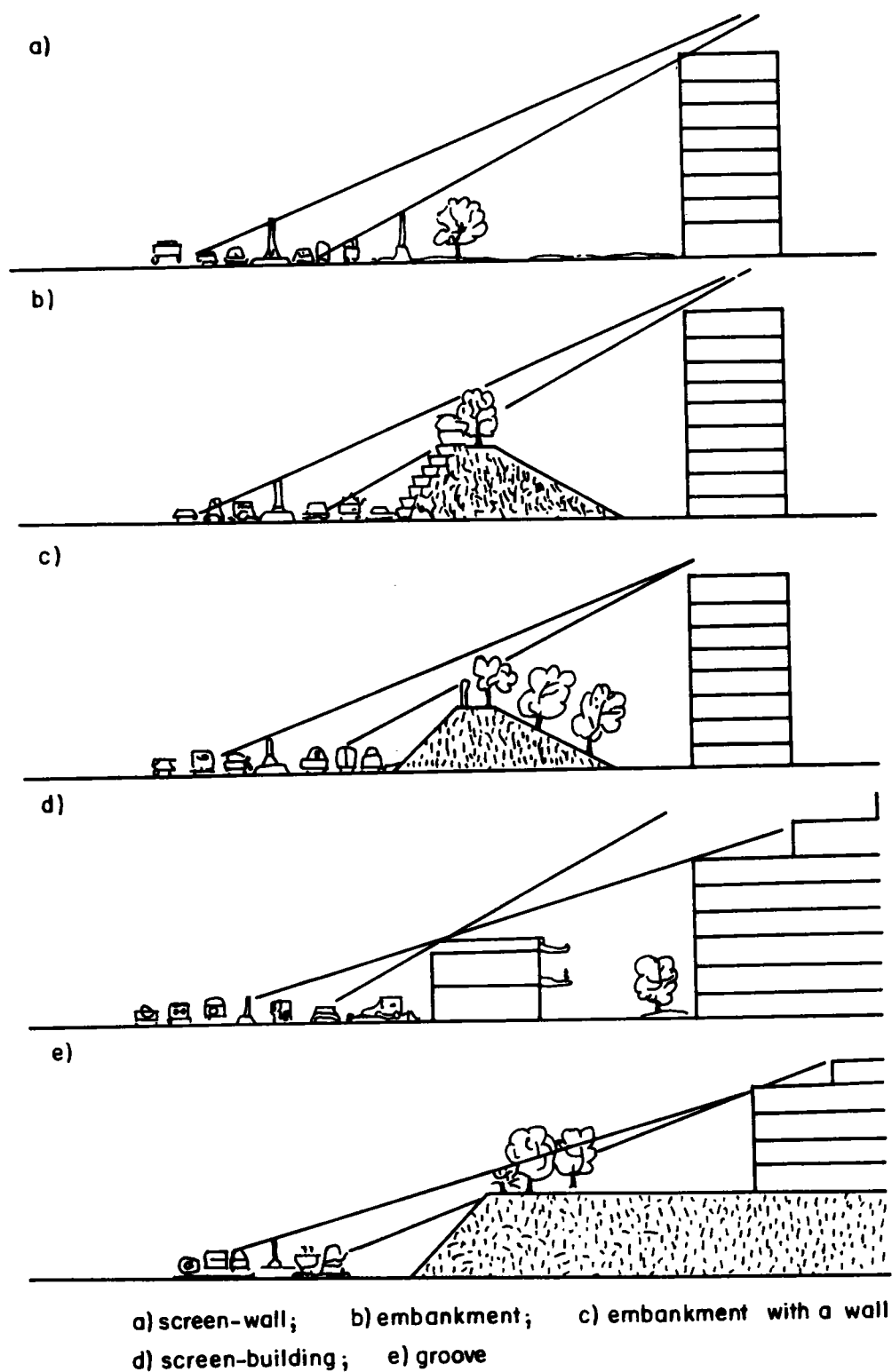
a)

b)

c)

d)

e)

a) screen-wall;   b) embankment;   c) embankment with a wall;
d) screen-building;   e) groove

Fig.16 :- Various types of noise-proof structures.

compressor units, ventilation openings linked to ventilation chambers, cyclones, mechanized transport systems, boilers, outdoor units of industrial equipment, like gas distributors, and others. The noise energy coming out from the buildings tends to come particularly from the various openings in the enclosing structure, like open windows, doors, and ventilators. In addition, equipment involving dynamic handling of air is in direct connection with the outdoor environment, and is often located outside the enclosing structures of the various buildings. Roof mounted cyclones are an important source of community noise disturbance. The noise radiated from a large aperture depends on the sound pressure level outside the facade, the sound pressure level inside the space, the area of the aperture, the distance from the source to the receiving point, and the directivity, which is a function of wall thickness and the product of the aperture width and frequency. The value of directivity can be determined from design charts (Oldham and Shen, 1982).

The width of protection zone needed for noise control can be estimated provided the corrected level of the sound power is available. Estimates of the average and maximum corrected sound power of an industrial enterprize can be based on data on the sound levels obtained on a measurement circuit located outside the boundaries of the enterprize at distances 5 to 30 m from the boundary at heights of 1.5- 3.0 m above the ground. It is important that the measurement points for obtaining the sound levels should not lie in the field of the sound shadow of buildings and structures, which are not the source of the actual external enterprize noise. In the UK a methodology was developed for estimating the number of measurement points needed at the boundary to give an adequate description of the external industrial noise field (Jenkins et al., 1976). The appropriate wind conditions needed for satisfactory measurement were specified. Data obtained from industrial premises were mapped. The noise level at boundary did not often exceed 70 dBA, except opposite open doors, close to dust extraction equipment, or in the proximity of external compressor equipment, when the boundary noise levels could exceed 80 dBA. The majority of the complaints from the occupants of nearby houses were associated with external compressor, blower fan or extract fan noise. The permissible sound level to determine the width of a protection zone in the USSR is set at 45 dBA during daytime and 55 dBA at nighttime. If the width of a protection zone is to be reduced, appropriate construction and sound damping measures must be taken.

Noise generated by ventilation equipment must be tackled at its roots, and localized by muffling devices at the inlet and outlet ducts, or by using closed loop air circulation, making use of appropriate air purification techniques in the ventilation filtration and purification chambers. Noisy outdoor equipment must be placed at reasonably remote spots, far from the industrial boundaries immediately adjoining the residential zones. Such equipment should also be screened by solid barriers, such as the industrial buildings themselves or by protective walls. Otherwise it must be enclosed in a noise reducing enclosure. Water cooling towers and gas distribution stations also must be either located as far away as possible from the residential zone or they must be effectively screened by appropriately designed noise preventive walls. In the case of cyclones, it is wise to surround them with special sound reducing structures.

In designing the general layouts of new industrial enterprises and in updating layouts of existing factories, care should be taken that the shops with the most noisy equipment are located far away from the industrial site boundary adjoining the residential area, i.e zoning the industrial construction site itself with regard to the noise factors that may cause problems to neighbouring sites. It is also recommended that, administrative functions, laboratory and other auxiliary facilities, design offices and training facilities should be located in long multistoried buildings placed close to the edge of the residential zone. Multistory garage buildings for cars can be located in the land area allocated for the noise protection zone, and designed as noise protection screens against the industrial noise sources beyond. It is sensible to make the garages as long as possible without any breaks in the building along the side facing the residential zone (WHO-EURO, 1986).

Aircraft noise has become an important problem. The worst conditions are associated with take off. It especially affects people living under the noise foot prints for take off and landing (FIGURE 17). The dimensions of the footprint depend on aircraft type and the take off engine thrust. Narrow fan jet engines tend to produce most noise, while wide fan turbo jet engines are quieter. The very long length of the 70 dBA take-off footprint may extend over 35 km, the breadth of the noise foot prints is typically about 2.5 km (FIGURE 17). In view of the international nature of air transportation, there have been strong pressures to standardize internationally noise assessment procedures for civil aircraft (WHO-EURO, 1986). In the past, each country tended to set-up its own aircraft noise descriptor, calculation method and noise level limits. In recent years, international cooperation on the uniform calculation of aircraft noise has been established within the European Civil Aviation Conference, ECAC, in its group of experts recommendations on the abatement of noise caused by air transport have been worked out and adopted (ANCAT).

Outdoor - indoor noise propagation

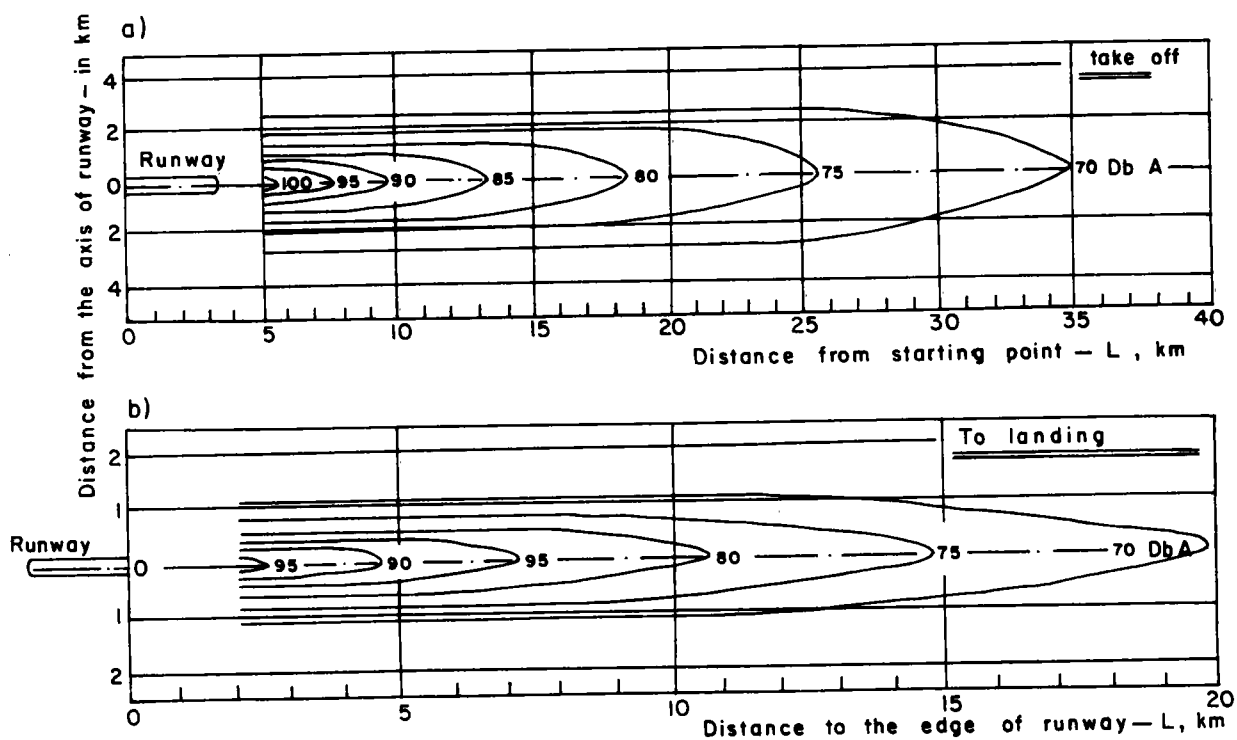The main route of outdoor noise into buildings is through the windows. Transmission through room

Fig.17 :- Typical maximum sound level "footprints" in the zone below aircraft flight take-off and landing paths. Such footprints, the precise size of which depend on aircraft type and engine power, are used in the setting up of sanitary protection zones in the vicinity of airports.

(Source: Supplied from USSR).

chimney flues can be important. Road traffic noise has a large low frequency element. Daytime traffic noise measurements on the 16th and 17th floors of a New York city hotel, showed octave band sound pressure levels around 90 dB at 20-75 Hz, falling roughly uniformly 5 dB per octave to around 55 dB at 4.8-10 kHz. Consequently it is the sound insulation properties of the facade at low frequencies, which primarily determines the equivalent noise level reduction between outside and inside for road traffic. With normal sealed double windows, the low frequency reduction is about 20 dB. Specially designed double windows with greater spacing, and sound absorption in the reveals can increase this to 30 dB or more. Single glazed windows typically offer a reduction of about 15 dB when closed. In buildings of masonry construction, these window properties dominate the sound performance of the overall facade. Once the windows have to be opened for fresh air or for natural cooling by ventilation, facade insulation performance falls right away to less than 10 dBA.

One of the problems in achieving satisfactory noise control at the facade, is how to secure a satisfactory air flow into the room, when the windows are closed in a sound-proofed dwelling. The accepted norms for living rooms with a partially opened window, are only achievable where the dwelling is located in the depth of a residential area, or facing local roads with the facade equivalent noise levels below about 55 dBA. The facade equivalent noise levels of dwellings facing the main city highways range between 65 and 75 dBA, and those located near roads with the heaviest traffic have even higher levels. This situation necessitates the development of window systems which secure both a high standard of sound insulation and a normal rate of fresh air exchange between the room and the outside air.

In modern building sound proof ventilation windows are being more widely used. They provide for a high sound insulation and simultaneously for room ventilation. In the USSR, typical sound proof windows consist of two fixed window casements separated by 100 mm with a sound absorbent treatment on the reveals. An opening is included under the window, and a muffler type box with a small ventilation fan secures the necessary inflow of fresh air. For areas where the facade noise levels lie between that acceptable in residential areas, and those found facing main city highways, an alternative technique, which allows some acoustic protection whilst allowing natural ventilation, is to use self protecting building configurations (Oldham and Mohsen, 1979, 1980). A self protecting building is one in which an element of the building acts to screen acoustic weak points on the facade, such as windows. A common self protecting building form is the courtyard house. A noise level reduction of the order of 10 dBA can be achieved in rooms facing the courtyard on the ground floor. Another common form are buildings with closed balconies in front of windows.

Noise reductions of the order of 6 dBA can be achieved. For the balcony form to be effective, the designer must ensure that the reflections from an overhead surface, such as the underside of another balcony, do not reflect sound into the protected space.

Indoor noise sources

Sound levels inside spaces of blocks and flats depend not only on external noise levels, and the acoustic properties of the external elements, but also on internal noise levels, and the standards of acoustical control achieved from room to room within the structure (Parkins et al. 1979). Indoor noise sources include engineering and sanitary equipment, lifts, water pumps, refuse chutes, ventilation systems and others. In modern buildings about 30 types of noise generating equipment has been identified. This situation can produce noise levels of 45-60 dBA inside individual flats. Important noise sources in blocks of flats are directed by the occupants such as sound household appliances, record and cassette players, radios and TV sets, musical instruments, and the occupants themselves. Walking, dancing, moving furniture, children running about within the building produce sound vibrations, which are directly transmitted by impact to the ceilings, walls and partitions, and are spread as structural noise further through the building, often to considerable distances from the original source. Such situations arise when the very low sound damping materials, including floor surface coverings, are used for the building construction. In multi-storied buildings, poorly designed and placed lifts can be an important source of noise. This noise is spread, partly through the air in the vertical well and in the staircase, but mainly along the building structure, due to the fact that the lift structure is rigidly fixed to the walls and ceilings, adjacent to it. The noise levels in flats due to the sum total of internal noise sources can be very high, though the average equivalent noise level rarely exceeds 80 dBA.

Internally generated noise should be controlled as far as possible at source. The noise necessary for human activity will remain, talking, shouting, singing, playing music, television and crying children. Adequate standards of sound insulation between apartments are essential to secure socially acceptable conditions. Control of internal noise disturbance can be approached through a planned clustering of noise sources according to noise levels: rooms with noisy activities are located together at one side of flats and rooms with quiet activities at the opposite side. The insulation against sound transmission from one room to another room depends very largely on the weight of the structure, and the absence of air paths through the common dividing element. Particular difficulties arise in hot climates, because of wide open outside windows for cooling ventilation, and internal cross ventilation through open doors and grilles. This may reduce

internal sound insulation within the building to unacceptably low levels.

Noise standards

A variety of different physiological studies have led to a classification of permissible and tolerable maximum noise levels, which form the basis for establishing hygienic norms. The noise level is considered permissible when protracted exposure to it does not lead to any negative responses and modifications in the complex physiological and mental functions, which are most sensitive to noise. The norms stipulate permissible parameters for various types of space incorporating different human activities, taking regard of the main physiological issues peculiar to that human activity. Thus the principle physiological processes in living rooms during the day are active rest, school homework, watching television and listening to the radio, playing recording equipment. In bedrooms, the principle activity is sleeping; in classrooms of schools and training establishments, educational processes, learning, and oral communication; in libraries mental work; in acute and preventive medical institutions rehabilitation of health; and so on.

Rating of noise for residential building in cities is currently carried out in the USSR to check on accordance of the noise found with the legal sanitary norms which state the permissible noise inside dwellings and public buildings, as well as outdoors in residential zones. The sanitary norms are compulsory for all ministries, departments and institutions engaged in designing, building and operating dwellings and public buildings. They are also compulsory for the groups responsible for planning the construction of towns, and urban areas, including dwellings, the various means of transport and communications. They are also mandatory for organizations designing, manufacturing and operating household equipment, and technological equipment, including engineering equipment. The responsible organizations must predict the noise conditions associated with their responsibilities and implement any noise abatement procedures needed to reduce noise to the levels stipulated in the norms applicable in that situation.

In the USSR the permissible values of the octave band sound pressure levels, and of the equivalent and maximum levels are given for the noise levels inside dwellings and noise levels outside in residential areas. The levels of the indoor norms for dwellings during night time are 30 dBA, and during daytime 40 dBA. For residential zones outside, they are 45 dBA by night and 55 dBA by day. Corrections ranging from 5 to 10 dBA are introduced to noise level norms to estimate the permissible sound pressure levels in specific octave bands, or permissible equivalent sound levels.

The availability of sanitary standards for permissible noise, creates the possibility of working out technical, architectural and planning approaches, as well as administrative measures aimed at ensuring a noise regulation regime. The norms thus provide an important tool for the hygienic requirements securing the health of the population. In the USSR separate standards (GOST 22283-76, 1982) for the permissible levels of aviation noise are established. This standard is used for newly planned areas for residential occupation in the vicinity of existing airports, as well as for the land areas of residential zones in cities and in urban type settlements likely to be affected by newly deigned airfields and airports. Rating is done by establishing the permissible parameters for the maximum sound levels outdoors in residential areas, for take off, landing, and overflying of aeroplanes and helicopters for each pass, also engine testing and run-up on the airfield. In addition norms are established for the permissible maximum equivalent sound levels over defined periods of hours (TABLE 14).

When reconstructing existing airfields and airports, the acoustic situation in nearby residential areas is not allowed to worsen. The levels of noise generated are not allowed to exceed the maximum tolerable levels. These standards are used when assessing noise levels created by air transport in established residential zones, particularly when considering noise complaints from the population living in that area. Administrative, technical and planning measures can be applied to counter noise in addition to controlling noise at source.

Elimination of noise at source is usually the cheapest and most effective noise control procedure, it has the highest priority. At the same time, one must note that effective noise control campaigns in industrial societies depend for their success on the application of the whole complex of available methods. Specific legislation is needed on noise control issues, allocating responsibilities at both central government and local government levels. If one accepts the law of responsibility as the basis of ecological policy, the cost of noise pollution control measures should be borne by those who cause the damage. This basic principle does not exclude governmental initiatives to provide appropriate incentives to encourage capital investments in appropriate measures in any campaign designed to produce an environment free of excessive noise. Governments must coordinate intersectorially the various sectorial policies and decisions on noise control issues. In centralized economies, normally the authorities responsible for supervising industrial enterprises are responsible for controlling industrial noise. Traffic noise control is the responsibility of the transport authorities and the police. The Civil administrative authorities, including the bodies responsible for supervising building practice, are responsible for the protection of residential areas against noise. If the policies of different agencies are not properly coordinated, the fight against noise becomes more difficult, and more expensive.

Table 14

Norms for permissible aircraft noise in the USSR

Time of day	Max noise level L_{Amax} dBA	Equivalent noise level L_{Aeq} dBA
07.00 - 23.00 h	85	65
23.00 - 07.00 h	75	55

Summary

There are several levels at which the noise exposure of the people can be controlled as sanitary measure for the maintenance of health and the prevention of complaints and illness. These are:

Administrative measures:

- legal norms for permissible noise levels
- establishment of sanitary protective zones to protect against noise from airports and industrial enterprises.

- creation of favourable conditions for the adoption of low noise equipment and devices.

Technical measures:

- elimination of noise at source, for example, by design in low noise transport systems, or through increased sound insulation of the noisiest industrial equipment.

- reducing noise as it traverses the propagation path, for example through the installation of noise control screens, placing transport systems underground, and use of noise proofed windows.

- in very high noise situations, providing personal noise protection.

Planning measures:

- paying proper attention to noise protection issues in urban and transport planning.

- additional regulations to secure smoother traffic flows

- forecasting the benefits of improved noise control measures,and explaining their importance to urban health improvement.

Chapter 5

Light Environment

Introduction

The importance of light in the indoor environment for health, social and economic policy is much greater than is usually recognized. The eye has some capacity for accommodating with bad lighting conditions, but this accommodation always confers loss of performance. Many physicians and administrators take the lighting systems they personally enjoy for granted, forgetting many people live without the advantage of satisfactory lighting. Good lighting is important for reasons of health and safety, for reasons of efficient productive activity and for reasons of basic human development. Light exerts both a biological and a socio-economic influence. The visual information provided through the eyes to the human brain, where it is subsequently further processed, is vast. When man is deprived of light, he is seriously deprived of visual information about his environment with all that means for his personal development, his social life and his general well-being. Light deprivation is a particular handicap to the young, whose development is the most active. They fortunately, in health, possess the most sensitive eyes. Eyesight deteriorates with age. The aging of vision starts relatively early in life, and a progressive loss of visual performance occurs beyond 40 years of age.

Significant amounts of natural light are only available during the hours of daylight. The available hours of daylight are strongly influenced by latitude. On the equator, the length of daylight is constant. With increasing latitude towards the poles, the length of daylight becomes longer in the summer, and shorter in the winter. At polar latitudes the sun does not set daily for a period around the summer solstice and does not rise daily for a period around the winter solstice. People living at high latitudes are light overexposed in summer and light deprived in winter. The daylight periods in low latitude areas are shorter than the physiological activity period of man. Before the development of effective artificial lighting sources, man's life was very circumscribed during hours of darkness. Many key social events and religious celebrations held at nighttime were linked in time with the phases of the moon for very practical reasons.

Man's life indoors and outdoors for a very significant proportion of people in the world has been transformed by the widespread availability of electric lighting. The availability of electric lighting substantially expands the proportion of the natural daylight period to the length of a 24-h day for effective visual information. This expansion takes place into the hours when the range of outside activity is restricted by natural darkness. Societies without widespread access to artificial lighting, are restricted in their opportunities for activities. Cultural life in such societies is much more dependent on the spoken word and on music rather than on activities related to written word. Lack of adequate artificial light compromises the expansion of educational schemes based on the written word for persons of all ages, particularly children. This deficiency has a significant influence on the extent of illiteracy with its various implications for the improvement of human health. Reading in the light of a dying wood fire is neither easy nor is it healthy, because of the fumes. Illiteracy and health improvement are thus intertwined. In the interest of health for all people the WHO attaches considerable importance to the provision of adequate artificial light. More effective use should be made of natural daylight inside dwellings as a natural resource and abundantly available without costs.

Light, besides being indispensable for visual perception of the surrounding space for work and recreation, also regulates metabolic and immunological processes in the human body, and has a considerable influence on mood and mind. The regulation of light perception involves the pineal gland as an endocrine organ and nervous structures in the brain with pacemaker functions for the maintenance of the internal rhythms of the physiological processes in the body, commonly referred to as the "biological clock". The ultraviolet portion of light incident on the skin facilitates the production of vitamin D and stimulates the process of tanning through melanin pigment formation in the skin. Excess of light has adverse effects at the eyes and the skin. Light, as a biological factor also indirectly influences the health of man, through its influence on other biological species, such as plants, microorganisms, insects and animals, in the vicinity of man outdoors and indoors. The behaviour of insects is very much affected by light. Good lighting encourages cleanliness and so helps eliminate reservoirs of potentially unhealthy microflora. Some harmful shade loving insects are discouraged by high daylight standards.

Residents of cities are often deprived of a natural light. They spend a large proportion of the day indoors: in their homes, at working premises, in transport systems, including subways, in stores and supermarkets, and in cultural institutions of different kinds. The lack of natural light for people living in urban areas is aggravated by urban atmospheric pollution which denatures the available light through specific spectral

absorption, particularly of the ultraviolet portion by as much as 40% compared with rural areas. The levels of artificial lighting usually found indoors are much lower than those that occur outdoors. Most artificial light sources produce light of very different spectral character compared to the spectral composition of natural light. Tungsten filament lighting is red rich and very deficient in light at the violet- blue end of the spectrum. Fluorescent gaseous discharge lamps, possess a spectrum containing distinct peaks of radiation, including ultraviolet (UV), not found in natural daylight, and an alternating light output, which normally coincides in phase with the frequency of the electricity alternating current (AC) supply. Many artificial light sources do not produce the same photochemical responses in man as natural daylight. New layout concepts for modern administration buildings like the landscaped office, have produced very deep rooms with relatively low ceilings. This has furthered the deterioration of the natural lighting environment. It is therefore necessary to employ artificial electric lighting over the whole day to supplement or substitute the very inadequate natural lighting. Experience in the USSR and in other countries has shown that the extent of exposure of the people to the artificial lighting environment in such premises has increased to levels that affect the working capacity and the state of health. There seems to be a strong human preference for well daylit buildings, as opposed to daylit buildings supplemented by permanent daytime artificial lighting, in spite of all the recent advances in electric lighting technology. The reaction of people against working in windowless environments with solely artificial lighting is even stronger. Such environments are sometimes proposed by thermal experts on grounds of energy economy or required for particular purposes. For reasons of land shortages in city centres, there is a growing use of underground or semi- underground buildings for commercial purposes. If such windowless environments are unavoidable, it is certainly very important to consider very carefully the spectral nature of the artificial light provided within them.

Physics and perception of light

In the quantitative description of the indoor lighting environment the two distinct physical parameters: illuminance and luminance are used. Illuminance is the quotient of the luminous flux incident on an element of the surface containing a point by the area of that element. Luminance is the flux of light energy emerging in a small solid angle in given direction from a small element of an area on the surface per unit apparent area per unit solid angle. The unit of illuminance is the lux or lumen per square metre, lm/m2; the unit for luminance is the candela per m2 or cd/m2.

Light is commonly divided into short-wave ultraviolet light, UV, visible light, and infrared light, IR. UV light and IR light cannot be perceived by the human eye.

Ultraviolet Light

The UV radiation can be divided into three main wavelength regions (WHO-EHC 14). The near ultraviolet UVA radiation ranges from 400 to 320 nm. The upper end is the lower practical limit of the visible spectrum and the lower end the upper limit for the erythemal response of the skin. The UVB radiation ranges from 320 to 280 nanometres (nm), and the damaging UVC radiation from 280 to 200 nm. The photons in ultraviolet radiation are relatively energetic. UVA and UVB and have important biological impacts, inducing photochemical reactions, both in various part of the eye and at the epidermis and dermis of the body surface (WHO-EHC 14; Steck, 1982). With extensive exposure these reactions may be adverse to health such as turbidity of the cornea or burning of the skin. Ultraviolet light may be produced deliberately for utilizing its bactericidal action.

The outdoor ultraviolet climate is discussed in WHO-EHC 14 Ultraviolet Radiation. The solar UV radiation flux that reaches the surface of the earth is a function of the solar spectral irradiance at the upper surface of the earth's atmosphere, and the subsequent absorption and scattering of UVR by the intervening atmosphere. The ozone layer in the stratosphere provides a high level of UV absorption. Further absorption occurs in the troposphere, due to tropospheric ozone, nitrogen dioxide, and aerosols, which also increase the scattering. The atmospheric scattering of UV radiation is so great, that the intensity of the direct beam UV flux is relatively low in relation to the amount of diffuse UV sky radiation received from the sky by multiple scattering. The UV radiation becomes very highly diffused by the time it reaches the surface of the earth. The intensity falls particularly rapidly below a wavelength of 320 nm, and virtually no solar radiation with wavelengths below 288 nm reaches the surface. The path length through the atmosphere thus exerts a very critical influence on the UV beam strength. With a low sun, the amount of UV penetration is very low indeed. Urban pollution further lowers the UV radiation received. The UV radiation falls off rapidly with the decrease of solar altitude and the elongation of path length, thus increasing the ozone absorption, and multiple scattering. The lower the sun, the greater the rate of fall off. The biggest proportion of the daily UV radiation flux arrives between the two hours before and the two hours after solar noon. The pattern of annual variation of UV radiation measured in the 290 - 380 nm band at the high latitude of Moscow are summarized in TABLE 15.

There is a difference of over an order of magnitude between UV radiation in June and December in

Table 15

Mean daily totals of global UV radiation (290-380 nm) measured at the Meteorological Observatory of Moscow State University. 1968-1980. Units MJ/m^2. Source Garadsha and Nezval 1987

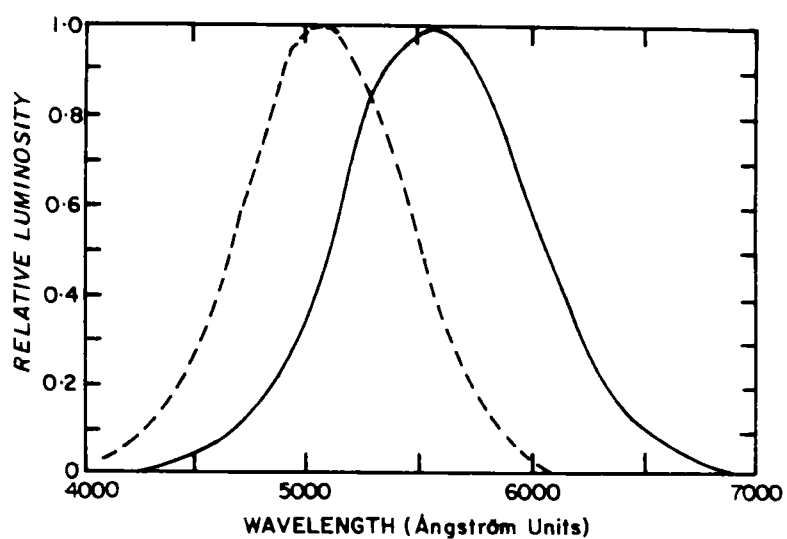| Month	Daily Mean	Daily Max	Daily Min
Jan	0.09	0.17	0.02
Feb	0.19	0.43	0.04
Mar	0.36	0.72	0.06
Apr	0.54	1.12	0.07
May	0.76	1.44	0.13
Jun	0.93	1.36	0.13
Jul	0.83	1.32	0.10
Aug	0.69	1.12	0.11
Sep	0.43	0.80	0.05
Oct	0.19	0.50	0.03
Nov	0.08	0.25	0.01
Dec	0.05	0.12	0.01

Fig. 18 a :- The photooptic, cone vision, relative luminosity curve for equal energy (full line), and the corresponding scotoptic, rod vision, curve, (dotted line).(Source: Weston, 12).
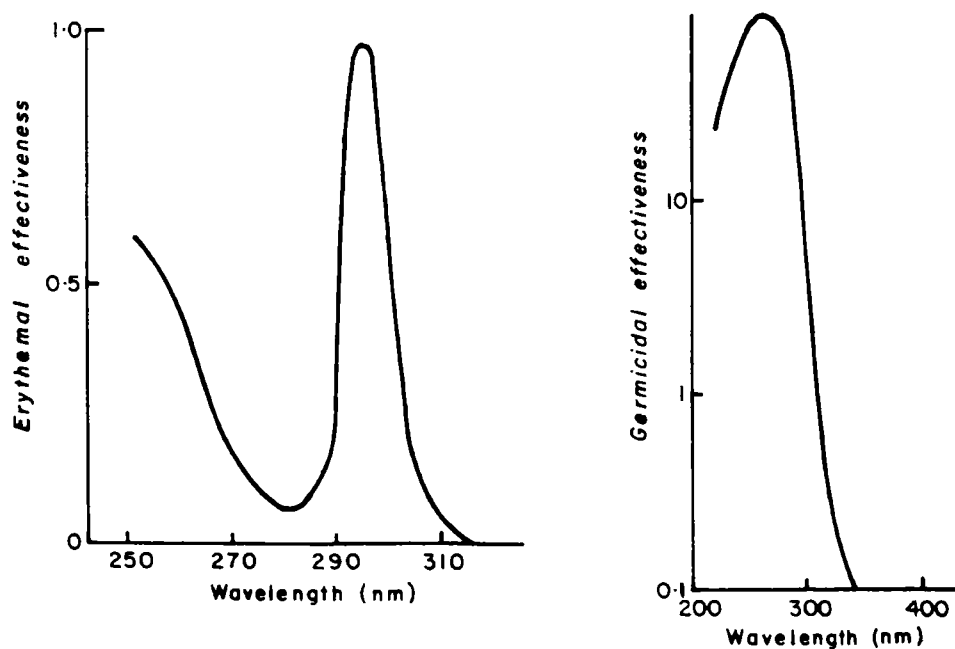

Fig.18 b :-CIC internationally agreed erythemal sensitivity curve (left side) and bactericidal effectiveness curve (right side). (Source: Jewiss,1978).

Moscow. 48% of the UV radiation flux arrives in summer, 32% in spring, 14% in autumn, and only 6% in winter. During the period 1968-1983, the annual global UV flux in Moscow decreased by 12% due to global atmospheric effects and increases in local pollution. A shift in latitude towards the equator, starts to raise the winter levels towards the substantially higher summer levels, so the winter summer ratios gradually become less. The losses of UV radiation in Moscow under average conditions of cloudiness amount to some 20-40% and to 85-95% under a completely covered sky by dense overcast cloud. The maximum diurnal values exceed the minimum values by a factor of 10 to 15 (Garadzha and Nerval, 1987). A contaminated atmosphere may reduce the average UV radiation outdoors by 50-60% compared with rural areas.

The detectable effects of ultraviolet irradiation on the skin have been widely studied, often using observable changes in the visible appearance of the epidermis. Such studies led on to the estimation of the action spectrum for erythema, standardized on an international basis by the CIE (FIGURE 18b left). The action spectrum for antirachitic radiation for a white skin was determined in 1938 as lying between the UVB range 270 to 320 nm. The precise action spectrum for the synthesis of D3 protovitamin is not known, but includes both the UVA and UVB. Dark skin melanin pigmentation lowers the UV penetration. The action spectra for the majority of other photochemical reactions of man are not known. While erythema does not occur to any detectable degree behind normal window glass, this does not mean that the same will necessarily apply to other photochemical reactions, whose action spectra could well be different.

Infrared Light

The shortwave infrared light IRA ranges from wavelengths > 770 to <1400 nm. The IRA radiation from the sun and incandescent light sources contributes to warming of the human body, but the photons in this region, lacking energy, do not produce significant photochemical reactions. The longwave infrared radiation IRB ranges from wavelengths >1400 to 3000 nm. The energy in the infrared solar spectrum with wavelengths >2500 nm is very small. The far infrared radiation IRC is the waveband >3000 nm to 1 millimetre (mm). Thermal radiation from the atmosphere and ground peaks from 10000 to 15000 nm wavelength. The infrared end of the optical spectrum is considered to lie at 1 mm.

Visible Light

A critical quantity in assessing the biological effects of electromagnetic radiation is the wavelength, which determines the energy of the photons in any waveband.

Optical radiation is electromagnetic radiation with wavelengths between 100 nm and 1 mm. The energy of a photon is inversely proportional to its wavelength The radiation received at the surface of the earth from the sun lies dominantly in the wavelength range 290 nm to 2500 nm. Photochemical reactions are chemical reactions activated by interaction of photons with chemical matter. The eye is a photochemical device, activated by photons of different energies to transmit colour related electrical signals to the brain.The human eye can only perceive optical radiation with wavelengths between about 380 nm and about 770 nm. Precise limits cannot be set because they depend on the amount of radiant power reaching the retina and the responsivity of the observer. The lower limit is generally taken to lie between 360 nm and 400 nm, and the upper limit to lie between 760 nm and 830 nm. The light adapted eye has its greatest sensitivity at 555 nm, which, when expressed in terms of the perceived colour, is in the green yellow region. The sensitivity to red light beyond 700 nm is very low. The perceptual sensitivity of the eye to violet radiation with wavelengths below 400 nm is also very low. Under conditions of very low illumination, the eye adapts within a period of time to an enhanced response based on rod as opposed to cone dominated vision. The peak response then occurs at a wavelength of 507 nm. This shift produces a significant change in colour perception.

In physical terms light is determined by illuminance and luminance. Illuminance or illumination is the flow of light energy falling per unit time on a surface; luminance is the energy emitted from a surface per unit apparent area in a particular direction. The retina of the eye, as a perceptual instrument, receives information about a complex pattern of luminances, focused by the lens on to it. Under conditions of high illumination, the iris contracts, improving the quality of the image, and the depth of focus. The spatially structured information falling on the two retinae is detected photochemically, and the abstracted information neurally transmitted to the brain. The signals contain information about the spatial and colour patterns in the visual scene. The brain then translates this information from the two separate optical sources into a pattern of perceived brightnesses, and formulates the information into a combined binocularly perceived visual structure, using substantial amounts of previously learned experience about the nature of the visual world. The eye never perceives the illuminance. It perceives only the light reflected from or diffused through objects together with any light coming directly from any light source located within the field of vision. The greatest acuity of vision is found for that part of the field of view focused on the fovea, a central part of the retina, where the receptors are most closely concentrated. Lighting design is thus fundamentally directed towards the creation of desirable patterns of luminance in the visual field. In lighting design, one usually attempts to keep bright light sources out of the
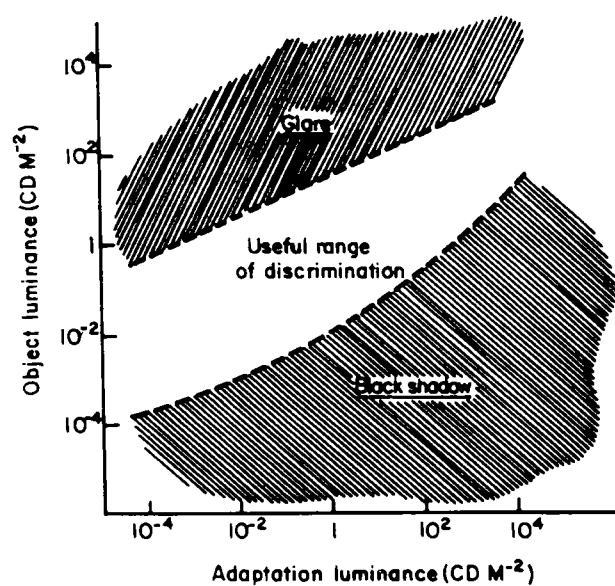
Fig. 19 :- The effect of the adaptation luminance on the
useful range of luminance discrimination.

direct field of view.

The eye adjusts photochemically to the level of incident retinal illumination, as well as by the autonomic adjustment of the size of the pupil. Adaptation is the process by which the state of the visual system is modified by previous and present exposure to stimuli that may have various luminances, spectral distributions and angular subtenses. The eye, working in conjunction with the brain, can cope perceptually with a luminance range of about 1012 cd/m2 through its various control mechanisms, but the perceptual system needs time to adapt photochemically to cover this range. A brightly sunlit snow surface may have a luminance of 250,000 cd/m2. Asphalt on a road on a clear night might have a luminance around 0.0025 cd/m2. The detail resulting from rod dominated vision at low night light intensity is very poor compared with cone dominated vision at high day light intensity. The range of brightness at which the eye can see well is over 1000:1. A person adapted to a bright light outdoors can see very little of the things in the shade or inside a room, when looking in a window or open door. The range of brightness of the outdoor objects may be only 100:1. Inside the shade or a room the eyes will adapt to the given lower light intensity to the range of useful brightness discrimination (FIGURE 19).

Human visual perception is based on the existence of contrasts of light and shade and contrasts of colour. The term contrast is used in both a perceptual sense and a physical sense. It involves the assessment of the difference in appearance of two or more parts of the visual field seen simultaneously or successively, for example brightness contrast, colour contrast, and successive contrast in dynamic lighting situations involving movement. Physically contrast can be expressed numerically in different ways. The simplest way is to state the contrast as the ratio between two adjacent luminances in the field of vision. Perceptually these contrasts of luminance will be perceived as contrasts of brightness. Adaptation not only affects the range of brightness perceived at any one time, but it also governs the ability to perceive contrasts. When adapted to good light levels, it is possible to perceive brightness differences amounting to no more than 1% of the average adaptation brightness. If the lighting is poor, as at dusk, only brightness differences of 5% or 10% are perceived.

In the indoor environment visual performance is aided by lighting that gives the correct brightness balances. It is desirable to make the visual task one wants to see well, the brightest object in the normal field of view. This leads to brightness ratios of contrasts between important and unimportant objects in the environment. Examples are:

-Contrast between task and adjacent darker
surroundings   3:1

-Contrast between task and remoter darker surfaces
10:1

-Contrast between lighting fixtures (or windows) and sizable adjacent surfaces   20:1

-Contrast not to be exceeded anywhere within the normal field of view (except decorative bright spots)
40:1

-Contrast that highlights objects to exclusion of everything else in field of view 50:1

Control of contrast is mainly achieved by appropriate choices of surface reflectances, and appropriate design of window systems and lighting systems in their surrounds.

Measurements of optical radiation

The physical assessment of the integrated impact of the light spectrum is based on weighting function for specific biological responses to the incident energy received. The Commission Internationale de l'Eclairage, CIE, has internationally standardized four different weighting functions

(1) CIE Standard luminosity curve for the light adapted eye,

(2) CIE Standard luminosity curve for the dark adapted eye,

(3) Photosynthetically active radiation, PAR (for chlorophyll based photosynthesis),

(4) CIE Standard erythemal sensitivity curve for UV light.

Three flux weighting curves are presented in FIGURES 18a and 18b. Some biologists prefer to express light in photochemical quantum energetic terms, with the einstein as unit. The differences in relative response of the light adapted and the dark adapted eye to light of different wavelengths is shown in FIGURE 18a. Eyes of insects, according to species, have a different response to the electromagnetic spectrum than the human eye. The eyes of many insects respond sharply in the blue and violet end of the spectrum, and of some species even in the UVA and UVB light (FIGURE 18b right side). This effect is practically applied for insect light traps with UVA lamps of peak emissions around 360 nm, placed indoors, that attract and destroy insects.

The retinae of the eye basically record a pattern of luminances, structured in terms of geometrical direction. These physically defined luminances are

perceived subjectively as a pattern of relative brightnesses or brightness of different surfaces. Illuminance is not perceived. The luminance of a surface in a given direction depends not only on the illumination falling on that surface, but also on the reflection characteristics of the surface. The surface may reflect the energy specularly like a mirror, or it may diffuse the energy like a flat whitewash paint. Many surfaces combine diffusing characteristics with specular characteristics, for example gloss paints (CEC, 1989). If the surface on which the light falls, is a perfectly diffusing surface, the luminance is related to the illuminance by the diffuse reflectance which is the ratio of the reflected luminous flux to the incident luminous flux.

The physical measurement of light

As the reflectances in buildings vary so widely, and the patterns of luminance are so complex and difficult to describe compactly, indoor lighting standards are normally stated for convenience in terms of illuminance. Behind this method of specification remains the need to achieve satisfactory patterns of luminance as the fundamental aim of good lighting design. Illuminance is measured with an illumination metre consisting of a colour corrected and cosine corrected calibrated photoelectric cell. The photocell must be adjusted to respond to variations in the spectral content of the incident light in the same way as the light adapted human eye responds (FIGURE 18a). This is normally done by placing a suitable colour filter in front of the photoelectric cell. To correct the effects of changes in angle of incident the light falling a specially dimensioned diffusing disc is mounted in front of the cell. This process to achieve the correct cosine response is called cosine correction. A special kind of illuminance metre devised for daylight studies is the daylight factor meter. The daylight factor meter consists basically of two colour and cosine corrected matched photocells: one cell is exposed horizontally outdoors to provide the overcast day outdoor illuminance, the other cell is used to measure the illuminance at different points indoors. The cells are connected in such a way that the ratio of the two signals is directly output. Luminance metres are far more expensive to make, as they have to incorporate a sighting telescope system to view the luminance field. As the energy available from any specific small area in the field is so small, its accurate measurement is difficult without considerable amplification. Sometimes neutral density wedges are used to provide a mechanical means of matching the external luminance to an internal reference luminance.

The issues of appropriate spectral response are important. Reasonably simple instruments are available to measure the surface reflectance. These devices work on the comparison of the signal reflected from the surface under study, with the signal reflected from a white reference surface of calibrated reflectance (CEC, 1989). A wide range of instruments with defined characteristics is now commercially available.

Lighting for effective vision

One must distinguish between lighting to aid visual performance of specific visual tasks and lighting to promote comfort and safety. Lighting for movement implies different requirements to lighting of a fixed visual task. The basic aim is to provide adequate light for the visual task in ways that promote visual and thermal comfort, and safety at the same time. This can be hampered by a number of important potential defects in the indoor lighting arrangements, which may lead to poor visual task performance and visual discomfort. One of these defects is glare. Glare may be divided into two main categories, disability glare and discomfort glare.

Disability glare disables efficient visual performance. It can occur when a bright source like the sun shines directly into people's eyes, or when the light from a bright source is reflected into the line of vision. Sometimes the detail of a visual task may become obscured by surface reflections, for example, reading print in a glossy surfaced magazine, with the lights in an position for adverse reflections. Sometimes the contrast between the perceived image and its background is reduced by reflection from the image. Glossy pencil writing on matt paper makes it difficult to read. This type of glare is known as veiling glare. Both types of glare are primarily controlled by correct placement of natural and artificial light sources in relation to the spatial arrangement of the various visual tasks, assuming mirror-like specular reflection patterns. The most common viewing angle for near tasks is 25 degrees from the vertical direction. The typical zone of vision when reading and writing is between 0 and 45 degrees. Ceiling lights or horizontal skylights set a slight distance forward of a horizontal visual task are particularly liable to cause unacceptable disability glare reflections.

Discomfort glare causes discomfort without serious loss of visual performance. It may arise from the design of the windows, or from light fittings without satisfactory light distribution. The amount of light travelling towards the eye from the glare source exerts an important influence, as does its angular size. Almost equally important is the luminance contrast between the glare source and its surround. The degree of discomfort glare can be reduced by the use of light colours, by modelling the shape better such as using better profiled window elements, and by the use of light coloured interiors enhancing internal interreflections. The glare discomfort is proportional to the luminance to the power 1:6. This stresses the

particular importance of the brightness of the glare source. The sky in humid tropical areas is often very bright, and consequently can cause especially severe glare, if the building occupant has a wide view of it (Chauvel et al. 1982).

The quality of lighting, to find or provide well lit places, primarily determines the human satisfaction and in a further sense well-being with the natural and artificial lighting systems. The WHO concept of a healthy light environment requires enough light an the interior at all times to allow work or other activities to be carried on effectively and safely, and to give its occupants the sense of being in a well lit building.

Three factors exercise a dominant influence on desirable illuminance levels, the fineness of the detail to be perceived, the luminance contrast between the task and its background, and the colour contrast between the task and its surround. The fineness of detail to be perceived is measured in angular terms, assuming an appropriate task distance. Two sorts of contrast may be identified, colour contrast and luminance contrast. Within limits, the details of a task are seen more easily, as the illuminance is increased. The extent of the improvement depends on the size of the detail, the contrasts of brightness and colour between the detail and its background, and the speed at which the detail must be seen, and the accuracy of perception demanded, and on the eyesight of the individual. The relationships between relative visual performance and illuminance for different angular sizes of the task is illustrated in FIGURE 20.

It will be noted with poor contrast and small apparent size, visual performance is much lower than with good contrast, regardless of illumination levels. Increasing contrast in circulation areas by measures like edging steps in white, is one of the ways of improving safety in circulation areas. Classifying tasks in this way, enables recommended illuminance levels for different tasks to be established on performance grounds. There are other factors besides indoor task illuminance assessed by people. Windows as the link to the outdoor light may set up internal brightness patterns that become unacceptable, especially in deep poorly lit spaces. In deep airconditioned office buildings, this problem has been increasingly countered by the use of external facades using reflective glazing or heavily tinted glazing. In buildings with poorly conceived daylighting systems people often put on artificial lighting to improve indoor-outdoor lighting contrasts.

Visual performance begins to deteriorate after the age of 40 at low lighting levels. The deterioration progresses with age. Older people adapt less quickly to changes in brightness. As the lens becomes more opaque, there is more scattered light in the lens, and this tends to veil the image. Glare free lighting becomes more important. This has to be considered in the design of lighting spaces for the old. Given good

lighting, and suitable glasses to allow for growing lack of accommodation, performance handicaps can be minimized. At 100 lux illuminance of a kitchen there was very little difference in visual performance between a group 18-20 years old and a group above 60 years old (McGuiness et al. 1983). The effect of illuminance on performance in relation to age are shown in FIGURE 21. Specialist knowledge on lighting to help people with visual disabilities is available in the scientific literature (Boyce, 1973; Julian, 1984). Visual performance is closely related to the topic of eye strain (Weston, 1962). Symptoms include disturbances such as hazy or blurred vision and colour fringing of objects. The failure of steady convergence causes a running together and confusion of visual impressions, which may lead to actual giddiness and sickness. Ocular symptoms include bloodshot eyes, reddening and inflammation of the eyelids, and watering of the eyes. Systemic symptoms include headache, but are not necessarily accompanied by pain in the eyes.

The daylight outdoors varies considerably with weather, and with solar altitude. In clear sunny weather, the illumination produced by the direct beam with a high sun on an unobstructed horizontal surface is typically about 5 - 8 times as great as the diffuse illumination from the blue sky alone. The greater the solar altitude, the greater is the typical level of clear sky horizontal illuminance. Full sunlight, with a high sun around 60 degrees elevation, can produce outdoor illuminances on horizontal surfaces exceeding 100000 lux. When the sun is at altitude of 15 degrees, the beam is less strong and also incident much more obliquely, and the light from the clear sky is also much less. The typical horizontal illuminance then falls to about 20000 lux. At this low solar altitude, the illuminance on a vertical surface facing the low sun will be around 50000 lux.

Overcast weather eliminates the direct beam. The illumination of a horizontal surface depends strongly on the cloud type and cloud thickness (Kittler, 1981). For the thicker cloud types, the illumination of an horizontal surface has values of the same order as the clear blue sky. Thin high clouds can produce much higher diffuse sky illuminances than the clear blue sky, sometimes about 5 times as great. Such skies can become quite glaring. In high latitudes, with the sun above the clouds at a solar altitude around 15 degrees, the representative overcast sky illuminance for lower cloud types on an unobstructed horizontal surface is about 5000 lux. This value is often used as a norm value in design setting. When the solar altitude reaches 60 degrees with a densely overcast sky illumination is around 15000 lux, with thin cirrus clouds of over 50000 lux. Partially clouded skies are often much brighter than either clear or overcast skies. The surface of edges of clouds in the vicinity of the sun can be especially bright, and often a significant cause of glare. Under partially clouded conditions, the direct beam illuminance oscillates in value as clouds pass the sun. The direct beam is of course highly directional, and
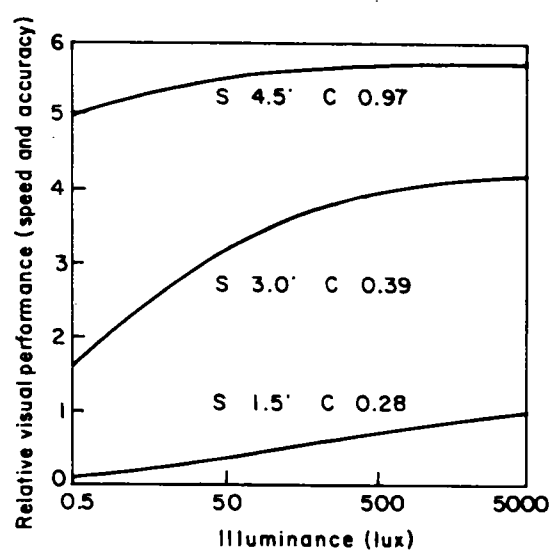
Fig.20:- The relationship between visual performance and
illuminance for different values of apparent size, S
(in minutes of arc), and luminance contrast, C. $[C=(LI-L2)/LI$,
task = luminance LI, background = luminance L2$]$.(Source:CIBSE
Code for Interior Lighting, 1984).

Fig.21:- Model of the general relationship between visual performance
and illuminance for three age groups, young, middle age and old.
At high levels of illuminance the visual performance of the three
groups is very similar. At low illuminances there are very big age
differences in performance. (Source: Boyce (9)).

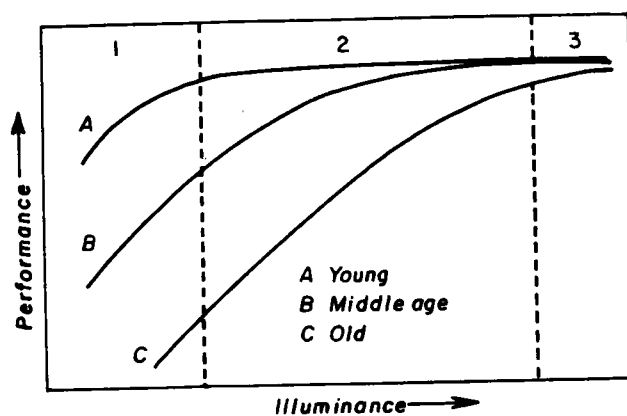will illuminate the surfaces facing it the most intensely. Such surfaces can be made light in colour to reflect diffused sunlight into buildings on those facades which face away from the sun. The luminance of the ground depends on the reflectance of the ground surface. Snow produces the greatest ground luminances, because in the clean condition, it reflects over 80% of the incident light. Desert soils can also be light in colour, and very dazzling. Ground covered with green vegetation only reflects about 10% of the light incident. Vegetation is considerable more reflective in the infrared region, not perceived by the eye. Urban pollution reduces the sunlight beam illuminance, and also the typical horizontal surface overcast sky illuminance, but tends to raise the brightness of the cloudless sky due to the increased light scattering by the aerosols. Pollution of the air will affect the colour of the skylight. The light reaching the facades of buildings is very much reduced by urban obstructions. Landscape features like trees and steep ground can also reduce daylight availability at building facades.

The daylight reaching vertical facades of buildings may come from four sources, the solar beam, the sky, the ground, and also from obstructions above ground level, for example opposing buildings, and courtyard walls. It is the function of urban planning to ensure, adequate daylight and sunlight remains available at building facades after development. Such hygienic norms for insolation and daylight play an important part in regulating the town planning pattern, since they determine, although indirectly, the density of town development, and the size, and structure of land parcels surrounding buildings.

The amount of daylight available indoors from the sky is nearly always substantially less than the amount of light available from the unobstructed sky outdoors, because much of the sky is usually obstructed by the opaque enclosing elements. The enclosing elements through which light can pass, form only a small proportion of the surfaces of the room. The problem is to ensure the entry of enough light inside without the rooms becomes overheated or undercooled. Entry of sunlight has to be controlled in the interest of good daylighting and, depending on season, of thermal comfort. Sun protection systems must be considered part of the daylighting system, as well as part of the thermal control system. The daylight from the sky is reinforced by the daylight externally reflected from the ground, which, in sunlight, becomes a very important source of light for indoor daylighting. Adjacent buildings can reflect light in significant quantities. The intensity of the direct light beam indoors is only slightly reduced by normal clear glazing. Indoor patches of sunlight tend to remain very bright, and are often in strong contrast with their immediate surrounding areas, directly lit by only a small part of the sky. Such strong indoor contrasts make task performances difficult.

The daylight illumination available at any point in the room can be expressed as a ratio to the external illumination falling on an unobstructed horizontal surface at that same time. By international convention, sunlight is excluded, in the definition. Under overcast conditions, typical levels of daylight at visual working levels indoors are around 0.5% to 5.0% of those measured outdoors. The outdoor-indoor illumination ratio is called the daylight factor, DF. The daylight factor is influenced by the size of the windows, the proportions of the room, and the colour of the internal surfaces. Close to windows, the DF values may be appreciably higher than in the depth of the space. High ceilings assist daylight penetration. Internally interreflected daylight increases the illumination and reduces contrasts between vertical window, if internal finishes are light in colour. High internal reflection also helps to carry light to the back of the room and even out the internal illumination levels under daylit conditions. It also helps reduce aperture in the facade and the immediate window surround, so reducing discomfort glare.

External obstructions exert an important influence on indoor illumination. An improvement in daylight with heavily obstructed outside windows will result if the obstructing surfaces are made light in colour to reflect daylight to the window. One of the objectives in setting planning layout space standards to ensure adequate daylight is actually available at the external facade. The building designer can then provide appropriate pass through daylighting elements in the wall to achieve required indoor daylighting. Spacing of buildings becomes more important as the latitude increases, because the mean solar altitude, especially in winter, becomes far lower, so the amount of daylight available in winter on obstructed sites becomes substantially less.

Top lighting

In the case of top lighting, the indoor lighting levels are usually more uniform across the indoor space, provided the pattern of openings is well considered. In high latitudes it has been found people tend to keep the lights on all the time in top lit buildings regardless of external horizontal illuminance, if the daylight factor is less than 2% (Lynes, 1968). This is probably indicating the perceptual judgement of luminosity is the key comfort factor. The contrast between the skylight and the inside surface of the roof is strongly influenced by the reflected light from the floor, and hence by the product of the floor reflectance, the ceiling reflectance and the average daylight factor on the horizontal working plane close to the floor. It is important that light colours should be used in ceilings incorporating roof lights to reduce contrast. If the assumption that such situations are governed by perceptual assessments, is true, then the daylighting standard for top lighting should not be adjusted downwards below the limiting figure of 2% to allow for the greater illumination from the tropical sky. The glazing material should always be

translucent and diffusing rather than clear both to diffuse the direct solar beam to avoid patches of sunlight, and to prevent people being overheated by being directly irradiated by sunlight. In high latitudes the minimum recommended design daylight factor for top lit factories is typically set at around 5%, but this value could sensibly be reduced for climates of high average external illuminance by half or more. The heat gain: loss characteristics summer: winter are especially bad for horizontal glazing. This daylighting route should be considered as an option for meeting natural lighting requirements that must be carefully controlled in maximum extent, as oversizing roof apertures beyond the minimum requirements for satisfactory daylight illumination, will have serious consequences for summer overheating.

Based on theoretical studies of top lighting for airconditioned building at mid latitudes, Treado et al. (1984) have concluded:

1. Skylights are the most effective fenestration options in of terms of minimizing total building energy for heating, cooling, and lighting, with 2% of roof area being the optimum size.

2. Skylights are the most effective daylighting source reducing electric energy by as much as 77% compared to the non-daylighting cases.

3. For any fenestration area, the use of daylighting reduces total building energy as compared to the non-daylighting case.

4. Clerestories are more effective than side wall windows of the same size, both as daylighting sources and in terms of total building energy.

Climatic influences on daylight design

Different approaches to the design of daylighting systems have evolved in different climatic regions to meet the range of visual needs discussed above (Kittler and Ruck, 1984). In the USSR light climates are defined and laid out as map of daylight climate zones. It is essential to pay due regard to the existing local traditions of daylight design in making new recommendations about appropriate fenestration arrangements for dwellings of different types. In domestic dwellings, four main specific climatic conditions and derived determined strategic approaches to daylight design have been suggested:

(1) **High latitude cloudy climates.** Daylight design is dominated by the high prevalence of overcast days, typically in winter (Kittler, 1981). People feel a need for light in winter and expect to have reasonably large windows. Summer conditions tend to be mild,

and hot weather relatively infrequent. People will accept some overheating indoors in summer, as, during such weather, they prefer to be outdoors. This is a different for office, school, and factory buildings with a higher priority for work situations than in domestic situations in these regions. Any sun controls over windows need to be moveable, so adequate daylight is still available during overcast weather. Wind produces problems in the economic design of adjustable external shading devices. Solar blinds tend to be placed in the less efficient indoor position, or between two sheets of double glazing, which is considerably better. Adjustable solar blinds are unsuitable because of the changeable weather.

(2) **Medium latitude Mediterranean climates with a relatively hot summer.** Hot summers make effective shading mandatory. Adjustable shading is still desirable during the winter period when the weather may be dull for quite long periods. The peak wind speeds are often low enough to make it economic to use external shading systems, set in the plane parallel to the window, or offset from this plane at an angle to allow better ventilation, and also to allow for more ground reflected light to enter. Shading is often provided by moveable external horizontal slatted systems, which can be adjusted to allow some air and light to penetrate between the slats. During hot sunny weather, use is often made of externally reflected light. There is usually a sound traditional habit of opening and closing solar protective systems at the right time of day during the summer season. The courtyard house is an acceptable house form.

(3) **Lower latitude hot dry climates.** Daylighting design is influenced by the strong externally reflected sunlight component. Blue clear skies predominate in many seasons. The blue sky is usually not very bright, and in terms of internal visual luminosity, the external scene is dominated by reflected direct sunlight. The strength of the solar beam is often unacceptably high, so attempts are usually made to exclude the direct beam. Fixed shading must be designed on sound solar geometrical principles to be effective. Daylighting is essentially achieved by inter-reflection of sunlight from the ground and from adjacent buildings. Surface colours are often chosen to modulate the excessive brightness of the patched sunlight falling on external surfaces. With lack of trees the ground is seldom shaded, and becomes a dominant source of useful daylight for buildings, especially when the sun is high, and so only very obliquely incident on any insolated vertical surfaces. The windows are typically set high and shaped to give an acceptable indoor luminosity in conditions of brightly sunlit ground. A light coloured interior is also helpful to increasing the internally reflected component, so reducing the contrast between the window aperture and the view out. High windows allow good stack ventilation. They are set above the level close to the ground where most dust is circulating.

While light interior colours, unlike those on the external surfaces of buildings, play no direct role in lowering indoor temperatures, they do play an indirect role in enabling a reasonable indoor luminosity to be achieved with smaller apertures exposed to heat radiation from sun, sky and ground. The overall solar gain has to be accepted in order to achieve adequate daylight. The inward looking courtyard house provides a very acceptable solution.

(4) Lower latitude hot humid climates. The amount of clouds is often considerable, and bursts of sunshine and periods of sun obstruction intermingle as clouds driven by the wind pass overhead. The diffuse illuminance received from the sky is often very high under these conditions. The associated direct beam illumination of the ground and the brightness pattern of the sky oscillate in time and intensity. The clouds are often vertical cumulus clouds, whose sides become very highly illuminated by the sunlight striking them, and the consequent visual glare from the sky can be intense. Close to the Equator, there may be little climatic variation in mean conditions month to month, but always a change from moment to moment. The ground is not very bright because the ground is normally covered with vegetation, and frequently heavily overshadowed by nearby trees. Daylighting conditions indoors in such climates are often relatively poor. In low buildings, the light incident on vertical surfaces is often basically low due to obstruction by vegetation. The large window openings, for reasons of ventilation, are often set low in a situation of considerable daylight obstruction. Doorways are an important source of daylight, as they usually stand open, when the building is occupied. Overhangs are necessary to keep both the rain and the sun from entering the interior through permanently open windows and doors.

Where suitable opportunities are present, much residential life takes place on verandahs with substantial overhangs, on which good air movement is available with good daylighting conditions. The depth of the verandah tends to make the interior of the dwelling rather dark. For the required penetration of daylight a band of high placed fenestration is provided, set above the level of the top of the verandah. Placed in this position, quite a small area of glazing will suffice. The colour of the verandah floor, and of the underside of the verandah ceiling is particularly important in determining the amount of light redirected inward towards the interior of the building. As buildings rise out of the tree layer, the problems of glare become more acute. Methods for assessing geometrically the impact of trees have been developed by Sattler et al. (1987). The courtyard house is unsuitable because it does not provide for natural wind ventilation required for cooling.

Monsoonal climates have the features of a hot dry

climate at one season and of a hot humid climate at another. The daylighting solutions then have to consider both challenges. It is not easy to generalize across different climates about the correct daylighting strategies to pursue in different cultures. The key goal is finding comfortable all year round solutions. This involves the capacity to increase indoor daylight in some seasons, and to reduce it at other times to control visual glare and solar overheating. The starting point in making recommendations about daylighting in different climates and regions must be, to analyse the broad strategies needed in the context of local climate and culture, and then to assess how to apply these strategies to select appropriate daylighting design solutions (Kittler and Ruck, 1884). The cost of extra artificial lighting in badly lit interiors has to considered into any assessment.

Cloudy skies daylight design

The luminance of the overcast sky is not uniform. The preferred method for the definition of illumination climates for design purposes in different locations is the classification of cloud amount. It is useful to start by classifying the relative frequency of occurrence of the three basic types of sky: cloudless sky, partially clouded sky, and overcast sky in different months of the year. Cloud observations offer the best way of doing this. In Australia, Ruck (1985) classified site illumination climates on the basis of their morning cloud observations, using three categories, clear (0 or 1/8 cloud), partly cloudy, (2/8 to 6/8 cloud) and cloudy (7/8 to 8/8 cloud). In tropical climates, the cloudiness may show very big variations from month to month, as the inter-tropical convergence zone oscillates in its position according to season. In Darwin, N. Australia, in February 93% of mornings were cloudy, 7% partially cloudy, and none clear, while, in August, 71% of mornings were clear, 29% were partially cloudy and none were cloudy. In Perth, W. Australia, with its maritime location on the Indian Ocean, partially clouded skies dominate throughout the year, with a 50% to 60% frequency, but in some months the predominant residual fraction is clear, October to April, and in the other months, the predominant residual fraction is cloudy (Ruck, 1985).

Another basis for preliminary analysis is daily sunshine data. In Glasgow, Scotland, there is no bright sunshine on 49% of the days in January, compared with only 4% in June. This is a daily statement of conditions, and not an instantaneous relative classification, as in the case of cloud amount. Such a preliminary analysis will indicate the daylighting design priorities between overcast, partially clouded and cloudless conditions objectively, and so indicate the primary design goals and the illumination data requirements needed to support daylight design in any specific area. Data for partially

cloudy skies may be needed in one season, and for overcast skies in another. Situations where clear sky daylighting design techniques should be adopted, will be thrown up by this relatively simple analysis. Provided the meteorological cloud data base is kept on magnetic tape, it is a relatively simple task for a national Meteorological Service to provide the purpose orientated seasonal assessment of data.

The daylight levels outside are constantly varying, so it is usual to state indoor daylighting standards as ratios to the external horizontal illuminance. The original work on daylighting standards was confined to overcast skies, a situation in which there is no direct beam sunlight present. In all the definitions that follow, sunlight, both direct and interreflected, is specifically excluded. It is normal in setting daylight standards to define a working plane on which the standard should be achieved. This is normally a horizontal surface set at normal table height, around 0.8 m. The overcast sky daylight factor on the working plane indoors has three components: a sky component, an external reflected component, and an internally reflected component. The brightness distribution of typical overcast skies was found to be similar in a range of different climates. A standard luminance distribution for the overcast sky has been internationally adopted by the CIE, defining the appropriate luminance to be used for overcast sky design.

Cloudless sky daylight design

There are many areas of the world, where daylighting design is dominated by cloudless sky conditions, and where reflected sunlight becomes the critical main daylight source, and where, in contrast, the brightness of the blue sky is both relatively low, and highly directional in relation to the position of the sun (Page, 1986; Tregenza,1982)). The pure blueness probably can be exaggerated, especially for inland continental situations in dusty climates. New daylighting research led on the international standardization of the relative luminance distribution of clear skies based on work of Kittler (1981). Many tropical blue skies are in fact brighter than was assumed earlier. In desert areas, the dust burden often contributes substantially to scattering, while, in more humid areas, suspended droplets of water scatter light, producing whitish blue skies. In using the CIE clear sky luminance model, it was assumed the direct beam sunlight would be shaded out, so the basic definitions could be left unaltered, provided the beam illumination effects on ground and on external obstructions were properly considered. Procedures for quantitatively assessing the geometry of sun patterns in courtyards by Mohsen (1979) show how complex these patterns are. The clear sky design problem is still not satisfactorily resolved for day to day design purposes. An important design variable is the

reflectance of the ground, which may vary from about 10% for watered landscaped surfaces and asphalted roads to 40% or more for bare sandy surfaces, and over 80% from clean snow. Assessments also have to be made of typical external surface reflectances of surrounding buildings for quantitative design to proceed.

Daylighting design in the USSR aims to provide adequate amounts of lighting in line with the visual purposes for which the building is to be used, to increase safety by appropriate lighting, to control excess light, and to avoid disability and discomfort glare. The sun can be a very important cause of disability glare. All living quarters and kitchens are required to have natural light. Provision of daylight is required in hotel and hostel rooms and corridors, and in service and recreational rooms. Indirect daylighting or solely artificial lighting is allowable in bathrooms and lavatories of residential apartments and hotels, and in washing and ironing rooms.

In residential buildings, daylighting is normally provided from laterally placed windows. The windows are sized on the basis of the minimum acceptable daylight factor, defined, as the ratio between the internal illuminance at a given point, and the simultaneous external illumination on an unobstructed horizontal plane. Special norms regulate the minimum permissible level of the daylight factor estimated at a point 0.8 m above the floor at a distance of 1 m from the wall opposite to the daylighting apertures. The daylighting norm required depends on the purpose of the space, on the orientation of the daylighting apertures, and on the external light climate at the location of the building. Basic information is taken from maps of daylight climate zones. The acceptable value of the residential daylight factor stands at 0.4% to 0.5%, and the optimal value at 0.5% to 1.0%.

At early stages of design, the ratio of the daylighting aperture area to the floor area, defined as the "luminosity factor", is applied to estimate the adequacy of the daylighting apertures. The surface area of the balconies adjoining the light apertures is included. The luminosity factor can only be used for the preliminary approximate evaluation of daylighting, because it takes no account of light losses caused by the design of the lighting apertures, of shading from opposing buildings, and the shape of the building itself. As a rule of thumb, the ratio for kitchens and living rooms should be between 1:4.5 and 1:8 according to region. the calculated area of the space. There are norms for the width of the solid spaces, separating the window apertures from the cross walls. This distance should not exceed 1.4 m, except in situations with windows in both walls of a corner room, to avoid dark areas close to the junction of the window wall and the cross wall. Rooms in residential buildings should not exceed a 6 m depth, and the room depth should not exceed double the room width, the depth of any bay window being

excluded.

As one of the aims is to achieve good daylighting without excessive overheating, it is important to provide guidance on the best orientation of daylighting apertures (FIGURE 22). At low latitudes, the biggest solar beam impacts fall on east and west facing windows, which are also the most difficult to shade effectively using overhangs. A strong preference must be expressed, in such low latitudes, for windows facing north or south. These apertures can be shaded with modest overhangs. When the sky is overcast, the illumination falling on differently orientated facades is, to a considerable extent, equalized. In courtyard situations, when use is being made of reflected sunlight from the ground and enclosure, outside the tropical belt, 23 N to 23 S, the ground on the equator side will be sunlit throughout the day in the winter half of the year from 23 September to 21 March in Northern Hemisphere, and from 21 March to 23 September in Southern Hemisphere. On the east and west sides the ground can only be sunlit for half the day throughout the year. Back reflection of sunlight from courtyard walls is considerably obstructed by the building itself, as the sun is low when it is in a westerly or easterly direction. A polewards facing window can receive considerable reflected sunlight from a courtyard wall opposite for quite a substantial proportion of the day. The techniques of Mohsen (1979) allow a detailed geometrical analysis to be made of precisely where the sunlight patches in courtyards are falling in practice. Further modifications can be achieved by using deciduous vegetation, vines, etc, to allow greater daylight penetration in winter than in summer. The issues of preferred orientation of daylighting apertures are regional, and need to be explored on a regional basis.

In the USSR the minimum norm for the daylight ratio for stair wells is 1:8. Corridors should have a ration >1:16. The length of corridors with daylighting at one end sections should be >20 m, with daylighting at both ends >40 m. For longer corridors, additional lighting should be provided by expanding the corridor beyond the outer wall to create a lighting hall way. The distance between hallways, or the distance between the hallway and the end window apertures, should not exceed 20 m. The width of lighting hallways should not be less than half of it depth, excluding the width of the adjoining corridor. The length of internal corridors and hallways without daylight should be <12 m. To conserve external daylighting availability, trees with large crowns, should not be planted at a distance of less than 10 m from house facades. The internal design of the rooms should allow for a suitable layout of furniture with respect to the available daylight. High furniture, thick bulky curtains, and large plants will obstruct the daylight. In light deprived climates, the space close to the window is particularly valuable for illumination. Provided the windows are properly insulated and close tightly, it is a suitable area for

childrens' play and studies, and infants can be placed by the window to obtain light in winter. The reduction of light transmission through uncleaned windows is 30 to 50%. Double glazing only allows about 65% of the incident daylight to penetrate, through not clean windows. Windows require cleaning about three to four times a year externally and about twice a year internally.

Normal window glass filters out the majority of the incident ultraviolet light. Only a very small proportion of the external UVB penetrates through normal window glass and translucent and transparent plastics to the interior. Comparative outdoor-indoor measurements in Moscow are presented in FIGURE 23. No UV radiation below 320 nm was detected, and the UV-A was many times weaker than that found outdoors.

UV radiation absorbing glazing materials offer the benefit of reducing the UV bleaching of fabrics and indoor decorations. There is a distinct possibility that short wave violet and blue light in the wavelength range close to the UV radiation confers biological benefits, through photochemical reactions at the body surface (Steck,1982). A great deal of the natural light at these short wavelengths comes scattered from the sky, and ground rather than in the direct beam. The biological exposure of man to such wavelengths indoors will be maximized with high internal daylight factors.

Normal indoor lighting sources produce very little UV light. The UV irradiation dose under an illumination of 1000 lux from typical fluorescent lamps during 240 8-h working days is equivalent to 12 summer 1-h outdoor days at 1500 m in Davos, Switzerland (Steck,1982). The UV characteristics of different types of electric lamp are discussed in WHO-EHC 14 and Sliney (1982). A risk of skin cancer in persons working in offices illuminated with fluorescent lights is most unlikely, because such persons receive the critical UV radiation dose when they are outdoors (Beral et al. 1982). In light deprived climates, attempts are often made to compensate for UV deprivation by artificial means, using suitable UV lamps and a controlled exposure. In the USSR contemporary UV radiation sources include multifunctional lamps that enrich the artificial luminous flux through the provision of an ultraviolet component.

Standards for sunlight availability

There is a need to regulate the availability of sunlight in urban development. Insolation standards determine the spacing of urban building layouts. Sunlight influences both the external environment and the internal environment. If no sunlight reaches the external environment around buildings, the dark
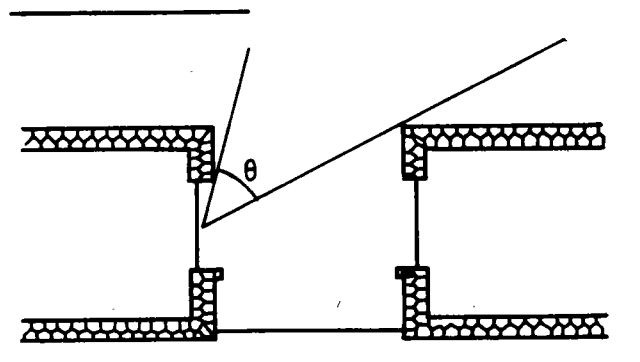
Fig. 22 :- Definition of the sky angle subtended at a window for
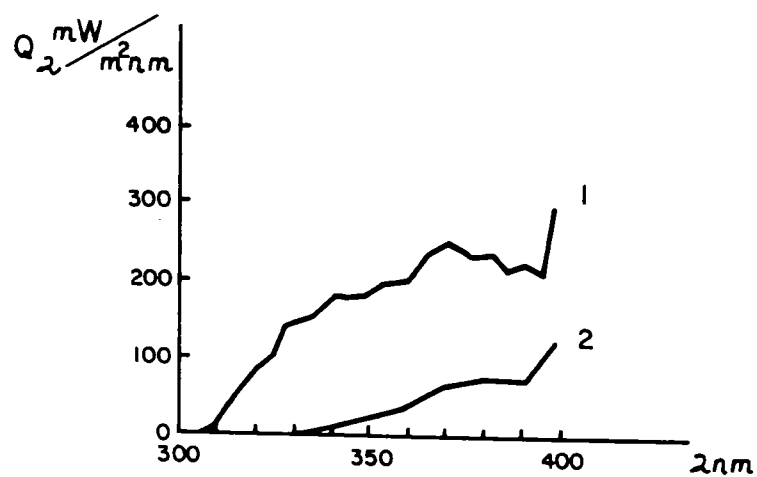approximate estimation of average room daylight factors.

Fig. 23 - Spectral distribution of global horizontal solar radiation under cloudless sky conditions, Moscow: 1. Outdoors: 27 degrees solar altitude, bearing due south; 2. Indoors: 1·5 m from a south facing double glazed window. (Source: Garadzha and Nezval, 1987).

outdoor spaces easily become dank and infested with undesirable flora and fauna. Biological decay is slowed, and cleanliness deteriorates. The evaporation of standing water after rain is hampered, causing an unhealthy deterioration of the state of ground, and offering opportunities for insects, like mosquitoes, to breed. Direct sunlight aids external sanitation like laundry dries more effectively and hygienically. Direct sunlight indoors exerts a bactericidal effect, promotes cleanliness through improved perception of dirt and dust. In hot climates, sunlight has to be carefully assessed, as it is the primary cause of severe indoor overheating, in norther climates with winters short of light, sunlight exerts an important influence on mood. In hot climates, it is best to make use of the sanitary benefits of sunlight early in the cool part of the day, before temperatures rise. Morning airing of rooms can provide both light and fresh air for an hour or two, before the necessary closure precautions against the rising heat and intense UV radiation of the day have to be taken. In humid climates, early morning sunlight is useful to promote evaporation of water accumulated overnight in hygroscopic materials like bedding, and clothing. Exposure to easterly sunshine in such climates is often welcome. Westerly exposure to sunlight in hot climates is always unwelcome, because the high solar energy inputs occur at the hottest time of day, further increasing thermal discomfort.

In major cities a compromise between the hygienic needs and the lack of available space for housing construction is mandatory. A tendency towards decreased insolation levels has been observed, particularly in major cities in the USSR. In the latitude zones of the USSR the minimum required insolation duration for buildings should be 2.5 to 3.0 hours, where ever possible 4 hours. The astronomical factors have to be considered. The standard is based on reference dates for three latitudinal zones: in the Northern zone from 22 April to 22 August, in the Middle zone from 22 March to 22 September, and in the Southern zone from 22 February to 22 October. The reference dates are chosen to be symmetrical about the summer solstice. The UK residential insolation standard for a range of latitudes close to the USSR Middle zone is also 3 hours sunshine with an altitude above 10 degrees, with a norm reference date of 1 March. As the sun rises progressively higher towards mid-summer, provided the design norms are met at the beginning and the end dates of the specified period, the minimum insolation standards are normally reached for the whole period. An exception occurs, when the insolation standard is achieved through gaps between exceptionally tall buildings, as the midsummer sun traverses horizontally at the fastest rate.

In major cities of the USSR, the norms allow the insolation pattern to be intermittent, provided that, with single >1-h sunshine interruptions, the established overall duration is achieved, and one of the insolation periods continues for at least two hours. In residential and municipal buildings, a reduction of the overall insolation period down to 2.5 hours is permitted on the condition that full natural value artificial lighting is provided. This exception does not apply to schools, childrens' institutions, and institutions for medical care.

Standards for artificial lighting

Lighting recommendations for a large number of indoor activities are contained in the Guide on Interior Lighting (CIC, 1975), based on the criteria:

1. Illuminance;
2. Directionality of lighting on the task;
3. Discomfort glare; and
4. Colour qualities of light sources.

In setting illuminance recommendations, the CIE distinguishes 9 categories of visual task or activity. These are set out in TABLE 16. For each category, three illuminance values are given. The middle one is the recommended illuminance value. The higher value is to be used when visual conditions are critical for accuracy, productivity, avoidance of errors, or where the task presents unusually low reflectances and contrasts. The lower value is considered acceptable, if speed and accuracy are not particularly important, the task is only carried out occasionally or the contrasts are unusually high.

In the USSR the optimal illuminance for office work is 500 lux for people of normal eyesight. For people with impaired vision, and for persons aged over 40-45 years, the optimal level is double at 1000 lux. The illuminance levels for class rooms of school are >500 lux. Illuminance levels below 200 lux are not sufficient for maintaining a high degree of visual activity for any considerable period of time. Increase in electric illumination through regulatory means provides a totally inadequate means for compensating for low daylighting standards. A artificial lighting step increment of 300 to 400 lux is very small compared with the levels of the missing daylight.

In various countries the artificial lighting levels are often set forward by the lighting industries. Such proposed standards do not always take adequate account of other factors like the climate, affordability of lighting in different economies, the impact of high lighting levels on the indoor thermal environment, and especially the lighting impact on airconditioning loads. Reasonable artificial lighting standards in different climates and economies need to be both affordable and thermally realistic. The use of efficient light sources and efficient light fittings helps bring higher standards at lower costs. As FIGURE 20 shows, if the visual task only involves large objects and good contrast, the performance penalties for a reduction in light standards

Table 16

Illuminance Standards recommended by the CIE (1975)

Range of illuminance lux	Type of task or activity
20 - 30 - 50	Outdoor entrance areas
50 - 75 - 100	Circulation areas, simple visual orientation or short temporary visits
100 - 150 - 200	Rooms not used continuously for working purposes, e.g. industrial surveillance, storage ares, cloakrooms, entrance halls.
200 - 300 - 500	Tasks with simple visual requirements, e.g medium machining, lecture theatres.
300 - 500 - 750	Tasks with medium visual requirements, e.g. sewing, inspection and testing, drawing offices.
750 - 1000 - 1500	Tasks with difficult visual requirements, e.g. fine machining and assembly, colour discrimination.
1000- 1500 - 2000	Tasks with special visual requirements, e.g hand engraving, inspection of very fine work.
>= 2000	Performance of very exacting visual tasks, e.g. minute electronic assembly, surgical procedures.

are very slight. If the objects to be seen, are small and the contrasts poor, then the economic penalties for accepting low illuminance standards become very considerable. Efforts are needed therefore by specialists in different economies to define appropriate local national standards for artificial lighting in buildings, incorporating different types of activity.

The electric lighting requirements in residential buildings in the USSR call for purpose sufficient, flexible, and glare free lighting. Lighting installations must be electrically safe; they should not pollute the indoor environment with noise or fumes, like kerosine lamps and wax candles. It is best to consider lighting in terms of functional zones. Only specific work places, such as desks, needlework tables, and preparation areas in kitchens, need lighting of higher intensity. Visual work performed by one member of the family should not interfere with the leisure of others.

Special attention ought to be given to the appropriate illumination of the places in the room where school children do their homework. Inadequate lighting may lead to short sightedness and bad posture. Table or appropriately fitted wall lamps should be used for lighting desks, preferably adjustable, to provide maximum light on the desk, while the eyes are protected by the opaque shade. Depending on the location of desks artificial lighting, as for daylighting, should be incident on the task from the left and front, so there are no shadows from the hand, pen or pencil. In the USSR the average level of the general lighting in residential buildings ought to be at least 100 lux with all the fittings operating other than table lamps and standard lamps. The recommendations of localized lighting for various functional zones in residential buildings are: 300 lux for desks, 200 lux for meal tables and periodic reading in arm chairs, and 400 lux for needlework. In kitchens, the minimal level of the illuminance should be 100 lux. This should be topped up with additional lighting over the cutting areas, and also the sink to raise the illumination to 200 lux. In stair cases, lift halls, corridors, bathrooms and lavatories, illuminance at floor level should reach 50 lux. Additional lighting is desirable near mirrors in bedrooms and bathrooms. Electrical wire safety is particularly important in areas with water taps. Light fittings in bathrooms and shower rooms should be mounted high, preferably on the ceiling. Special fittings to increase electric safety are appropriate. Some countries require cord operated ceiling switches for safety in bathrooms.Important sources of technical information on daylighting.

The technical issues involved in daylight assessment are well set down in detail in BRE (1986), BSI (1964), CEC (1989), Chauvel et al (1982), CIBSE (1984, 1986, 1988), CIE(1970, 1973, 1975, 1980), IDC (1984), ISC (1968), Page (1986), WHO-EHC 14, UNCHS (1989). A most useful document to study currently for developing country situations is the German DIN Code

on Daylight (DIN, 1983 and 1985). Examining a high latitude daylighting code in a different context it has important limitations for tropical situations. Relatively little daylighting research has been carried out at lower latitudes. From the international point of view the CIE recommendations and standards are basic with new updating work in progress. New versions will remain biased towards high latitude experience because of current lack of information on low latitude daylighting concerning the adequacy of indoor daylighting of buildings of different types in situations where strong natural cooling demands dominate, and where windows are heavily shaded.

Defining daylight standards

The definition of design performance standards is critical in all fields of building (Robbins, 1986). Daylight standards may be established by one of two basic approaches: the psycho-physical approach, and the visual task performance approach.

The psycho-physical approach is based on the systematic study of the reaction of experimental subjects to specific visual environments. People are asked to judge their visual environment on a voting scale, in some properly designed psycho-physical experiment (Seidl, 1979, 1984). In Berlin, Germany, the judgements were influenced by time of year. More light was expected in summer than in winter, a finding which indicates the daylight factor and not the absolute level of daylighting is a key variable for the psychological perception of the adequacy of the daylighting arrangements in buildings. By studying statistically the balance point between too dark and too bright, the required average illuminance levels at reference points were:

-170 lux at the time of the summer solstice,

-110 lux at the equinox,

-40 lux at the time of the winter solstice.

To secure adequate daylight conditions in living rooms considering window height, window area and window width DIN 5034 Part 1 states:

-the average of the daylight factors of an overcast sky measured at the two reference points should at least equal 0.9%.

-the window head height should be at least 2.20 m above floor level.

-the width of the transparent part of the window (or the sum of the widths of all existing windows) should be at least 55% of the room width.

-the top edge of the sill should be no more than 0.90 m

above floor level.

DIN 5034 indicates the same standards apply to work rooms of similar dimensions to living rooms, i.e. height of room less than 3.50 m, depth of room less than 6.0 m. and area of room less than 50 m2.

Experience certainly indicates kitchens require good standards of daylight for visual task reasons. The European standards favour equal illumination for daylighting bedrooms and living rooms (Chroscicki, 1980).

It is not known to what extent do these subjective psycho-physically based standards apply to other regions of the world where the sun is higher, and where there is much more light. The reliability of extrapolations cannot be encouraging because of the impacts of local climate on window design. Thermal expectations intermingle strongly with lighting expectations. People used to hot climates have different perceptions of desirable indoor environmental conditions to those of people used to cold climates. In hot climates, the interactions between thermal perceptual experience of radiatively overheated rooms and visual perceptual experience are likely to interact. The visual standards may be corrected strongly downwards the minimum window areas securing proper thermal conditions. The application of psycho-physical techniques to establish daylighting standards is obviously repeatable in different climates, and will produce different recommendations according to climate and custom. The short term answer is to study existing local experience concerning what currently seems perceptually adequate and inadequate in daylighting terms in the context of the local climate and culture, and then to incorporate that experience in simple design recommendations.

The traditional scientific method for establishing indoor daylighting standards is the task illuminance approach. This approach to daylighting standards in high latitudes was based on the adoption of a standard reference value of the illuminance from the overcast sky, representative of the external design conditions in the duller part of the year. The choice was thus biased towards the winter overcast period, with a relatively low altitude sun. The value generally used in N. Europe was 5000 lux. It now has particular relevance in situations where artificial lighting is controlled by photocells, which bring in or modulate the artificial lighting when the daylighting level at the task reference point falls below some preselected task illuminance level. The control level has to be preselected to meet the recommended task illuminance for each specific activity, the finer the visual detail and the poorer the contrast, the greater the required illuminance. In deep sidelit rooms, this approach may not bring the degree of user satisfaction hoped for, because building occupants often use their electric lighting to reduce discomfort glare luminance on bright days.

Cross comparison of UK recommendations based on an external illuminance of 5000 lux and the Berlin recommendations based on psycho- physical findings have been initiated. If the relationship between solar altitude and typical overcast sky horizontal illuminance can be established, an alternative approach can be adopted. One can calculate the typical times of day at which the overcast sky task illuminance will fall below the minimum criterion level for any specified daylight factor Krochmann and Rattunde (1980). This process can easily be carried out too for tropical areas which encounter significant periods of overcast weather, providing a representative mean overcast sky model can be achieved to relate the representative horizontal overcast sky illuminance to solar altitude. In Europe, a formula of Krochmann (CIE, 1980) has been found representative, but the formula is not properly tested for low latitudes. At a typical midwinter noon solar altitude of 13 degrees in Northern Europe, the formula predicts an overcast horizontal illuminance of about 5000 lux. At low latitudes the sun is higher, so the mean illuminance levels are greater. When using a task illuminance basis it would not be unreasonable in those low latitude areas where daylighting standards are to be based on overcast conditions to assume a representative overcast day horizontal illuminance of 10000 lux. This value is associated with a solar altitude of approximately 30 degrees. One cannot proceed very far in this downward direction without running into subjective luminosity and glare contrast problems. Overcast sky daylight factors below 0.5% are always likely to produce some dissatisfaction. On grounds of acceptable subjective luminosity and acceptable task illuminance in conjunction, it is suggested that the room average DF level of 1% used to define a marginally daylit space, cannot be adjusted further downwards at lower latitudes to adjust for the greater horizontal illumination available, without encountering serious luminosity problems. The top value of 5% for a well daylit space could be adjusted downwards to allow for the greater horizontal illuminance externally available, which will result in a greater task illuminance being achieved for a given daylight factor. Tentatively, the reference values for low latitudes might be set at 1%, 1.8% and 2.5%.

Another traditional method is the use of average daylight factors. The conventional specification of daylight factors implied the use of point by point calculation methods, which can be quite time consuming, and not suitable for early stages of window design, when many details have yet to be settled. Recently there has been a growing interest in the use of average daylight factors, as a simpler way for establishing standards. Essentially lighting energy balance methods are used (Crisp and Littlefair, 1984). A key variable with this approach is the ratio of window area to total room surface area, and not the conventional historic luminosity factor ratio of the window area to the floor area.

One current problem in standardization is how to interrelate the working plane average daylight factors to alternative existing standards like the daylight factor at the centre point of the room, the German DIN reference points, or the USSR 1 m from back of room reference point. Standards based on room average daylight factors have to take this factor into account, and the recommended minimum design values are set higher than those traditionally suggested using the point by point approach. The adjustment needs to be such that, if a full daylight design analysis is carried out at a later stage of the design process, there should be a convergence of recommendations.

In seeking to promote improved daylighting standards in the interest of human health and well-being, there are a number of technical issues that must be addressed, involving making recommendations on how to interrelate thermal aspects and daylighting aspects. There are also important institutional barriers to progress. The most critical is the current low priority given to systematic daylighting design by contemporary designers in most parts of the world. The study of the economics of daylighting has been neglected. Progress will depend on the local availability of suitable simple design tools for daylighting design, that are applicable to the various stages of the design process. These design tools must be related to the needs imposed by local climatic conditions. National Meteorological Services will have a role to play in the provision of appropriate data. One problem in practice will be how to reinterpret the technical requirements in clear simple terms for local use at different levels in the community. There is an important additional educational task to be set in train in this area.

Conclusions

A high priority should be given to visual aspects of indoor environmental design. The requirements of insolation standards and daylighting systems are strongly influenced by climate. Countries need to establish their own standards for daylighting and for sunlighting appropriate to their specific range of latitude and climates. These norms may vary considerably across a specific territory. Artificial lighting standards are mainly influenced by socio-economic considerations, rather than by climate. While it is important to assess realistically appropriate standards related to the actual circumstances of each community, this assessment must be carried with a proper awareness of the importance of lighting both for healthy living and for social development.

The needs of children, middle aged and old people need special consideration. Improved knowledge of the principles of healthy lighting would enable a lot more to be achieved with the same resources as at present. This is especially true of daylighting, which is free. Education, both at a professional and a community

level is needed. People need to be taught how best to look after their own visual health and visual well-being. Groups in the community caring for the aged need to be made far more aware of how to light for safety, to help the old with their visual disabilities.

The primary aim here is to suggest how to develop a regional daylighting design methodology, together with appropriate standards in developing country situations, that can be executed at a local level. It must be stressed, one is seeking recommended regional solutions to cover areas within specific countries having similar daylight and thermal climates, and norms may need to vary across national territories. The problems to be faced can be set down in order.

-Setting standards for daylight provision

-Quantitatively and qualitatively ascertaining the characteristics of the local daylighting climate

-Establishing daylight design assessment methods for :
(a) Overcast day conditions, (b) Cloudless sky conditions, and (c) Partially clouded conditions.

-Developing design aids to assist in practical daylighting design, both to help building designers find better daylight solutions, and to assist planners handle better the daylighting issues interlinked with town planning layouts, spacing and zoning.

These problems have to addressed at the local and international level. Computational design tools are available with which to attack the problem of daylight design aids.

Chapter 6

How to use this Guidebook

The Guidebook may be considered with regard to a statement by Dr Halfdan Mahler, former Director General WHO "We do not need just a little bit more health education here and a little bit more health education there; we need a new approach to public health action and we need a strong public health alliance to move us forward."

The primary target of this Guidebook, is to secure for a better state of health substantially improved indoor environmental conditions worldwide for people in dwellings. The health issues are related to the state of human physiological, perceptual and emotional well-being and to the causation of specific diseases. Human productive performance is strongly influenced by indoor environmental conditions. Preventive medicine should have a high profile in considering health goals for the indoor environment.

There are two main objectives in this Guidebook for the improvement of indoor environments. One objective is the achievement, by systematic and affordable means, of more satisfactory control of all recognized indoor health risks resulting from:

Adverse indoor thermal environments
Poor indoor air quality
Unsatisfactory indoor noise conditions
Unsatisfactory indoor lighting conditions.

The second objective is to provide, by systematic and affordable means, appropriate indoor conditions for effective human visual and auditory perception in conditions of thermal and respiratory comfort. This does not imply a constant environment.

Indoor environments have to be responsive to changes in needs across the course of the day and year, therefore recognition has to be given to the variations in perceptual and thermal environments required to match the diurnal indoor patterns of work, social activity, family activity and rest, essential for human health and well-being. This implies giving proper attention to issues of environmental controls to regulate the indoor environment to match present human needs. Such controls are often best operated by people themselves. Control in indoor environments is also strongly linked with economy of energy use in view of limited resources.

International policy issues

Within UN policy, four fundamental international strategic policy goals demand to be effectively interrelated:

1. A housing policy goal - acceptable shelter for all by the year 2000. The primary UN Agency responsible is UNCHS (Habitat).

2. A health policy goal - acceptable health for all by the year 2000. The primary UN Agency responsible is WHO.

3. An environmental policy goal - sustainable development without ecologically unacceptable consequences, like harmful pollution and global climate change. The primary UN Agency responsible is UNEP. The issues involved in this Sector were high-lighted by the World Commission on Environment and Development (WCED, 1987).

4. An world climate preservation goal - sustainable development without interference with natural climate. The primary UN agency responsible is WMO.

UNCHS considers as shelter not only the structural enclosure of an indoor living space, but also the provision of a healthy indoor environment that offers the occupants adequate protection against heat and cold, and that shields them from precipitation and winds, excessive sunlight, external noise, and external pollution. The concept of the house as a structural box, in which people and goods are kept, has impoverished the design of much low cost development in the world. The environmental basis of shelter must be given the prominence it deserves for the informal sector of the building economy as for the formal sector. The means of achieving the environmental goals may be very different in the two sectors, but indoor environment is just as important in both cases.

WHO is concerned with indoor health in all types of dwellings, and not just buildings. A great amount of the information in this Guidebook is applicable to dwellings of all types. The majority of people spend a significant proportion of the year in and around their dwellings. Their homes should be health promoting and not health undermining. This applies particularly to four especially vulnerable groups, who are identified throughout this guidebook:

Infants and young children

Pregnant women and nursing mothers

Elderly persons,

Handicapped and disabled persons.

WMO has a key supporting role in international policy. Outdoor climate is an extremely important factor conditioning the interactions between the above policy sectors. This Guidebook has attempted in each Chapter to explain the impact of the outdoor climate on indoor environments. Climate is also an important energy resource, used to improve indoor environments, in providing solar energy, light energy and wind energy. WMO is responsible for indicating to national meteorological services how they can best service those responsible for improving indoor environments with adequate quantitative climatic information to support successful planning, design and construction. Such information is needed both to design buildings to promote day to day health in them, and also to provide an adequate basis on which to design for protection from life and property threatening events like hurricanes and floods. The World Climatic Applications Programme, WCAP, established by WMO, aims to provide national meteorological services with appropriate methodologies for the effective application of meteorological data to development problems. The WCAP programme has produced material of considerable value for the support of the type of health based indoor environment programmes such as the Leningrad Conference on Climate and Human Health (WCAP, 1987), and the Mexico City Conference on Urban Climatology (WMO, 1986).

National policy issues

The Guidebook is aimed at professional personnel in Government Agencies having responsibility for policy and for setting standards and norms for the indoor environment of residential housing, schools, administrative buildings and others. This would include health, housing and planning agencies. The Guideline is applicable to personnel in agencies and groups responsible for increasing the awareness of improving indoor environment from the point of view of health, and improving the education of professional cadres associated with building education of the general public, and the education within in the health sector.

It is suggested that the first stage in using the information presented in the Guidebook is to implement effective nationally based measures and to improve health in the community through the achievement of higher health standards of indoor environment in buildings. This implies a need to identify, on a interdisciplinary, multisectorial basis, the interrelationships between planning for health and planning for development. It also requires establishing responsibilities for safe guarding the external

environment of buildings. The production of a national indoor environment health policy statement can then serve as the basis for attracting the consequent effective political and social support needed. Not only will the goals in different sectors of the economy have to be established, but the detailed methods for achieving those goals will have to be identified. This must include a review of the relevant existing administrative and scientific support structures. Their roles can be then expanded in a systematic way to meet the perceived responsibilities. The consequent issues of training and education will then need to be addressed.

Once the policy task is completed, it is obviously important to communicate this policy document as widely as possible. As policy development is an on-going activity, arrangements will be needed to maintain and develop the profile, so some standing policy organization eventually may be necessary. In health terms there will be two main goals:

(1) Setting policies to avoid ill-health due to indoor environmental conditions.

(2) Setting policies to promote well being and improved human performance through improved environmental indoor conditions.

These national goals will have to be reconciled with the primary goals of international development policy. Proper account will have to be taken of resource limitations in attempting to achieve better indoor environments for people. For this reason, a clear distinction has been made in each chapter between the requirements for acceptability and the requirements for full comfort. A clear indication has been given as to what indoor conditions are environmentally incompatible with human health. The priority in health policy for the indoor environment must be to attempt to eliminate, in all sectors of the economy, indoor environment conditions, which are incompatible with human health.

It is suggested that the policy statement in low latitude developing countries should take account of the very different policy issues involved in different sectors of the built environment. In discussing the needs of shelter, three sectors, each with its own policy priorities can be identified:

(1) The formal building sector. Health policy for the indoor environment for the formal building sector has an importance in its own right in setting standards. Standards in the formal building sector are also important as exemplars to the informal building sector. The formal sector is primarily based on the use of manufactured building materials, which must be manufactured to conform to proper health specifications in use. Centralized energy services like electricity for artificial lighting are normally available in

this sector.

(2) The informal building sector - urban

located. There is a need to judge indoor environment priorities in relation to urban health risks, experienced in the informal sector. The layout planning of informal settlements is critical, if control of adverse interactions between manufacturing industry, roads, waste tips, airports, mineral workings etc, is to be handled in ways that safeguard health. Preserving adequate space about buildings, to secure adequate daylight and natural ventilation, contributes very much to the quality of the indoor environment in such settlements, but is often very difficult to secure in practice due to land use pressures. Outdoor atmospheric pollution from a high concentration of indoor domestic sources can aggregate to become quite serious. Indoor air pollution from heating systems and especially cooking stoves, can be health threatening. Policy will probably need to consider what means of education of the settlement occupants are likely to make most impact. Cost effective demonstrations are often a good means whereby to promote progress. Construction is often based on the use of a combination of manufactured building materials, recycled urban materials and traditional rural building materials. Unsafe and unhealthy building materials practices may need identification. Centralized energy services often are not available. If they are, their capacity is usually very limited. Land use decisions are critical in the context of indoor environment and health.

(3) The informal building sector - rural

located. There is a need to analyze priorities in relation to rural health risks, and to structure community education accordingly. The goal is to promote effective progress in rural health. This requires understanding of traditions, habits of people, village customs and the reasons for them. Visual images and especially practical demonstrations usually communicate better than the written word. Agricultural development planners often have a key role. They are usually in close touch with such communities, respected for their agricultural contributions, and many rural building materials are drawn from the agricultural sector. There is a dominance of rural building materials drawn from the immediate environment, including local soils. Rural settlements are usually not overstructured by basic land shortages, but are often handicapped by the shortages and high costs of key building materials. Centralized energy services very often are not available. Outdoor air pollution levels are usually low, but indoor air pollution due to simple cooking and heating facilities and open fires may be high.

Energy issues

The achievement of acceptable indoor thermal environments under adverse climatic conditions often requires substantial inputs of energy, when aggregated over populations. The combustion processes may produce considerable indoor pollution. The extensive use of large amounts of fossil fuels is becoming less and less acceptable internationally because of the impacts of carbon dioxide on global atmospheric warming. The increasing demand and wide spread use of biomass fuels in unsustainable ways is causing considerable problems of land degradation. The WCED (1987) Report addresses the wider issues of energy in relation to environment and development, stressing the underlying need for the world to move from unsustainable energy policies to sustainable energy policies. Wood fuels are discussed as the vanishing resource. National policies for healthy buildings are going to need to give far higher priority to energy conservation and to the more effective use of renewable climatic resources, like wind and solar energy, than they have done in the past. The use of large amounts of CFC's, classified as greenhouse gases, for cooling and refrigeration is also becoming less and less acceptable. Effective natural cooling for these reasons is far to be preferred as the sustainable policy path, rather than reliance on air conditioning. The actual availability of energy sources of different types in different sectors of the economy may be of critical significance to the range of indoor environmental solutions actually open at any place. For example there can be no effective electric lighting without an electricity supply. Less healthy and more expensive lighting practices based on indoor combustion then have to be substituted. As the WCED Report points out "The woman, who cooks in an earthen pot over an open fire uses perhaps eight times more energy than an affluent neighbor with a gas stove and aluminum pans. The poor who light their homes with a wick dipped in a jar of kerosine get one fiftieth of the illumination of a 100 watt electric bulb, but use just as much energy".

Multisectorial policy groups

Multisectorial teams will need to be established, in each of the three areas indicated above, to prepare national policy statements. The teams should include representatives from health sector policy makers, from building and physical planning sector policy makers, and from energy policy makers. National meteorological services should be involved at an early stage, as should national building research organisations. Groups concerned with outdoor environmental policy, especially the implementation of effective outdoor pollution control policies, will also need to become involved. Adequate representation of

specialists in preventive medicine will be essential. Building materials issues will also require review.

The Guidebook intends to encourage setting up multisectorial teams with the scientific basis for their initial reviews of current national policies. The Guidebook has been prepared at a suitable professional level, so as to provide guidance to the top levels of health and building policy making. In application at the local level, much simplification of the Guidebook material may be needed to achieve proper communication to builders and to the general public. WHO and UNEP see this as a task best undertaken by national experts, who know the region well, it's people and their health and educational status, as well as the economic resource limitations.

The Guidebook necessarily had to cover the range of problems encountered on a global scale. Some of the material included may be irrelevant in specific climates. A useful start in the framing of national policies would be to take this Guidebook and then highlight what appear to be the key national issues for discussion. The national policy response to the identified issues then must take account of current difficulties, and current problems in each locality, before establishing indoor environment health priorities for the formal and the informal sectors.

Indoor environment policy control system

The setting up of multisectorial policy groups will imply a need to identify and interrelate, within the overall structure of government, the present and future roles of different policy makers and their professional advisers on indoor environment and health issues. Such a review is likely to demonstrate defects in existing governmental policy structures. Such defects will need to be rectified before appropriate balanced progress can be made. A lead ministry will have to be designated. Experience points to the choice of the ministry responsible for construction for the lead role, because of their position as enablers in the implementation of improved building policies. Such ministries lack expertise in health issues compared with ministries directly responsible for health concerns. A very positive relationship between the two ministries is essential to ensure the scientific basis of health policy for the indoor environment is correctly appraised. Clear assignment of executive responsibilities is essential. Looking in greater detail, the following specific areas may require exploration:

> Identification of existing chains of responsibility for control of indoor air quality in relation to outdoor air quality, and the consequent need to identify the chain of responsibility for the control of the outdoor air

quality environment in relation to the present and planned future locations of buildings.

> Identification of methods and responsibilities for securing improved thermal environments in buildings at cost affordable levels in ways which are compatible with global climate.

> Identification of responsibilities and powers for controlling external and internal noise, and establishing appropriate sound insulation standards for facades and internal construction elements, as well as standards for the control of external noise.

> Identification of responsibilities for establishing town planning norms for achieving adequate daylight and sunlight at building facades, and, probably in another part of the governmental structure, for establishing building design norms for satisfactory indoor daylight and the setting of artificial lighting standards.

Issues of economic planning are also implicit in the evolution of policy. The health effort has to be related to the development planning process, implying establishing a communication system between the health planning and the development planning sectors. There is the underlying need for any governmental actions concerning improvement of indoor health environmental, to set achievable policies, which match the actual structures of building activity and respect the climate. Account need to be taken of the actual economic resources available in different parts of their territories. Energy availability and cost are important limiting factor in practice.

Finally there is a legislative aspect to consider. The evidence of public health in developed countries points strongly towards the basic need to have governmentally organized and controlled legislatively based systems for regulating potentially unhealthy developments indoors in buildings, especially to regulate conditions incompatible with human health and safety. Simultaneously, in spite of current economic difficulties in many regions, there is need to plan to work towards the eventually desirable. Outdoor environmental controls based on legislation are essential to safeguard the indoor environment from health damaging outdoor developments. Environmental law enforcement agencies are also needed to ensure the legislation is properly respected. The complementary roles of fiscal incentives and legal penalties in environmental policy will need examination.

There is a clear need to consider carefully the interrelationships between all the above groups in the interest of a better coordinated national policy for healthy indoor environments. The best and most easily achievable policy would seem to build on and strengthen existing administrative structures, by

widening their terms of reference, where necessary, to cover any identified gaps. The supportive training needed to enable them to effectively carry out their widened responsibilities must be arranged.

In looking at the evolution of appropriate institutional structures, the policy review will need to consider detailed administrative and scientific support structures needed, at:

the national level.

the local level, formal sector, urban.

the local level, informal sector, urban.

the local level, formal sector, rural.

the local level, informal sector, rural.

Structures are also needed to ensure that vertical coordination is achieved between the national and local levels, and that local horizontal coordination is achieved between the formal and informal sectors in the two basic types of location, urban and rural.

Blocks to progress

An underlying block to current progress in this field is the widespread governmental and public identification of health services, as services preoccupied only with issues of ill health such as communicable disease infections. Physiological strain due to excessive heat or cold may not be seen as issue of health, because no cross infections occur. As a consequence, the correct appreciation of the balance of issues involved in indoor environment and health may not be reached in public health policy. This situation may lead on to severe distortions and diversion of public health policy directed towards the indoor environment, from what is really required. Health policy consequently may fail to address important indoor health issues.

Systematic building climatology assessments

The outdoor climatic analysis is of critical significance in deciding the range of building designs likely to acceptable in different regions of the country. The Guidebook has suggested some climatic methodologies, which can be applied to policy assessment. Thermal, daylight and man-made noise climatic analyses help unravel the causes of indoor stress in a way that identifies appropriate building responses. As climates often differ very much across national territories, there is always a danger in central policy making that regional rural and urban problems may be assumed to be the same as those of the capital. There is also particular value in gaining objective knowledge about

the indoor environmental profile at different seasons in different parts of the country in buildings in different sectors of the economy by systematic scientific measurements. The results of scientific studies in the field can be compared with the indoor environment recommendations as given in this Guidebook. Current shortcomings can be objectively identified.

Epidemiological profiles as a basis for policy

Another approach for establishing health control priorities is to use epidemiological methods for identifying the actual situation of ill-health of different risk groups and of accidents in different sectors of the built environment (WHO, 1974; WHO-EHC 27). Policy making will be very much strengthened by developing systems to generate and distribute sound epidemiological information about the health effects of housing and environmental conditions. If the health problems associated with poor housing can be quantified, then programme objectives for urban and rural planning can include specific health goals. Epidemiological studies serve establish control priorities against the actual experience of ill health of different risk groups and of accidents in different sectors of the built environment.

Productivity as a basis for health policy

The indoor environment also plays a critical role in influencing human productivity in work environments. An examination of the defects in the indoor environment of the work place at different seasons in different types of buildings in different regions of a country may show up important reasons whether and where labour productivity is affected by environmental strain. A improper work space environment may cause ill health, encourage high absenteeism, and a high work force turnover. It is a legitimate goal of development policy to attempt to provide better guidance on suitable standards and to draft regulations on health and safety aspects of the indoor work space environment. As work space indoor environments in policy terms are often the responsibility of a different ministry to housing, there is a strong case for setting up with those responsible a work space indoor environment policy group. As in housing, one must distinguish between the work spaces in the formal and those in the informal economy. Many work spaces in the informal economy are located within the home. The health dangers are then shared by all the household. Work based on the home often provides a key economic plank in the informal economy. Attempts to eliminate it by regulations can be very damaging to the economic life of the poor. The appropriate policy is to attempt to control the indoor environment risks better, where

feasible, and avoid conditions incompatible with human health. Often simple changes in working practices can give big dividends in terms of health and safety.

Steps in establishing the programme

It is envisaged that progress would follow a well defined timetable, which might well proceed in the following stages:

(1) Systematic survey of the current situation, and identification of priorities for human health indoors in different sectors of the economy.

(2) Stimulating public opinion to enable an indoor health policy to be established with proper political and social support for the allocation of financial resources implied.

(3) Establishing desirable standards and norms for the formal sector, and identifying the practical difficulties to be overcome in achieving them. Relating short term indoor environment improvement targets to the achievement of longer term indoor environment goals.

(4) Establishing short term economically realistic norms and standards for the informal sector, distinguishing between desirable situations and situations incompatible with human health. Plans in the informal sector should include public health based policies for the eventual evolution of initially compromised environmental standards towards the more acceptable levels recommended, on public health considerations, for the formal sector, as longer term economic progress is achieved.

(5) Identifying how best to set up positive incentives for accelerating indoor environment improvements.

(6) Identifying and establishing the appropriate legislative measures needed to ensure that damaging adjacent developments cannot destroy satisfactory progress in indoor environment improvement.

(7) The creation of education and training structures for:

persons professionally operating in the formal sector
persons professionally operating in the informal urban and rural sector

the general public

children in school.

environmental self help in the informal sector.
industrialists servicing indoor environments with equipment and chemicals

building materials manufacturers and materials importers.

(8) The design of an enforcement system for ensuring intolerable indoor conditions are eliminated in the interest of public health as an issue of urgency.

Scientific resources

In the Guidebook, a quantitative approach has been taken on issues of the indoor environment. While some progress can be made using measurement data from other areas of the world, it is obviously far better to have the capability of making outdoor and indoor environmental measurements in and around buildings at specific places. It is also very hard to legally enforce environmental norms and standards without access to scientific measurements. Appropriate scientific measuring resources are essential to support improved health policies for indoor environments. The national policy statement on the improvement of indoor environments will need to define a structure for laboratory responsibilities with appropriate facilities. This would best be done by building on and strengthening existing facilities. Many countries already have Building Research Institutes, National Chemical Laboratories, and Medical Laboratories. Increasingly University Departments are being asked to take on more specific roles, aided by earmarked Government funds.

Three levels of facilities will have to be provided: *central facilities, regional facilities, and field based facilities.* There is the need to consider ease of use, reliability, cost and durability, especially of field instruments. Mobile laboratories are especially valuable for field investigations of indoor environments, and central organizations can often become much more effective nationally, if they are provided with improved mobility. There are also important calibration considerations. Maintenance of adequate national calibration facilities are usually made the responsibility of centralized laboratories. The potential role of universities and polytechnics should be assessed. Their help may be especially valuable in specialized areas like identifying unknown substances, and the chemical and radioactive measurement of rare substances.

Information resources policy

The Guidebook has attempted to reference some of the vast amount of material available on indoor environments, giving special emphasis to WHO publications. In common experience the lack of adequate access to the scientific literature is greatly retarding scientific advances in the world. The national policy review might, among its deliberations, usefully consider how to set up a national information base for

health in the indoor environment. A start could be made by assembling in one place for national reference all the material referenced in this Guidebook. This starting collection could be then be systematically added to. As progress is achieved, more advanced information technology systems could be introduced to keep up with national and international scientific progress. The centre should be able to pass information in selective relevant ways out to the various points of action in the field. The information resource centre could also provide the main resource foundation for the development of mid career training courses. The material should be accessible, both within government and to outside users. This facility could be built up by the relatively modest expansion of some existing national information facility, using specifically earmarked funds.

Personnel needs, training and education

The most sensible way forward seems to be to build on existing administrative and technological structures, rather than attempt to develop new cadres of personnel working in new organizations dealing with the indoor environment in isolation. The first stage is to identify the basic training and educational needs in relation to the policy and managerial responsibilities allocated between different branches of central, local, and rural government. In the informal sector, Non-Governmental Agencies are often very influential, and are desirably brought into the programme early. The task of providing the required levels of education and mid career training for personnel working at different levels in the different sectors then becomes critical. Intersectorial approaches are particularly desirable in mid career training, to avoid training separate professional cadres to pursue sub system goals in isolation from the other groups involved in the total system. There is a great need to break with traditional isolation of disciplines, and to encourage interdisciplinary professional collaboration on indoor environmental health issues between the building based sector, the physical and economic planning sector, meteorological-climatological sector and the medical health sector.

The following comments are offered on education and training for different professional groups.

Medical personnel: The majority of medical practitioners are preoccupied with coping with ill health, rather than actively promoting health. Preventive medicine is more orientated towards health, but not sufficiently involved with current thinking and training in building hygiene. In medical circles, the relationship between people, indoor environment and their health does not receive the proper attention. In particular, adverse physiological strain is not recognized

to be important for health. It is hoped that the Guidebook will provide the means by which a start on this attitudinal reorientation can be achieved. Medical schools clearly should give greater attention to such issues, though such changes take a long time to work through. Mid career training of practicing doctors, especially public health specialists and hygienists, in the areas discussed by this Guidebook, will produce quicker results. The trained medical personnel can then address the training of medical personnel at different levels. This will require those responsible to prepare suitable training material for hygienic workers, sometimes at a very much more simplified level than would be suitable at the full professional level.

Architectural and building professionals: In the past, health issues, with the exception of water and sanitation, have not figured very large in the education of architects and builders. However the formation of indoor environments in the formal sector is determined very largely by their actions. The improvement of the indoor environment is dependent on improved understanding of health issues by building professionals through education. Norms and standards are very important to these groups, and practical progress is accelerated by the availability of enforceable standards. Awareness of the responsibilities and indoor chemical impacts on indoor air quality is inadequately developed at present. The Guidebook should not only assist directly in the improved education and in the mid career training of these cadres, but, also indirectly contribute through its application to the development of improved national norms and standards for the indoor environment. It is very important that the health related professions should be involved in the development of such building and planning related norms and standards, in topic areas where they relate to health.

The building energy specialists, mainly heating, ventilation and air conditioning engineers, tend, in their decisions, to acquire by default some responsibility for maintaining satisfactory indoor air quality. They do not always take on this responsibility with proper regard for the health effects of adverse indoor air quality. There is often an important unresolved conflict between desirable indoor air quality standards, and energy conservation goals based on reduced fresh air supply standards. Education and training is needed to make building energy engineers far more aware of the adverse effect of the indoor and outdoor noise environment. The achievement of a healthy indoor environments, at economical levels of operating cost, is the strategic objective.

Planning professionals: Professional cadres concerned with physical planning have a special responsibility for the formation of the outdoor environment at the facades of buildings. Their education, in the context of securing improved indoor

environments, falls into the groups:

Regulating the external production of pollutants

Regulating the interactions between the remaining sources of external pollution and the external facades of buildings;

Securing adequate access from inside buildings to the benefits of the outdoor natural environment. This issue is strongly linked to issues of space about buildings, and its effective planning control;

Providing protection from the adverse effects of the natural environment, especially from extreme events likely to lead to injury, loss of life, or severe property damage.

Outdoor air pollution, outdoor noise control, the availability of daylight and sunlight, and the climate of towns are especially relevant to these groups. Their professional education and mid career training in these specific sectors needs to be strengthened.

National Meteorological Services: The national meteorological services have an important role in the propagation of the issues of indoor climate. Meteorological data is place specific. If there is a national plan of action to improve indoor environments, local climatic information for specific places will be needed by various groups. This means detailed enquiries will be received at various levels of the National Meteorological Service. The data supplied will have to be assessed and structured into appropriate forms, helpful for decision making. Steps to train appropriate personnel to respond to such enquiries must be taken. It would seem appropriate to allocate the task of coordinating health related aspects of meteorology to senior meteorologists. They could not only liaise with the groups taking part in national policy formation, but also become responsible for training in this sector throughout the national and international meteorological services, not only in material from this guidebook, but also the recommendations emerging from the World Climatic Applications Programme, the Leningrad Conference on Climate and Human Health and the Mexico City Conference on Urban Climatology. They could also liaise with national educational institutions concerned with meteorological and climatological education with the aim of advancing knowledge of the role of meteorology and climatology in healthy and sustainable development.

Guidance of industry

The building materials industry in all countries forms a key part of the industrial base. It is essential the industry should have firm guidance on the standards for health to be applied to building materials in use in buildings. It is also necessary to ensure that imported building materials match the appropriate health standards. Unsafe and unhealthy building materials must be excluded. Indoor environment standards set on grounds of health, influence the design of building components like windows, and stoves. It is essential for manufacturers to have firm guidance on the norms that are acceptable. Industry needs clearly defined stable norms and standards to define stable manufacturing policies, justifying investment. The manufacturing industries producing energy supply systems have a particularly strong responsibility for producing designs that, in use, do not impact adversely on the health and safety in the indoor and outdoor environment. Their role in noise control is important too. An industrial policy to secure safe and health consistent building products and components forms an important component of public health policy for the indoor environment.

The informal sector

Progress in the informal sector is likely to prove particularly difficult to achieve, because so little lies within the effective direct control of government. However the health benefits to be gained from making progress in this sector could be very considerable. A start can be made by attempting to control industrial plant operating to low environmental standards. The location of traffic routes and airports is important. If a degree of plot layout control can be achieved within such developments, then some progress can be made through more environmentally appropriate use of the space about buildings. This should make it possible for self build groups to achieve better indoor environments, through increased availability of daylight and better natural ventilation. From this point on, the indoor environment issues become very much issues of community education. People need to know what indoor environments are unhealthy, and how they might be cheaply improved to become more healthy. Some improvements in simple dwelling construction and layout cost very little money, such as correct orientation of dwellings, or appropriate location of shading trees and shrubs. Some other improvements cost money, but give vast health improvements, for example flues to extract the smoke from indoor polluting wood, coal or coke stoves. Some self help building materials may be very hazardous indeed for health,such as site mixed asbestos cement. The problems are very dependent on context. A social awareness of indoor air quality hazards needs to be stimulated. Practical demonstration of simple means of achieving healthier indoor environments in informal settlements is likely to be a particularly useful route for stimulating progress. Part of the problem is to stir people from an apathetic acceptance of poor health as a feature of their lives. The concept of self improvement of indoor environments in the interest of health of the individual needs to be fostered within the community. The Guidebook provides information, which could help in this task, provided it is

appropriately reformulated to meet the local social situation.

The importance of educating the public

Effective policies must be established to communicate the selected priority indoor environment improvement goals to various sections of the public. The Guidebook could have a role in the development of "how to improve" documents, aimed at the general public, as well as for the preparation of training material angled at different professional sectors of the national economy. One must note the key role of women as the environmental managers of most homes. Material addressed towards the general public will both help initiate a market led demand for better indoor environment solutions from the building industry, and simultaneously stimulate self improvement actions to improve health in the home. As interactions between dwellings influence indoor environments, better understanding of the causes of environmental conflict should encourage better community collaboration. It is certainly worth harnessing the energies of voluntary agencies. Community involvement in environmental improvement helps secure locally supported responses. This social support helps safeguard local projects against the vandalism and neglect, which is so often associated with externally imposed solutions.

One must not underrate the potential impact of primary education. In many countries, issues of outdoor environment now form part of the primary school curriculum. There is no reason why the relationship between indoor environment and health should not form part of the primary school curriculum. School teachers could have a special role provided their needs for supportive teaching material are adequately met. Another route forward is through the award of prizes and setting up of local competitions to promote more positive attitudes towards indoor environmental improvement, to foster a better social awareness of health issues in the indoor environment.

Finally government buildings, if properly designed in line with the various suggestions of this Guidebook, can serve as exemplars of good indoor climate practice, and also as effective vehicles for the demonstration of new ideas.

Conclusions.

1. The Guidebook has set out to help member states meet the WHO goals of better health for all, especially important in areas of accelerated development in the world, through environmental progress in the four key sectors of indoor environment: thermal comfort, air quality, noise, and light.

2. Lack of economic resources will make progress slower than might otherwise be the case. Many improvements in indoor environments will cost virtually nothing, being simply issues of improved building design, and thus issues of basic environmental education, and not investment.

3. The fastest progress will come through a strategically based approach founded on multisectorial interdisciplinary collaboration, rather than through tactical approaches conceived in limited sectors.

4. The first key task is to establish an intersectorial national strategy and then to make plans to implement it, making use of the total community and governmental resource and not only the special skills of the health care community.

5. There is a need to identify national priorities for action. It strongly recommended that national plans of action should be implemented by widening the range of responsibilities of existing organizations relating to the built environment, and to health. Effectiveness in their expanded roles should ensured through adequate mid career training programmes to cover newly allocated responsibilities.

6. Climate exerts a key influence on indoor environments. Securing the full collaboration of national meteorological services is vital.

7. While outdoor air pollution is important, there is strong evidence that indoor air pollution is usually more significant for health.

8. There is a strong case to strengthen studies of the epidemiology of complaints and diseases to gain a more objective view of health improvement priorities in human settlements in different areas.

9. The greatest challenge perhaps lies in how to make adequate progress in the informal sector. While environmental aspects of town planning are especially crucial in this sector, the main tool of progress to secure better indoor environments will be social mobilization. It is essential to involve the whole community in the programme.

10. The field must be viewed as a dynamically active field. This Guidebook should be viewed as a distillation of current 1990 international experience on indoor environments in relation to health, to which new material is constantly being added. Policies adopted must be flexible enough to allow for advances, but firm enough to ensure effective execution.

Abbreviations

ANCAT European Civil Aviation Conference

ASHRAE.   American Society for Heating, Refrigerating, Air-conditioning Engineers, 1791 Tullie Circle, NE Atlanta, GA 30329 USA

ACGIH. American Conference of Governmental Industrial Hygienists

ASTM. American Society for Testing and Materials.

BRE. British Research Establishment. Publisher: HMSO.

BSI. British Standard I London

CEC. Commission of European Communities, Brussels.

CIBSE. Chartered Institution of Building Services Engineers. Delta House, 222 Balham High Road, London.CIE.

Commission Internationale de l'Eclairage, Paris

DIN. German Standard

FAO Food and Agricultural Organization. Rome, Italy

GOST. Standard Publishers, Moskow

HMSO. Her Majesty's Stationary Office, London.

IDC. International Daylighting Conference.

ISC. Indian Standard Code. New Delhi

ISO. International Organization for Standardization

NRC. National Research Council. National Academy of Sciences. Washington, DC.

OECD. Organization for Economic Cooperation and Development, Paris.

UNCHS. United Nations Centre for Human Settlements. Nairobi.

UNEP. United Nations Environment Programme. Nairobi

WCAP. World Climate Application Programme. World Climate Programme. World Meteorological Organization, Geneva, Switzerland.

WCED. World Commission on Environment and Development.

WHO. World Health Organization. Geneva, Switzerland.

WHO-EURO. Regional Office for Europe, World Health Organization, Copenhagen, Denmark.

WMO. World Meteorological Organization, Geneva, Switzerland.

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