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HEALTHY BUILDINGS

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A Journal of Science, Technology, Health, Monitoring and Policy

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HEALTHY BUILDINGS

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EDITORIAL

HEALTHY BUILDINGS

Indoor air quality has been the subject of numerous investigations. The number of meetings, symposia, and workshops devoted to indoor air is large and these encompass subjects dealing with a small segment of indoor air to international gatherings covering the entire subject. The number of pages of this journal dedicated to indoor air pollution is large, including entire volumes on the subject. The emphasis of most of these activities has been the identification of indoor air contaminants and their potential human health effect. The environmental scientific community is gradually recognizing the need to emphasize its positive accomplishments. Although it is true that one must address adverse effects of pollutants, it is equally true that one can express scientific findings in averted potential problems. Therefore, one could assess sick buildings and design healthy buildings based on lessons learned in the assessment of sick buildings.

The international conference "Healthy Buildings '88", held in Stockholm, Sweden, had the objective of not only learning the current status of sick buildings but also understanding what constitutes a healthy building. During the preparation of this conference it became clear that sufficient scientific information was available to avoid most of the problems related to sick buildings. Accordingly, there appeared to be a need for information that went beyond solving sick building problems and added measures that provided for a comfortable and high-quality life. This new concept required a more fundamental reassessment of the "built environment". It also required an evaluation of materials used in construction, the location of the building, and the building envelope. This insight led to the expression of a need for an integrated process of planning, design, construction, installation and maintenance of the building, and its components. Clearly, many new topics had to be considered that were not commonly included in an indoor air assessment. Accordingly, the conference focused on technical solutions and functional requirements contributing to healthy buildings for people to live and work.

Subsequently, selected papers from that conference were chosen and subjected to the customary peer review. This issue contains these papers along with several contributions which, to the judgements of the editors, were supplementary to the selected papers including a consensus report on thermal climate prepared by a Nordic scientific group. A careful observer will find contributions in this issue which fall somewhat outside of the scope of this journal. For example, topics dealing with thermal comfort, architectural assessments, and similar topics are included. The process leading to a decision of inclusion of these topics was careful and deliberate. The primary reason for the decision was the desire of the editors to emphasize the need for a comprehensive and strategic assessment of important environmental issues of specific concern to the indoor environment. A building with an acceptable indoor air quality is unacceptable if other parameters such as temperature, humidity, noise, and lighting make it uninhabitable. Furthermore, measures that lead to an acceptable indoor air quality may have adverse sideeffects on other equally important parameters that make a building a healthy building. Finally, the ultimate goal of environmental protection is not only to avoid adverse effects but to promote the positive qualities of the various environmental components. An optimization process must take these parameters and their harmony into account. This includes the promotion of human health and comfort achieved through healthy buildings. The editors hope that the readers will find this volume to be useful. We believe that our decision to expand the scope of this issue will help to improve the concept of healthy buildings and the goal of all indoor air studies.

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A. Alan Moghissi

STRATEGY OPTIONS FOR THE DEVELOPMENT OF HEALTHY BUILDINGS

The international conference upon which this issue of *Environment International* is based was more than a series of sessions where scholarly papers were presented. It included a number of discussion groups with specific missions. The conclusions of these discussion groups were subsequently evaluated by the editors of this issue and used for identifying strategy options for the development of healthy buildings.

Despite significant efforts by national and international organizations, the world population is increasing rapidly. The population growth and the migration to large cities are overwhelmingly in the developing countries, but include most of the industrialized countries as well. The need for additional housing and associated amenities is obvious.

Historically, the energy consumption has been linearly correlated with the standard of living. During the last two decades, major steps have been taken to reduce energy consumption. Much of the success in energy conservation has resulted from the recognition by industry, car manufacturers and producers of appliances, that consumers and governments are expecting energy efficiency and, within limits, are willing to pay for it. An area where energy conservation has had a less than perfect performance is in building heating and cooling. Poor design of buildings and equipment, installation and maintenance of equipment by less than qualified workers, and inadequate source control have led to the occurrence of poor indoor climate and, in some cases, adverse health effects, including the Sick Building Syndrome (SBS).

A basic requirement for a healthy building is that the room air must not cause illness or discomfort during normal use. The building must also be able to withstand a reasonable misuse by its occupants without giving rise to adverse health effects. Basically, indoor air quality can be controlled by a combination of 1) adherence to guidelines or standards for air pollutant concentrations, 2) source control of emissions, 3) prescribed outdoor air flow requirements, and 4) specific design requirements.

For commonly encountered and well-researched pollutants, concentration limits should be specified. However, there is a need for more toxicological knowledge about many pollutants at low levels and indicators of their presence. An area of considerable importance is adverse effects of mixture of indoor air pollutants. There is ample evidence that these effects are not necessarily additive.

For healthy buildings, it is essential to choose building materials with minimum pollutants emission to the indoor air. These should be expressed in quantitative requirements.

It appears logical to develop a strategy for healthy buildings. The following parameters need to be considered:

1. Design, construction, and management of healthy buildings require a combination of proven experience and scientifically founded information.
2. Priority should be given to adverse health effects of major concern, such as building-related cancer and hypersensitivity reactions including allergy. Sensory reactions, discomfort, and annoyance reactions are frequent, widespread, and are early signs of adverse health effects. They are important parts of the health assessment.
3. Should a conflict arise between energy conservation and health, the health goal should prevail.
4. The target is to control human exposure and should be reached primarily by source control.
5. A ranking system is needed for buildings and consumer products. Fast-screening procedures should be developed for appropriate end points of health and comfort. Test facilities are needed to assist governments, manufacturers, builders, and consumers.
6. Microorganisms are important as allergens and causes of diseases including legionnaire's disease. Ideally, the presence of microorganisms must be kept to a minimum, yet avoiding exposures to hazardous biocides.
7. The physical planning is critical. If buildings are erected on poor grounds or close to sources of hazardous or annoying emissions, specific requirements must be met.
8. Feedback of experience must not be neglected. Inadequate design, poor materials, and actions during the construction that may cause problems for the users are examples of the experience which must be evaluated.
9. Technical systems in the built environment should either be simple and self-explanatory or automated in order to reduce the need for maintenance and control.
10. A national strategy must be realistic and must accept and compensate for the occurrence of failures in design, manufacture, installation, maintenance, and use of buildings and building components.

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THERMAL CLIMATE

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This report resulted from a Nordic seminar on "Thermal Climate—Research Needs", held at the University of Stockholm, Sweden, March 19-21, 1986. The reason for the seminar was that climatic discomfort is an environmental problem highly ranked by most people in industrialized countries. At the same time, there are economical and practical limits to what countermeasures can be taken. Furthermore, demands on energy conservation require a cost-benefit assessment. For that purpose, the biological consequences of thermal distress/discomfort must be examined and evaluated regarding its importance for health, performance, and well-being. This document is a review which evaluates available information on the biological effects of thermal distress/discomfort, identifies research needs, and provides scientific priorities. The report directs itself to both authorities and researchers interested in climate control and in environmental health. It may serve as a basis for priorities in research support. Subsequent to the Nordic seminar, a meeting was held to discuss suggested guidelines on thermal climate in dwellings, sponsored by the Swedish Board of Social Welfare and Health, and a final discussion took place among agency representatives and the seminar participants. The seminar was organized by the Karolinska Institute and the National Institute of Environmental Medicine, in cooperation with the University of Stockholm. The seminar was sponsored by the Swedish Council for Building Research, the Swedish Board of Occupational Health, and the Swedish Board of Social Welfare and Health.

WORKING GROUPS

The persons contributing to this document are listed below. In addition, valuable comments have been received from Professor Gunnar Borg. The work was conducted in plenary sessions as well as in subgroups.

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1. INTRODUCTION

The goal of the program on thermal climate is to identify critical characteristics of the climate which are or may be related to health effects on humans. It thus focuses on (1) the identification and quantification of comfort as well as adverse health effects, and relate these to specific climate characteristics, (2) the mapping of the biological and psychological mechanisms causing the effects, (3) the identification of sensitive groups, and (4) the evaluation of the impact of regulations developed to protect the groups at risk.

This report aims at summarizing current knowledge on effects of indoor thermal climate, at evaluating important research problems, and at serving as a plan for continued research. The report covers applied as well as basic research, and encourages cross-disciplinary activity and international cooperation. Research on thermal climate effects is needed as a background for developing comprehensive and useful environmental criteria, but also to assure the public that major health effects are being assessed in proposed control actions.

2. THERMOREGULATION

2.1 State of the art

The core temperature of the human body is biologically maintained within a narrow range, during rest being close to 37°C. It is independent of even large variations in environmental temperature (M. Nielsen 1938). The core temperature is usually measured as rectal temperature. However, the temperature in the core is not uniform, but varies among the different body organs depending on the local heat balance; some organs are heated by the blood flow and others cooled by the blood flowing through them. Core temperatures assessed at other places, for instance in the deep esophagus or on the tympanic membrane, may be a better index of the thermal state of the body and of the temperature signal to the thermoregulatory centers than the rectal temperature (Benzinger et al. 1963; B. Nielsen and M. Nielsen 1962; Saltin and Hermansen 1966). The latter lags behind due to the thermal inertia of the abdominal organs.

In conditions of changing body temperature, such as during physical activity, the core temperature rises proportionally with the intensity of the exercise (M. Nielsen 1938; B. Nielsen and M. Nielsen 1965). For different persons this rise in temperature is dependent on the relative work load which is proportional to their maximum oxygen uptake capacity (Saltin and Hermansen 1966).

The skin surface temperature of a naked person varies greatly between different locations. The more distal parts, for example, hands and feet, are generally cooler than the temperatures on the trunk and head (Hardy and DuBois 1938). The average skin temperature, $\bar{T}_{sk}$, is an area weighted mean which can be calculated from several surface temperature measurements (see R. Nielsen and B. Nielsen 1984). $\bar{T}_{sk}$ varies with ambient temperature, but it is independent of work intensity if heat balance can be maintained.

Temperature regulation is achieved by an autonomic regulation which matches the rate of heat loss to that of heat production. The centers for this regulation are located in the hypothalamus. A large number of studies have described the organization and function of these centers.

Neurophysiological studies have shown that temperature sensors in the brain respond to local thermal stimulation (Nakayama et al. 1961; Hardy et al. 1964). Other cells in the hypothalamus receive information from skin thermoreceptors or other brain areas and interact by modifying the signal from the first-mentioned sensors, which control the activity of the thermal effectors (Hellon 1970; Nakayama and Hardy 1969). Other regions of the body such as the spinal cord (Jessen et al. 1968; Simon et al. 1964) and the abdomen (Rawson and Qui 1970; Jessen and Feistorn 1984), contain thermal sensors responding to local temperatures. These may influence the activity of the hypothalamic sensors.

The transmitter substances in the neuronal network and synapses in the temperature center have also been mapped. Heat production and heat loss signals are activated by different neurotransmitters, but no general pattern is found. The same transmitter substance may elicit heat loss in one and heat production actions in another species (see Bligh 1973). Furthermore, the reader is referred to Heath (1986) who reviewed the topic of thermoregulation, integration, central processing in temperature regulation, neurotransmitters in temperature control, cutaneous temperature receptors, and temperature receptors in the central nervous system.

Many models for the thermoregulation system have been suggested which describe the interaction between "central" and "peripheral" temperature signals and their relative importance. Most models imply a "thermostat" principle, with a reference "set-point". A deviation from this reference point drives the appropriate thermal response (sweating, panting, vasodilation/constriction, shivering, and nonshivering thermogenesis). The "sensitivity" and/or "threshold" of such a proportional control system in the hypothalamus may be steered by skin sensors, extrahypothalamic sensors, physical activity, etc. (Benzinger 1959; Benzinger et al. 1963; Hammel et al. 1963; Hellström and Hammel 1967). Other models without a reference set-point have also been proposed (Mitchell et al. 1972; Houdas et al. 1973). For example, Snellen (1966) argues that mean body temperature or body heat content is the variable of control.

In spite of extensive research on the theroregulatory system briefly summarized above, the models, which mostly emanate from animal studies, still fail to explain the complex reactions of human thermoregulation. This is especially true when exercise is involved as discussed by Houdas (1982) and Nadel (1977). Other, non-thermal factors, such as electrolyte balance and hydration state, exert influences on temperature regulation and on the sensitivity of the effector mechanisms (e.g., B. Nielsen 1974, 1984; Fortney et al. 1981).

The mechanisms involved in human acclimatization to heat are well-studied. Increased sweat secretion and diminished electrolyte loss in the sweat are the most important (Nadel 1977). Lowered threshold temperatures for the elicitation of sweating and vasodilation are involved. With regard to acclimatization to cold, only insignificant changes occur. The most important is a local adaptation due to cold involving vasodilation in the hands and face (LeBlanc 1975; Åstrand and Rodahl 1986).

2.1 Research needs

Most of the basic research on human thermoregulation has been done with young men as subjects. The differences in age, sex, and race of thermo-regulatory capacity (sweating, vasodilation/constriction) and in acclimatization are not well-known (Drinkwater et al.

1982; Horstman and Christensen 1982). Field studies on acclimatization to the environmental stressors in hot and cold industries are few. Interaction between environmental temperature and health/disease is not well-documented and deserves further research.

Specific research needs are as follows:
(1) age, sex and race differences in thermoregulatory capacity,
(2) acclimatization in groups of different age, sex and race, and on environmental stresses in hot/cold industrial workplaces, and
(3) interactions between thermal environmental characteristics and health/disease.

3. NEUROPHYSIOLOGY OF THERMAL SENSATION

3.1 State of the art

Thermal sensations consist of multisensory perceptions among which cutaneous sensations are of primary importance. For some sensory systems such as vision and hearing, much is known about the sensory evaluation process. For the cutaneous senses, surprisingly little is known, not only of the transduction and assessment of sensory signals, but even of the mechanisms behind the reception of the signals (Marks 1974). Unfortunately, there is no testable psychological theory of thermal sensations (J.C Stevens and B.G. Green 1978). For a long time, the theory of von Frey (1894) prevailed. He assumed that the receptors of each cutaneous modality (warmth, cold, touch, pain) have one form of energy. Furthermore, he suggested that the skin receptors have specialized physiological properties and that definite receptor types could be assigned to each of his four modalities. Von Frey also made the assumption that distinct nerves and pathways of the four different qualities run from four specific kinds of stimulus transducers in the skin to four specific receivers in the brain. As pointed out by Melzack and Wall (1962), the most questionable part of von Frey's theory is his assumption that each psychological dimension of somesthetic experience bears a one-to-one relation to a single stimulus dimension and to a given type of skin receptor. Today, there is considerable evidence that there is no such simple relationship between perceptual dimensions and the dimensions of the physical stimulus. Furthermore, the somesthetic perceptions have never been operationally defined and, thus, the concept of four rigid modalities of cutaneous experience has been criticized by a number of authors (see e.g., Weddell 1955; Sinclair 1955; J.C. Stevens and B. G. Green 1978; Hensel and Konietzny 1979).

Opposite to the von Frey theory stands the quantitative theory of feeling, introduced by Nafe (1929), in which the sensory systems perform a pattern analysis of nerve activities. Nafe suggested that the pattern of neural discharges determines the somesthetic sensations by the variation in frequency of impulses, the length of time the impulses continue, the area of skin where the impulses arise, and the relative number of fibers being activated. Nafe's view is close to the conceptual model proposed by Head (Studies in Neurology, London 1920; as quoted in Melzack and Wall 1962). "Primary sensations" such as heat, cold, and pain were looked upon by Head as abstractions. He argued that afferent physiological processes are most complex at their origin; they become continuously more specific and simpler as they are subjected to the modifying influence of the central nervous system (Gibson and Gibson 1955).

Melzack and Wall (1962) tried to explain sensory coding by combining the von Frey and the Nafe theories. Sensory quality is assumed to depend on the spatio-temporal pattern of neural impulses and on a minimum amount of receptor specificity for the production of the characteristic patterns. Thereby, this theory also incorporates the neurophysiological phenomenon of spatial summation described by Hardy and Oppel (1937).

Recordings of neural impulses from individual fibers in cutaneous nerves have shown that a kind of specificity of the thermal senses is likely. Although no thermal sensors have been positively recognized, two types of nerve fibers have been discovered that respond specifically to temperature stimuli but not to pressure or thermal pain (Hensel and Boman 1960; Konietzny and Hensel 1975). Other fiber types have been shown to respond to heat, chemical irritants, and more intense mechanical stimuli, and are thus multimodal in stimulus terms (Torebjörk 1974). The multisensitive so-called "C-nociceptors" (responding to a multitude of noxious agents) in human skin can be activated by various modes of stimulation, such as thermal, mechanical, or chemical, that threaten to damage the skin (Torebjörk 1979).

3.2 Research needs

Research in this field is complicated by the fact that very little is known about the structural basis for thermo-receptors and thermal sensation. However, a reason for encouraging work in this field would be that knowledge about the receptor mechanisms will most likely give us information of general importance in sensory physiology, and might even contribute to solving the code for receptor transduction. An argument for directing the research on receptor mechanisms to the thermal field is that the resulting perception has so special features, is fairly distinct, and can be repeated without adverse health effects even in humans.

Specific research needs are as follows:

(1) receptor mechanisms,

(2) pathways of conduction of nerve impulses; although substantial contributions have been made, much has still to be learned,

(3) central representation and interpretation of thermal sensory inputs,

(4) feedback mechanisms on central or peripheral levels,

(5) modifying factors such as local biochemical changes, interaction with sensors, changes in local blood flow, and inflammation,

(6) neurophysiological or other characteristics which determine the perception of the qualities "warm" or "cold",

(7) how the perception of draft or asymmetric temperature is elicited and contributions by other sensory systems in the perception of these stimuli, and

(8) the influence of inflammation or vasodilation on thermal sensation.

4. PATHOPHYSIOLOGICAL ASPECTS OF THERMAL DISTRESS

4.1 Short-term effects

When a person is exposed to extreme hot or cold environments, the capacity limits for the thermoregulation effectors can be reached, and thus control is lost (Vuori 1987). During activity in hot environments, the rate of sweating and the possibility for evaporation of sweat set the limit for heat loss. If the heat loss is insufficient, the core temperature will increase above the controlled level (hyperthermia). This, in combination with dehydration due to sweat loss, may lead to heat exhaustion (heat prostration, heat syncope); the person cannot continue the activity, blood pressure drops, and the subject may faint. This condition may eventually lead to heat stroke, where sweating stops and core temperature rises to fatally high levels. The person would then become unconscious and would need immediate hospital care. Other acute effects of thermal distress are heat cramps, dehydration, and heat edema. In addition, skin afflictions such as heat rash and anhidrosis may appear. The acute heat illnesses have been described in detail, for example by Leithead and Lind (1964), and Minard (1976).

For cold environments, a heat loss greater than production due to activity and shivering, in spite of maximal vasoconstriction, causes the body core temperature to fall. This condition, hypothermia, becomes increasingly severe as body temperature falls. At a core temperature of 35-34°C the person becomes confused, shivering stops, and the decline of core temperature occurs at a faster rate. At about 30°C, the person becomes unconscious, and the heart will stop beating at about 27°C. However, people can be resuscitated by proper rewarming, even from very low core temperatures. Acute cold injuries also include frostbite and other frost injuries.

Some people are disposed to spontaneous hypothermic reaction, since their subjective cold sensation is not affected adequately by body cooling. For them, prolonged exposure to cold may result in spontaneous hypothermia, which can be fatal. Most at risk are those suffering from thyroid dysfunction, chronic diabetes mellitus, hypoglycemia, and uremic conditions. Also at risk are patients exposed to x-rays, those requiring muscle relaxants, psychogenic drugs, or beta blockers, as well as alcohol addicts, undernourished, elderly people, and sick small children and infants (Popovic and Popovic 1974; Braun 1982; Huttunen and Kortelainen 1990; Lomax 1984).

Short-term heat and cold hazards may be experienced in indoor situations, for example in industrial work (Rodahl 1989). In steel works, the glass industry, etc., the workers may be exposed to heat stress. Cold store rooms and freeze rooms in the food producing industries may cause cold discomfort and hypothermia (R. Nielsen 1986). Cases of hypothermia have been reported in elderly persons even in normal dwellings, where they have been too weak or too poor to protect themselves against the cold in their homes (Lomax 1984).

4.2 Long-term effects

It has not been demonstrated convincingly that thermal distress at levels occurring in the community has long-term physiological effects which may be adverse to health if there is no underlying disease.

4.3 Heat stress

Heat load causes annoyance at work (Wenzel and Piekarski 1982), increases strain on the cardiovascular system (Brengelman 1983), and evokes other thermoregulatory adjustments (Smolander 1987; Ilmarinen 1978; Wenzel and Piekarski 1982). It is assumed that the pathophysiological effects of heat stress (as well as of cold stress) are due to prolonged overloading of the homeostatic system of the body as revealed in studies conducted among miners in South Africa (Strydom 1971; Wenzel and Piekarski 1982).

Pathophysiological effects of prolonged heat stress and chronic heat illnesses, are not discussed in the literature in a systematic way. Dukes-Dobos (1981) classifies the chronic heat illnesses according to their etiology: Type I are the after-effects of acute heat illness, Type II are the cumulative effects of long-term exposures, and Type III are the effects of living in climatically hot regions. Chronic after-effects of acute heat illnesses (Type I) are, among others, reduced heat tolerance, dysfunction of sweat glands, reduced sweating capacity, muscle soreness and stiffness, reduced mobility, chronic heat exhaustion, and cellular damage in different organs, particularly in the central nervous system, heart, kidneys, and liver.

Cumulative effects of long-term exposures (several months) to work in hot environments (Type II) result in chronic heat exhaustion; the illness being characterized by a set of symptoms including headache, gastric pain, sleep disturbance, irritability, tachycardia, vertigo, and nausea. After many years of work in the heat, the symptoms gradually become worse and there can be observed hypertension, reduced libido, sexual impotency, myocardial damage, nonmalignant diseases of the digestive organs, and hypochromaemia (Hales and Richards 1987).

The symptoms of chronic heat illnesses observed among people living in climatically hot regions (Type III) are in the tropics: frequent skin diseases, sleep disturbance, susceptibility to minor injuries and sickness, psychoneurosis (tropical lethargy), and anhidrotic heat exhaustion. In the deserts there can be symptoms of kidney stones and anhidrotic heat exhaustion (Hales and Richards 1987).

4.4 Cold stress

Numerous epidemiological studies have attempted to prove that long winters and long periods of exposure to cold have harmful human effects such as an increased rate of cardiovascular disease mortality and morbidity (Abramov 1971; Dunnigan et al. 1970; Hall et al. 1970; Leon et al. 1970; Näyhä 1980, 1984).

The anginal pain typical of coronary heart disease can be provoked by different types of cold stimulation, and changes appear in the electrocardiogram. In cold weather, anginal pain occurs earlier with the identical stress load, and even as a result of less strain, than at room temperature (Harjula 1980). Both systolic and diastolic blood pressures are higher in the cold than at room temperature (Fleischer and Jungman 1965; Sarna et al. 1977). Furthermore, it has been shown that acute cold elevates at least the systolic blood pressure, even in healthy people who are in generally good physical condition (Harjula 1980). Even slightly elevated blood pressure may be a risk factor in heart failure (Reunanen et al.1983). Research also shows that the occurrence of hemorrhagic cerebral diseases increases when the weather is cold (Näyhä 1980, 1984; Sotaniemi et al. 1970).

Together, cold weather and physical strain are considered risk factors, especially for those middle-aged and elderly persons who suffer from latent or manifest disease of the circulatory or respiratory systems. Patients with coronary heart disease often experience a deterioration in their condition in cold weather. Many of them state that their symptoms are provoked by cold wind (Epstein et al. 1969; Freedberg et al. 1944; Harjula 1980).

Besides coronary heart disease, exposure to cold increases the symptoms of other diseases such as rheumatoid arthritis, some respiratory diseases (asthma, chronic bronchitis), and various skin diseases. Very common are the symptoms and signs of dry skin and nasal mucosa, which are indications of repeated exposure to cold. Different vascular diseases can also arise from cold injury (Tebrock and Fisher 1960) including trench foot, immersion foot, foxhole foot, frostbite, pernio, chilblain, and high-altitude frostbite. To this group also belong "cold sensitivity", Raynaud's phenomenon, cutis marmorata, and cold allergies. Hypersensitivity to cold is probably a pathophysiological phenomenon: exposure to cold causes progressively more harm because the symptoms become more severe after each winter.

Raynaud's phenomenon is a symptom of vasospastic disorder occurring during general and/or local exposure to cold. Depending on the etiology, Raynaud's phenomenon is classified either as primary or secondary. In the "primary" Raynaud's disease, the etiology of the disease is unknown but symptoms occur in 6-12% of individuals among populations (primarily in females), and both local dysfunction (hyperactivity) of the adrenergic receptors and enhanced centrally-mediated autonomic nervous responses have been hypothesized. Among the "secondary" Raynaud's phenomena, vibration-induced white finger (VWF) is one disorder that occurs after prolonged exposure to vibration. For the etiology, enhanced sympathetic output and/or local fault in the receptors has been proposed. The prevalence of VWF varies, and is from 7-40% among forest workers. This Raynaud's phenomenon can constitute a serious handicap in cold environments. Since the etiology is unknown, efforts should be made to clarify the pathophysiological mechanism leading to the symptoms. Such efforts have recently been made by determining the role of central autonomic mechanisms and local vascular-bed responses to cold (Gemne et al. 1986; Pyykkö et al. 1986a, 1986b).

4.5 Research needs

The reason for heat intolerance in untrained subjects with poor physical fitness and in some patients with a marked disturbance in the autonomic nervous system (e.g., diabetics and alcoholics) has not been explored yet, though a defect in the function of the autonomic system might be the immediate cause. More research in causal mechanisms is needed.

Specific research needs are studies on:
(1) patients with deteriorated cardiovascular functions in the heat which may increase the risk for heat-related disorders,
(2) pregnant workers under heat and cold stress and the effect of heat on spermatogenesis,
(3) workers exposed to frequent drastic thermal transients: cold storage workers, bus, tractor, and other work vehicle drivers, and postmen,
(4) people suffering from skin diseases such as deranged cutaneous sensation, vascular regulation or sweating, and
(5) combined effects of thermal distress and drug abuse, smoking, ethanol, xanthine beverages, medication (especially psychopharmacological agents), and ß-blockers.

5. PERCEPTION OF THERMAL SENSATIONS

5.1 State of the art

The definitions used in this chapter for the different types of response decrements to repeated stimulus presentations are in general use in psychophysiology, physiological psychology, and neurophysiology. Response decrements due to processes in the sensory cells (adaptation) or effector cells (e.g., fatigue in muscles) are not dealt with in this chapter. The interesting pro-cesses are the synaptic changes involved in the identification of nonsignals, and in particular, cognitive processes. When these deal with stimulus expectancies, they are referred to as defense; when they are related to response outcome expectancies, they are referred to as coping. Extinction, which is due to changes in reinforcement conditions such as lack of positive reinforcement or punishment, may also be involved.

Whether a thermal climate is classified as comfortable or not depends in part on the quality of the perception it produces. The engineer might prefer to classify climates according to physical terminology, but most people prefer to classify thermal climate according to perceptual quality. It would be desirable to have a model that would relate thermal perception (cold, warm, drafty, humid, etc.) to physical measurements of climate factors, as well as having another model which would, in turn, relate the quality of the thermal perception to the comfort/discomfort produced by thermal factors. Unfortunately, our knowledge is not extensive enough to allow the development of general models, but some specific models have been applied to certain conditions.

It is important to establish indices based on physical measurements which correspond to the thermal-perceptual qualities produced by different climate situations. However, these qualities are functions of not only environmental factors and thermoregulation but also of a set of personal and psychological factors such as expectation, habituation, and social activity. A number of climate indices are probably needed, based on different physical parameters, each one designed for a specific purpose.

The skin senses are stimulated by the temperature of the air and the surrounding surfaces. These senses are very sensitive to temperature changes that are so rapid that the perception of neutral temperature cannot be kept by sensory adaptation. Thermal sensation is not only dependent on the air temperature but also on the duration of stimulation, the body area stimulated, and the thermal balance of the body. Although much is known about thermal perception, it is not possible to predict a perception from a certain pattern of stimulation. Most of the knowledge in perception concerns small body areas and less is known about whole body exposures. Different kinds of equations have been developed that are used for predicting thermal perception from physical variables (Fanger 1970; McIntyre 1980). The most common aim is to predict thermal comfort in various environmental contexts. Therefore, it is especially critical that the perceptual attributes are measured in a fashion appropriate for the problem, for example, thermal comfort, feeling of warmth or coldness. Each of these will need its own equation for predictions.

Thermal perception can be divided into whole-body perception and perception of local effects originating in the human skin. Whole-body perception is significant for the interpretation of the level of the ambient temperature. Local perception is important for the phenomenon of draft, radiant asymmetry, sensation of cold and warm feet created by floor temperature, and the impact of vertical air temperature gradients.

Most of the present research literature has covered human perception when exposed to steady-state environmental conditions, while little has been done on the impact of thermal transients. Transients comprise the fast changes appearing in turbulent air movements in the occupied zone of the ventilated spaces as well as the step change occurring when moving from outside to inside or between different air spaces.

The relationship between thermal comfort/discomfort and thermal sensation has been investigated in a number of laboratories (McIntyre 1980), including both whole-body studies and studies of local effects. The context under which the data were collected limits the implementation of the results. So far, field studies have only provided limited information.

5.2 Methods for measuring subjective attributes of thermal environments

Various procedures have been used to evaluate people's responses to thermal climate (Levey 1980). Research starting in the early 1960s has shown that comfort/discomfort and other complex psychological attributes can be scaled by direct ratio scaling methods (S.S. Stevens 1957, 1975). These methods have become known as absolute scaling methods, that is, absolute magnitude estimation and absolute magnitude production (e.g. Baird and Noma 1978).

In addition to ratio scales of perceived sensations (S.S. Stevens 1975; Marks 1974), these absolute scales are expected to provide not only the slope of the functions but also the absolute perceptual scale values. Assuming individuals use the same subjective units for different subjective variables, equality of assigned numbers would predict equality of subjective magnitudes. In controlled laboratory experiments this assumption might be justified.

One of the central problems in assessing the perception of thermal climate is that different persons may be required to make judgments of different climate situations, widely separated in time and space. It is then dubious to compare judgments across conditions because of individual differences in people's perception of climate and in their response behaviour. One way to deal with this problem is to construct a "master scale" that can be used as a common reference for all judgments of climate conditions independent of the judgment peculiarities of individual subject groups. Such a scale provides a defined unit of measurement of the attribute. When applied to a psychophysical problem, the target climate can be expressed in terms of the perceptual or physical units of the master function (Berglund et al. 1983).

Another way of solving the problem that direct scaling methods do not give any direct "levels" for practical use and for interindividual evaluative comparisons has been proposed by Borg (1961). When comparing different individuals, the perception at the "maximal intensity" (or close to maximum, as in a voluntary maximal performance during an exercise test) can be set equal for all individuals, independent of the different stimulus intensities and the different numbers used in a magnitude estimation task. The total range, that is, the variation from zero (or an extremely low intensity) to maximum, can then be used as a "frame of reference" for interindividual comparisons.

5.3 Research needs

A major task is to develop appropriate methods to scale psychological attributes or the specific subjective response to thermal climate.

Specific research needs are as follows:
(1) methods to determine and measure subjective attributes of climate effects, e.g., comfort, thermal intensity, freshness, etc.,
(2) development of climate indices with reference to specific effects on people, e.g., discomfort, and performance interference,
(3) the draft phenomenon and its causes, especially the impact of turbulence intensity of moving air,
(4) thermal transients and models of human response to step changes and temperature profiles typically occurring in buildings, and
(5) the relationship between comfort/discomfort and thermal sensation in a wide range of field situations.

6. BEHAVIORAL EFFECTS

Man's behavior is constantly being affected and modified by the thermal climate, just as he also actively affects his own microclimate by adapting his clothing or changing his work rate to achieve maximum comfort. Thermal stress may affect behavior in many ways and at many levels, both directly through changes in physiological capacity and indirectly via effects on the central nervous system.

Research on the behavioral effects of thermal climate developed markedly after the Second World War with the increased strategic importance of climatically extreme areas (Burton and Edholm 1955). Military research was generally conducted under severe conditions on selected groups of well-trained men, and the results are therefore not always relevant to everyday occupational conditions. In recent years the issues of energy conservation and accident prevention have helped renew the interest in research on the effects of less extreme thermal stress.

A basic problem is the measurement and definition of the independent variable, the climate effect. A definition in terms of physical parameters must include specification of clothing and activity of the subjects. Even in the same thermal climate, considerable differences in physiological reactions may be found between individuals. Monitoring physiological reactions to thermal stress, usually skin and body temperatures, may also present difficulties. Thus, for example, under conditions of rapid change, surface skin temperature measurements do not always accurately reflect the temperature of deeper-lying tissues.

Behavioral reactions can be assessed as follows: as effects per se, as indicators of a biological process, and as indicators of a risk factor. The effects of thermal stress on behavior can be broadly defined in three categories: local effects, primarily on manual functioning; central effects on mental processes; and general effects on social and complex behavior patterns.

6.1 Local effects

The particular difficulties in adequately protecting the hands from the thermal environment without impairing manual function have been a focus of interest in both military and industrial research. While there is little evidence that heat affects manual tasks negatively, other than when sweating causes the hands to become slippery, research on behavioral effects of cold has been largely concerned with the local effects of cooling of the hands. The existing evidence indicates that the degree of cooling of the hands themselves determines manual functioning capacity, while cooling of the rest of the body has less effect (Gaydos and Dusek 1958). Manual performance in the cold has been summarized in several reviews (Provins and Clarke 1960; Fox 1967; Enander 1984).

During the 50s and 60s much work was devoted to attempting to establish "critical limits" in hand skin temperature for unimpaired manual performance (R.E. Clark and Cohen 1960; R.E. Clark 1961). Manual functioning was thought to remain fairly stable down to a certain hand skin temperature, below which rapid deterioration would set in. More recent research (Meese et al. 1984) indicates that the deterioration in manual dexterity is gradual and can be demonstrated at relatively high finger skin temperatures. The complex interactions between cooling, task variables and individual factors suggest that the term "critical limits" has little practical relevance.

While decrements in manual dexterity have been established for a great number of tasks and cooling conditions, no systematic work has been conducted to study the factors aggravating or ameliorating these effects. Among the few factors studied have been the significance of training conditions (R.E. Clark and C.E. Jones 1962) and auxiliary heating of the hands (Lockhart and Kiess 1971). In view of the many occupational situations where manual work must be carried out in the cold, the question of optimal training conditions, work routines, and rewarming activities deserves high priority. The considerable individual differences in reaction to cold indicate that possible risk groups need to be identified.

6.2 Central effects

Central effects of thermal climate have been studied using a wide range of tests of, for example, vigilance, cognitive ability, memory, tracking, etc. The most sensitive tests seem to be those requiring continuous and prolonged accuracy and divided attention. However, recognition memory has also been shown to be affected in the region 20-30°C air temperature (Wyon 1969; Wyon et al. 1979).

Studies of the effects of heat on central processes have been summarized in several reviews (Grether 1973; Hancock 1981). There appears to be little negative effect, and often even improvement, on many tasks up to an Effective Temperature Index of 29-30°C. On the other hand, a reduction of work rate may take place below 29°C Effective Temperature to maintain thermal comfort. Above this limit, performance tends to deteriorate. Generally expressed, performance decrements are thought to occur when complete thermo-physiological compensation is no longer possible. There is, however, a complex relationship between climate effect, task demands, and individual characteristics such as skill and experience. Such interactions have generally been discussed in terms of arousal (Poulton 1976), for example, performance on a non-arousing task would benefit from the arousal created by the addition of high levels of heat stress, while with a more demanding task, heat might create an overload situation with subsequent task decrements. However, the post hoc nature of arousal interpretations of complex data tend to be weak in predictive power.

A thermal environment leading to optimal comfort does not necessarily promote optimal performance, but the long-term effects of conflict between comfort and performance in terms of subjective cost are not known. The complex effects of heat alone and in combination with other stressors are, as yet, far from satisfactorily established, and there is little theoretical basis for prediction of performance in heat.

Cold has generally been thought not to affect central processes, at least not until cooling becomes more extreme and body core temperature is low. Thus, performance on cognitive and memory tasks have been found to remain unaffected even at low levels of exposure. Recent work (Ellis 1982; Ellis et al. 1985) does indicate an increase in errors on tasks requiring rapid, accurate responses during cold exposure. Effects of cold on central processes have been discussed in terms of arousal or distraction effects, although the hypotheses generated from these theoretical viewpoints have as yet had little predictive value.

6.3 General effects

Mental irritation and distress arising from thermal stress are mentioned in passing in several research reports, but there has been almost no systematic study of the significance of mood changes on social and complex behavior. An increase in unsafe behavior at workplaces has been reported at temperatures above and below a comfort zone between approximately 17-23°C WBGT (wet bulb globe temperature) (Ramsey et al. 1983). After-effects and social consequences of work in thermally stressful environments have not been studied.

6.4 Research needs

Specific research needs are studies on:
(1) manual functioning in the cold, in view of the significance of the "cold hand" problem in terms of productivity and accident risks, and its relationship with training conditions, work routines, experience, etc.,
(2) interactions between thermal stress, comfort/discomfort and performance, including possible acclimatization or habituation effects on behavior, and individual differences,
(3) possible central nervous system effects of cold since even small negative effects may have a considerable impact on industrial and transportation safety, and
(4) after-effects of thermal stress, both in terms of analysis of the process of recovery and of possible social consequences.

7. ACCIDENT CAUSATION

7.1 State of the art

Thermal stress at the moderate (10-30°C) levels commonly occurring in buildings can increase accidents by up to 30 percent (Vernon 1936). Other factors interacting with thermal causation of accidents are sex, age, fatigue, noise, vibration, and task demands. The physiological effects of thermal stress would not predict and cannot explain all of these interactions; behavioral responses to thermal stress must be invoked.

Thermal stress reduces the total capacity of a human subject to perform useful work; at the same time it increases the difficulty of the primary task. For instance, the subject must compensate for his reduced manual speed and skill in the cold, for his tendency to fall asleep, and his slippery hands in the heat. To do this, he must use some of his spare capacity, normally used to perform the secondary task of avoiding accidents. Eventually, when the demands of the primary task begin to exceed total capacity, accidents will happen. Long before this, the subject begins to compromise, to perform the primary task less well in order to have some spare capacity available to attempt to avoid accidents. Thus, a study of accidents and accident causation can indicate the existence and probable causes of reduced productivity, which is usually much more difficult to study directly than accidents.

7.2 Research needs

Specific research needs include studies on:
(1) the mechanisms of accident causation,
(2) accident frequency and types of accidents in order to verify the mechanisms of accident causation identified in the laboratory, and
(3) interactions between thermal stress and other, non-thermal factors in accident causation.

8. THERMAL INDICES

8.1 State of the art

Environmental factors which are of importance for the heat exchange between a person and the environment are: temperature (air, radiant), air velocity, and water vapor pressure. Heat exchange takes place through convection, conduction, radiation, and evaporation. The size and direction of the exchanges are mainly determined by the temperature gradients (and water vapor gradient) between skin or clothing surface and the environment. Other factors may influence sensation such as thermal asymmetries, the person's recent thermal history, and his own individual make-up. With appropriate clothing, variations in environmental temperatures between -50°C and +70°C are tolerated (Wenzel and Piekarski 1982), although all conditions are not equally comfortable or acceptable, and some may be endured only for a limited time (Nishi and Gagge 1974).

For the environment to be found comfortable, the range of the thermal variables is rather narrow (Gagge et al. 1941). Conditions which are felt to be comfortable are such that they activate the physiological mechanisms only to a small degree. Cool or cold environments are conditions in which the heat conservation mechanisms are active (vasoconstriction, shivering, etc.), while in warm or hot conditions, the heat loss mechanisms (sweating, vasodilation) are active. Thermal comfort is defined as a condition in which the subject would prefer neither warmer nor cooler surroundings (Fanger 1970). It should be noted that sweating is not necessarily considered uncomfortable in conditions that permit adequate evaporation from the skin.

The much wider "prescriptive zone" or "thermoregulatory zone" is the range of environmental temperatures where thermal balance can be maintained (Lind 1963). The upper and lower critical temperatures denote thermal conditions in which the person is unable to maintain heat balance during a given activity, and in which the core temperature rises or falls. If it is necessary to be exposed to such environments, limits must be set for the time which can safely be spent in them.

The purpose of thermal stress indices is to evaluate the combined effect of the environment factors on the person, and to predict his/her physiological and subjective response to the environment. Over the years many thermal indices have been proposed for predicting or evaluating comfort and heat or cold stress. The term "index" here refers to any integrated measure of environmental conditions. Some indices or models describe the thermal stress on the organism but take no account of the control of the biological effects of thermal stress. Other indices or models focus on the thermal strain in the body by also considering measures of body state. The early comfort indices, like Effective Temperature (ET) were based on extensive observation in the laboratory or in the field. In principle, these indices were the result of statistical analysis of the experimental data on which it was based. Such data were applicable for lightly-clothed sedentary subjects. The accuracy of the indices for other conditions is limited.

New indices like Fanger's Comfort Equation and Standard Effective Temperature (SET) start from the premise that it is possible to define the comfortable state of the body in physiological terms (mean skin temperature, skin wetness, etc.) rather than the environment. The recognition that the comfortable levels of skin temperature and sweat rate were affected by activity level allowed the construction of comfort equations which apply over a wider range of variables than the earlier indices. The index Predicted Mean Vote (PMV) is claimed to predict the thermal sensation, as expressed on the 7-point scale of ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers), for any given combination of the environmental variables. When extending the range of application for the index from lightly clothed sedentary subjects to a wide range of conditions, the thermal sensation at a given activity level is proposed to be a function of the thermal load of the body. The thermal load is defined as "the difference between the internal heat production and the heat loss to the actual environment for a man hypothetically kept at comfort values of the mean skin temperature and the sweat secretion at the actual activity level" (Fanger 1970). The thermal load is thus an expression for the physiological strain upon the effector mechanisms of the body. Fanger's comfort equation is today accepted worldwide. In ISO standard 7730 (1984b), the PMV index is used for evaluating moderate thermal environments.

For estimation of heat stress, ISO has chosen the WBGT-index (wet bulb globe temperature). The WBGT-index was originally designed (Minard 1961) for the purpose of enabling military officers to judge whether the outdoor environment was too severe for military exercises. It combines in its original form dry and wet bulb temperatures and includes a measure of radiation by use of the globe thermometer. As the index is now specified in the ISO standard 7243 (1982), the dry bulb temperature is omitted when used indoors or outdoors with no sunshine.

There are many other indices for estimating hot environments, but WBGT is now the most accepted. The reason for this lies in its simplicity and ease of measurement relative to most other indices. However, Kerslake (1972) has argued that WBGT is theoretically inadequate as a predictor of heat stress if applied over a wide range of environmental variables.

On the cold side, the most widely used index is the Wind Chill Index (Siple and Passel 1945). The wind speed and air temperature are combined into index values that can be linked to sensory and physiological effects from "pleasant" via "exposed flesh freezes" to "intolerable". This index has serious disadvantages when used as an index to predict the heat loss from a clothed person (Wyon 1989a), but it can satisfactorily help in predicting the cooling effect on bare skin and has proved useful in practice. Holmér (1984a) has proposed a new index IREQ (required insulation of clothing) which can be used for cold and moderate wind-speeds but which needs to be further evaluated.

All indices or models of thermal effects have been developed for specific purposes (environments) and have mostly very definite limitations for how and when they can be used in a meaningful way. Models have proved to be very useful in simulation studies of different climates and in forecasting thermal stress/strain in specific situations. Comfort models are primarily intended as a means for adjusting thermal climate conditions to optimal comfort. Indices such as PMV express the deviation from comfort, but the gradings are on a rank order level which restricts their use for calculation and comparison purposes. The choice of an adequate index for use in a specific situation should not only be governed by the biological meaningfulness of the index, but also simplicity in handling, and a long history of experience with the index will count.

8.2 Research needs

Specific research needs include studies on:
(1) how specific indices work in different environments, including comparative studies and evaluations of validity in real-life situations,
(2) practical, meaningful, and reliable psychometric measurement methods which allow for a grading of sensations/perceptions on an adequate measurement level,
(3) criteria for discomfort and methods which take into account individual differences in preference and value judgements (response criteria),
(4) influence of local effects such as local cooling when people are not in thermal comfort, and the relationship between mean skin temperature and local deviations not accounted for in the calculations of the mean, and
(5) physiological indices of asymmetries in body heat exchange with the environment, e.g., based on heat-flow differences between parts of the body.

9. INSTRUMENTATION FOR THERMAL MEASUREMENTS

9.1 State of the art

A wide range of instruments is available for measuring the main physical parameters in relation to the thermal indoor climate. The basic parameters are: (1) air temperature, (2) mean radiant temperature, (3) mean air velocity, and (4) air humidity.

The international standard ISO 7726 (1984a) specifies how to measure these parameters and to which accuracy they should be measured. Derived parameters that integrate the effect of two or more of the basic parameters, and perhaps also the clothing and activity of the persons, are also possible to measure directly by special instruments. For practical field measurements of all the below-mentioned parameters, there are reliable instruments with reasonably short response time (short time constants for the transducers). Examples of the derived parameters are:
(1) operative temperature which combines the effects of air temperature, radiant temperature, and air velocity (ISO 7730 1984b),
(2) directional operative temperature (Swedish: "Riktad operativ temperatur", ROT), which is the operative temperature measured in relation to a small plane surface,
(3) WBGT (wet bulb globe temperature), which is a parameter used specially to describe thermal stress in hot environments (ISO 7243 1982), and
(4) PMV/PPD (predicted mean vote/predicted percentage of dissatisfied) for use in moderate thermal environments (ISO 7730 1984b).

Research work on draft (Fanger and Christensen 1986) has shown that the mean air velocity is insufficient to describe the air movements when draft problems can occur. There is a need for instruments that, besides the mean air velocity, can also measure standard deviations of the air velocity (or the turbulence intensity) over a selectable time period.

Research work is being done on the development of a new generation of thermal manikin (human analog) that can sweat. Sweating is an important parameter when simulating warmer conditions and conditions with a higher activity level than sedentary. A thermal manikin is a valuable instrument and can, in some cases, save many experimental hours with human subjects in laboratory investigations. However, manikin measurements are not standardized. Recently, inter-study comparisons have been undertaken. Furthermore, measurement with a thermal manikin can never overrule the measurement result of perceiving subjects. On the other hand, manikin measurements are sometimes necessary to assess subject response in complex environmental settings.

No special instruments are available for measuring cold indoor climate, probably because there is no common index to describe such conditions. The Wind Chill Index (Siple and Passel 1945; Wyon 1989a), which combines the effect of air temperature and air velocity, is primarily for outdoor use.

9.2 Research needs

Specific research needs are:
(1) more accurate instruments for measuring air velocity, variability, and turbulence intensity,
(2) manikin measurement methods in order to achieve reliable and reproducible results on different manikins, and
(3) instrumentation for measuring derived thermal parameters in cold indoor climate.

10. CLOTHING

Clothing is one of the primary factors that influence the human body's heat exchange with the environment (Newburgh 1949; Fourt and Hollies 1970). Clothing is part of the boundary layer between the human body and the environment and thus affects heat exchange by modifying thermal insulation and impeding evaporative heat loss. Since thermal properties of clothing are components of the human heat balance equation, clothing is an important means of adjusting to the thermal environment (Siple 1945; Belding et al. 1947; Belding 1949). Selection of clothing to satisfy thermal neutrality (comfort conditions) may be based on the required basic insulation as predicted by, for example, a comfort equation. Similarly, selection of adequate protective clothing for extreme environments should be based on predictions of thermal stress. Predictions of the physiological strain associated with wearing work or protective clothing in thermal environments provide a basis for risk assessment and work organization (Ilmarinen 1978).

The thermal properties of clothing are thermal insulation and water vapor diffusion resistance (Cena and J.A. Clark 1979). Thermal insulation (I) is defined principally by the expression

$$I = \frac{\Delta t}{R + C}$$

where t is the temperature gradient across the clothing layer and R+C is the heat exchange by convection, radiation and conduction in Wm^{-2}. Water vapor diffusion resistance is defined in terms of vapor pressure difference across the clothing layer, in Pascal, and the rate of heat exchange due to evaporation, in Wm^{-2}.

Insulation is defined for fabrics and garments and for various conditions as well (Seppänen et al. 1972). Insulation of fabrics or garments is primarily determined by the trapped air layers between fibers and layers of the system. The insulation properties of the fiber material are of minor importance for the resultant insulation value. Water vapor resistance may be defined for fabrics as well as for garments. It is determined primarily by the porosity of the material (fabric) and its absorption properties (Fujitsaka and Ohara 1977; Holmér 1984b).

The thermal properties of garments are significantly different from the properties of fibers and fabrics due to the influence of size, form, drape, layer effects, etc. It is therefore necessary to measure the thermal properties of garments and clothing systems when on humans or on thermal manikins. Predictions based on fiber or fabric properties are poor.

10.1 Methods

As mentioned, measurements of thermal properties of textile fibers and fabrics are of limited value for the prediction of the thermal function of garment assemblies or clothing systems, although some prediction models have been suggested (Sprague and Munson 1974). Thermal insulation and evaporative resistance of clothing are best measured on man-sized, thermal manikins or human subjects.

A thermal manikin simulates the heat exchange of the human skin (Olesen et al. 1982). The complete "skin" surface of the manikin is heated in one or several independent zones. The power required to maintain the "skin" at a constant temperature or temperature distribution under equilibrium is a measure of the heat exchange. Manikins have been developed for static measurements, standing or sitting, and measurements during body movements (Wyon 1989b). A thermal manikin allows quick and reproducible determinations of thermal insulation of garments and garment assemblies. The more sophisticated manikins allow measurements of regional heat loss and, accordingly, regional variation in the insulation of clothing.

Thermal insulation may also be measured on subjects. Convective and radiative heat losses are determined during steady state conditions by indirect calorimetry (Mitchell and van Rensburg 1973). Due to intra- and interindividual variation, the error of this method is fairly large. Measurements on subjects are costly and time-consuming.

A direct assessment of the resistance to evaporative heat transfer by clothing is best made on subjects. Simultaneous measurements of evaporative heat loss and skin-to-ambient water vapor pressure grad-ient under steady state conditions allow determination of the resultant evaporative resistance.

10.2 Factors affecting thermal properties of clothing

A number of factors related to fibers, fabrics, individuals, and environment influence the basic thermal properties (insulation and water vapor resistance). The textile properties related to moisture and water are important (Woodcock 1962). A water-repellant fabric is tightly woven, and reduces the water vapor transfer rate. On the other hand it is difficult to wet, thus minimizing a detrimental effect on insulation. Absorption properties are important as buffers of water vapor under transient conditions. When moving from dry to humid ambient conditions thermal sensation and heat exchange are affected by the absorption or evaporation of moisture in clothing. In the presence of sweating, clothing may absorb some moisture and increase the skin comfort. However, with profuse sweating, the moisture absorption of clothing layers may be so high that the insulation is reduced and post-chilling due to re-evaporation of moisture is significant. With profuse sweating a porous, nonabsorbent material may be worn close to the skin, allowing vapor to pass to more distant layers in the system before condensing or passing to the environment.

Reflective properties of textiles affect the radiation heat exchange. Color of surface is important for the energy exchange by shortwave heat radiation (visible spectrum). Surface structure is important for the heat exchange by infrared radiation. A polished, glossy surface may reflect >90% of the radiation, while a black and matted surface reflects <10% and, in other words, absorbs >90% of the incoming radiation.

The resistance of fabrics and fibers to chemical and physical factors may affect heat transfer. Preparations to reduce flammability, etc., sometimes interfere with moisture permeation properties. Similarly, properties related to resistance to penetration by chemicals significantly interfere with moisture permeation properties. Resistance to wind penetration necessitates wind resistant (proof) fabrics. This property is contradictory to water vapor permeability and therefore increases evaporative resistance.

When it comes to garment properties, all factors that change the amount and distribution of trapped air in garments and between layers will modify the thermal properties of the system. An identical garment of a bigger size will have a higher insulation value on the same subject, but not necessarily on a bigger subject, who fits into the garment. Design is important. Loose, wide clothing has a higher insulation value than tight clothing. Type of material has little effect on insulation (Rodahl et al. 1973; Holmér 1985). More important is the construction, such as knitted material versus woven material. Knitted fabrics, for example a fiber pile or wool sweater, trap a thicker layer of air compared to plain fabrics and have higher insulation values. Design of a garment is also important for chimney effects and bellows ventilation (see below). The effect is facilitated by loose and open clothing with no restrictions (e.g., by a belt at the waist).

Insulation of a garment is dependent on the percentage of coverage of the body surface. By definition, the clo-value relates to the whole body surface area. Thus a mitten has a very low clo-value in terms of whole body protection, but it may have a very high local insulating effect on the hand. Similarly a t-shirt has a lower clo-value than a long-sleeved shirt made of the same material. Distribution of insulation over the body surface is important not only for local heat exchange, but also for whole body insulation, due to variation in thermoregulatory responses. Thermal insulation and evaporative resistance are dynamic properties of a clothing system. The basic values determined under standardized and static conditions do not immediately apply to all sets of environmental conditions under which the garments may be worn.

Insulation of a garment varies with body posture due to changes in drape, fit and compression (Olesen et al. 1982). With body movements the air exchange of the clothing microclimate is increased as a result of pumping action (Vokac et al. 1972; Birnbaum and Crockford 1978; Vogt et al. 1983). This ventilation increases both convective and evaporative heat exchange and, accordingly, reduces the resultant values for insulation and evaporative resistance of the clothing system.

Wind may reduce the thermal properties of clothing by penetrating the pores of garment fabrics and thus increasing the convection (microclimate ventilation). At higher wind speeds, compression of the material may reduce the resultant thermal insulation. The magnitude of these effects varies with air permeability of fabric, design, stiffness, and number of layers of clothing. The effects of laundering and wear on the thermal properties of clothing are insignificant (Breckenridge and Goldman 1977).

10.3 Research needs

Specific research needs are studies on:

(1) validity of standard laboratory measurements of clothing thermal properties for field application,

(2) modification of standard values for use under realistic conditions (influence of wind, activity, wetting, etc.),

(3) validation of heat balance equations for prediction of thermal effects,
(4) local heat exchanges and their significance for total heat balance, physiological strain, and thermal perception,
(5) effect of clothing on heat exchange under transient climatic conditions and/or intermittent work,
(6) effect of clothing on radiant heat exchange (solar and infrared),
(7) significance of radiative heat exchange in and between clothing layers (reflecting layers etc.),
(8) efficiency of evaporative heat transfer through cold, moist, and wet clothing,
(9) significance of microclimate ventilation for heat exchange in cold environments and with impermeable clothing,
(10) improvement of instrumentation for laboratory measurements (sweating thermal manikin etc.), and
(11) instrumentation for field evaluation (portable equipment).

11. COMBINED AND INTERACTIVE EFFECTS OF THERMAL AND OTHER ENVIRONMENTAL FACTORS

11.1 State of the art

The number of empirical studies devoted to interactions between the thermal system and other sensory systems is not impressive. Temporary hearing loss or temporary threshold shift (TTS) due to high ambient noise levels may interact synergistically with temperature (Menshov et al. 1984; Rentzsch et al. 1984; Manninen 1985). There are also some reports claiming that temperature interacts synergistically with vibration in producing TTS (Menshov et al. 1984; Manninen 1985).

A number of interactions take place within the cutaneous senses. Many skin receptors respond to at least two classes of environmental stimuli. This phenomenon has been widely reported for temperature and pressure (e.g., Hensel and Zotterman 1951). In the famous experiment by Weber (1846; revisited by J.C. Stevens and B.G. Green 1978), a cold silver coin placed on the forehead felt as much as two times heavier than one with a neutral temperature. The same holds for a warm coin. It has also been shown that sensory thresholds depend on the local conditions of the skin. Most important is the skin temperature. Warming and cooling the skin can affect the sensitivity to punctuate-touch stimulation, the sensitivity to vibrotactile stimulation, and the magnitude of touch sensation (J.C. Stevens 1979).

According to Melzack and Wall (1962), it is likely that the transducer activities of virtually all mechanoreceptors are modified by warming or cooling of the skin. However, the authors emphasize that this does not mean that every receptor responds to the full range of all environmental stimuli.

Melzak and Wall (1965), in their gate-control theory, suggest that the coactivation of certain mechanoreceptors may have an inhibitory influence in the central nervous system on the nociceptive input (input modulation; see also Melzak and Dennis 1978). For example, mechanical stimulation of multimodal nociceptors together with excitation of mechanoreceptors does not necessarily provoke pain, whereas chemical and heat-induced nociceptor stimulation of the same intensity does (van Hees and Gybels 1981; Hensel 1982).

The sensory thresholds also depend on the stimulus duration and the total stimulus amount. A series of sub-threshold stimuli directed to the same skin spot may result in a perception that the sensation threshold has been exceeded (R.T. Green 1962). The threshold is influenced by general factors such as age, anxiety, attention, and other sensitivity variables. As mentioned earlier, hyperemia of the skin can lower the threshold for prick, pressure, and thermal stimulation.

Nasal symptoms have been shown to be dependent on the condition of the autonomic nervous system. Exposure of the skin surface to infrared rays has been reported to change nasal resistance to airflow (Hill 1931, 1932). Similarly, warming of the skin causes a reflex nasal congestion (Cole 1954; Drettner 1961).

One theme in thermal comfort research has been to find out whether a person's choice of comfort temperature is affected by nonthermal factors. The influence of color and noise on thermal comfort was studied by Fanger et al. (1977) who found no significant effects.

Poulton and Edwards (1974) investigated behavioral responses such as tracking, vigilance, and a five-choice task under combinations of mild heat and low-frequency noise. They reported that the combined effect of heat and noise was smaller than their sum, in other words an antagonistic interaction. Bell (1978) found performance decrements associated with high noise and high temperature, but no interaction between them. Viteles and Smith (1946) reported no effect of noise and an effect of temperature only at the highest level (37°C) for a group a Naval recruits who worked for seven weeks on seven demanding tasks. In a reanalysis, Wilkinson (1969) found a significant positive effect of noise at the intermediate temperature (31°C), and a significant negative effect of noise at the highest temperature. Wyon et al.

(1978) had boys perform various tasks at 20, 23.5, and 27°C in quiet and noisy conditions. The noise had no reliable effect on most of the tests, but an open-ended creativity task yielded better performance at 27°C in the quiet, while no effect of temperature was found in noise on this task.

A counteracting effect of heat and noise in a five-choice serial reaction task was reported by Wyon et al. (1978). At 30°C, noise of 85 dB(A), in contrast to 50 dB(A), increased the proportion of coordination errors in subjects who found the tasks easy and the climate condition uncomfortably hot.

To explain any interaction between heat and noise on behavior and performance, the inverted U-hypothesis and Easterbrook's (1959) cue-utilization hypothesis have been widely used (Hockey and Hamilton 1983). The idea is that noise increases arousal and mild heat stress decreases arousal. High arousal reduces the utilization of secondary cues while low arousal increases it. However, marked heat stress in the form of uncomfortable heat will add to the arousal from loud noise, and, if the arousal passes the maximum of the inverted-U curve, performance deterioration is to be expected.

Interactions between heat and noise have been questioned (Broadbent 1971; Hockey 1979; Hockey and Hamilton 1983; D.M. Jones 1983; Poulton 1966). Hockey and Hamilton (1983), for instance, stated that heat does not normally interact with either noise or sleep loss. Heat may be affecting mechanisms other than those affected by noise, and the arousal concept may not be unidimensional.

11.2 Research needs

Specific research needs are studies on:

(1) heat and noise interactions and underlying mechanisms, and

(2) commensurability of thermal discomfort and discomfort from other sources such as noise, vibration, lighting, air quality, and odor.

12. CODES AND CONTROL ACTIVITIES

12.1 Recommended guidelines

The following guideline values for the thermal climate in dwellings, schools etc. are recommended:

(1) The operating temperature in premises should be between 20°C and 24°C.

(2) The difference in air temperature at the head and feet of a seated individual (1.1-0.1 m above the floor) should not exceed 3°C.

(3) The radiation temperature asymmetry due to the influence of, for instance, a cold window or a cold wall, should not exceed 10°C.

(4) The radiation temperature asymmetry due to the influence of a heated ceiling should not exceed 5°C at a height of 1.1 m above the floor for standing persons, and 0.6 m for seated persons.

(5) The average air velocity at an operating temperature of 20-24°C should not exceed 0.15 m/s. It should be noted that rapid variations in air velocity can lead to drafts even if the average velocity is low.

These guideline values relate to the cold part of the year.

12.2 Research needs

Specific research needs are:

(1) Identification of the most protective but cost-efficient levels for use in thermal stress regulations and guidelines, and

(2) relationships between perceived and factual risks of thermal stress and discomfort.

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CLOTHING: AN ESSENTIAL INDIVIDUAL ADJUSTMENT FACTOR FOR OBTAINING GENERAL THERMAL COMFORT

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In air conditioned buildings where thermal conditions comply with existing building codes and standards, many people often complain of unpleasant thermal sensations. These complaints may often be caused by differences in the occupants' activity level and the fact that people are not alike and may prefer different thermal conditions. In this paper, the important role played by clothing in the attainment of thermal comfort is stressed and it is shown how the clothing may be used to compensate for different activities and personal differences. This phenomenon is analyzed by assessing the sensitivity of the Predicted Percentage of Dissatisfied (PPD) index to the subject's activity and to the thermal insulation of the clothes they wear.

INTRODUCTION

Those who have experience in the operation of air-conditioning systems know that, even though they may be well designed and constructed, they are often the cause of complaints. Especially when windows cannot be opened and if the working environment is large and does not allow differentiated localized adjustments. Even if the results of measurements indicate that environmental parameters are constant over time, uniform and equal to the design values, often there is a large number of dissatisfied occupants. This phenomenon will be analyzed here in the light of the existing and well-established body of theory. It is then suggested that this phenomenon has a much wider scope than has been envisaged by the theory itself.

As is well known, by the Fanger Theory (Fanger 1970), it is possible to evaluate the Predicted Mean Vote (PMV) index which predicts the mean value of the votes of a large group of persons on a seven-point thermal sensation scale, with PMV = 0 for neutral, or comfort condition. The PMV index can be determined when the metabolic rate and the clothing thermal insulation are estimated and the following environmental parameters are measured: air temperature, mean radiant temperature, relative air velocity and relative humidity. By the Fanger Theory, when the PMV value has been determined, it is also possible to find the Predicted Percentage of Dissatisfied (PPD) index that establishes a quantitative prediction of the number of thermally dissatisfied persons.

In the S.I. system the metabolic rate and the clothing thermal insulation are measured respectively in W/m^2 and in $°C \cdot m^2/W$; but often they are measured also, respectively, in met-unit (1 met = 58.15 W/m^2) and clo-unit (1 clo = 0.155$°C \cdot m^2/W$) which will be used in this paper.

ANALYSIS

The analysis performed in this paper is based on the assumptions of winter season, that the facility is operating correctly, environmental parameters are uniform and constant, operative temperature is 20°C, relative humidity is 60%, relative air velocity is 0.10 m/s, and that there is no cause of either local thermal discomfort (excessively warm or cold floors or walls, vertical temperature gradients, air draughts, radiant temperature asymmetry) or other (acoustic, lighting, psycophysical, air impurity, etc.) discomforts.

Under fixed values of physical parameters (air temperature, mean radiant temperature, air velocity, humidity), the comfort condition (PMV = 0) may be established for infinite combinations of metabolic rate and clothing thermal insulation values.

The influence of activity

Assume, initially, that the basic thermal insulation of clothes worn by people occupying the air-conditioned areas is exactly equal to 1.1 clo, that is, corresponding to the following clothes (ISO 1990)

Men: briefs, T-shirt, shirt, trousers, suit jacket, calf-length socks, shoes.

Women: panties, half-slip, pantyhose, long-sleeve shirt, V-neck sweater, skirt, suit jacket, shoes.

From the Fanger Theory we derive that at an operative temperature of 20°C, the condition PMV = 0 (PPD = 5%) holds for a metabolic rate of 74.3 W/m^2 (= 1.3 met), typical of a light activity, like sitting for desk-writing (ISO 1989; Spitzer et al. 1982). Quite obviously, however, if we assume to refer to offices, it may easily happen that an individual, either in the same day or in different days, is engaged in activities associated to metabolic rates ranging from 58 to 114 W/m^2, that is, from 1.0 to 2.0 met [the former value is obtained for a sitting and still individual while the latter refers for instance to an individual typing at a speed of 40 words per minute (Spitzer et al. 1982)]. It may also happen that in the same time and in the same environment people are engaged in different activities.

In order to assess the influence exerted by different types of activities, we have plotted the PPD index in Fig. 1 as a function of the operative temperature; the three curves refer to the three above-mentioned metabolic rates, to a relative humidity of 0.60, to a relative air velocity of 0.10 m/s, and to a basic clothing insulation of 1.1 clo. The diagram shows that for sitting and resting individuals (1 met) and for typists typing at the speed indicated above (2 met), the percentage of dissatisfied individuals at 20°C is 13.8% and 18.3%, respectively, which is clearly above the limit value of 10%, recommended by the ISO Standard (ISO 1984).

To obtain a PPD index of 10%, people working at 1 met should change the clothing up to an insulation value of 1.2 clo (PMV = -0.5) and those working at 2 met up to an insulation value of 0.78 clo (PMV = 0.5). To obtain a PPD index of 5% (PMV = 0), the insulation value has to become respectively 1.6 and 0.44 clo.

The influence of clothing

From a survey of the experimental data on clothing insulation reported in literature (Alfano et al.

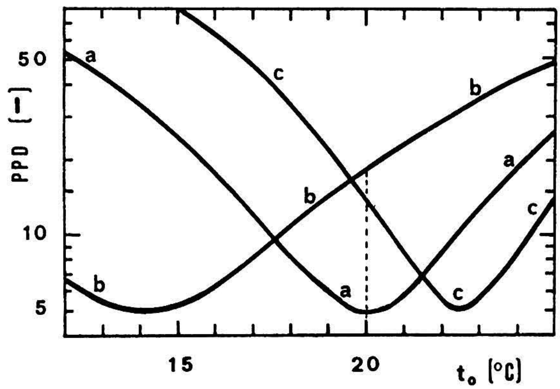

Fig. 1. PPD index as a function of operative temperature for three metabolic rates (curve a: 1.3 met, curve b: 2.0 met, curve c: 1.0 met); the diagram refers to: relative humidity 60%, relative air velocity 0.10 m/s, basic thermal insulation of clothing 1.1 clo.

Table 1. Mean value of basic thermal insulation and associated standard deviation for selected garments with relative changes of comfort-operative temperature (Alfano et al. 1986).

GARMENTS	I_{cl} (clo)	$\Delta t_{o,g}$ (°C)	σ (clo)	$\Delta t_{o,\sigma}$ (°C)
man				
socks	0.05	0.3	0.03	0.1
briefs	0.03		0.02	0.1
T-shirt	0.11	0.6	0.01	0.1
underwear sleeveless	0.04	0.2	0.01	0.1
shirt, short sleeve knit	0.23	1.2	0.06	0.3
shirt, long sleeve	0.25	1.3	0.07	0.4
shirt, long sleeve knit	0.32	1.7	0.08	0.5
sweater heavy	0.30	1.6	0.10	0.5
jacket heavy	0.43	2.3	0.09	0.5
trousers	0.29		0.05	0.3
shoes	0.05		0.01	0.1
woman				
bra and panties	0.04		0.01	0.1
pantyhose	0.02		0.01	0.1
belt	0.04		--	
half slip	0.17	0.9	0.06	0.3
full slip	0.22	1.2	0.04	0.2
dress	0.45	2.4	0.15	0.8
skirt	0.28		0.07	0.4
blouse	0.38	2.0	0.04	0.2
trousers	0.29		0.05	0.3
sweater light	0.17	0.9	--	
sweater heavy	0.30	1.6	0.10	0.5
jacket light	0.17	0.9	--	

1986; d'Ambrosio et al. 1986) it was found that for each garment the standard deviation of thermal insulation is about 30% of the mean value, as is shown in Table 1. This means that two typical winter clothing ensembles, consisting of the same garments, can display thermal resistances which may even differ by 0.30 clo. In order to assess PPD sensitivity to clothing, it can be assumed that this difference amounts to 0.1 clo only. We assume that sitting and still individuals wear clothes whose thermal resistance is 1.0 clo and that typists wear clothes with 1.2 clo of thermal resistance. Under this assumption, the curves PPD,t_o become those plotted in Fig. 2 which shows that, for t_o = 20.0°C, the percentage of dissatisfied individuals rises to 19.6 and 20.8, respectively.

In Table 1 $\Delta t_{o,g}$ is the change in the comfort operative temperature relative to that garment: for example, if a woman takes off a light sweater (I_{cl} = 0.17 clo), the clothing insulation, supposed to be 1.1 clo, becomes 0.96 (0.96 = 1.1 - 0.82·0.17) (ISO 1984; ISO 1990). At this value, the comfort operative temperature, which is 20°C for 1.1 clo and 1.3 met, becomes 20.9°C with a change of 0.9°C. The change in the comfort operative temperature relative to the standard deviation of the insulation value is $\Delta t_{o,\sigma}$. For example, if you wear a heavy sweater with an insulation of 0.40 clo (the mean value plus the standard deviation), t_o becomes 19.5°C with a change of 0.5°C.

Realistic evaluation

For a realistic evaluation of the relationship which exists between the percentage of dissatisfied persons and the variables on which comfort depends, reference must be made to the conditions under which the

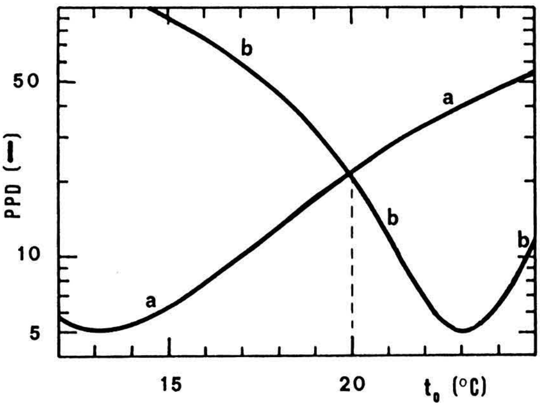

Fig. 2. PPD index as a function of operative temperature for: curve a: M = 2.0 met, I_{cl} = 1.2 clo; curve b: M = 1.0 met, I_{cl} = 1.0 clo. The chart refers to: relative humidity 60%, relative air velocity 0.10 m/s.

experiments by Nevins et al. (1966), Fanger (1970), and Rohles (1970) were conducted and from which Fanger derived both the fundamental comfort equation and the relation (PMV, PPD). As is known, in these experiments:

1) the individuals were always occupied with identical levels of activity and they were all dressed with the same garments which were provided to them by the investigators. Obviously, such conditions prevented the occurrence of those differences analyzed in Section 2;

2) the subjects used for the experiments were all volunteers who received a compensation for their service: psychologically, this may have made them more willing to accept the thermal environment. By contrast, in real-world conditions, problems of work adaptation and/or personal problems may accentuate a light discomfort caused by the environment;

3) in the climatic chambers used for the experimental trials, it was always made sure that no cause of local thermal discomfort existed. Also acoustic, lighting and inefficient air-exchange discomforts were excluded. In real world conditions, however, it is not always possible to eliminate such causes as, for example, acoustic discomfort like the inevitable noise generated by office machines;

4) subjects who were not completely healthy or who had not slept regularly, were not admitted to the trial. Furthermore, 1 h before the beginning of the experiment the participating subjects had a normal meal: it is known, in fact, that states of physical distress, sleepiness and hunger can, in general, lead to environment intolerance;

5) subjects were kept for 3 h in the climatic chambers where constant conditions were ensured. Every 30 min they were asked to give a score, with the final score being derived as an arithmetical mean of the last three scores. This obviously meant that the final score was given to the thermal environment once the human body had reached a steady-state condition. As a matter of fact, owing to continuous changes in activity and to the need of going in and out of air-conditioned environments, the subjects are not always experiencing steady-state conditions.

In order to compare the real-world conditions with those adopted in the trials, we must be aware that:

6) even in the best air-conditioned environment, it is not possible to have the uniform and constant environmental parameters which are found in the climatic chambers for laboratory trials and this may often cause a higher number of dissatisfied individuals than predicted.

It must be observed that the typical curve that gives the PPD index as a function of the PMV index, was computed by considering those who had scored ±2 and ±3 as dissatisfied while considering as satisfied all those who had scored +1 and -1; the latter scores, however, corresponded to the "slightly warm" and "slightly cold" sensations. Many individuals, who are at work, may not be satisfied with a feeling of "slightly warm" and "slightly cold" for 8 h. With respect to this, Table 2 shows the score breakdown of the U.S. and Danish experiments for selected values

Table 2. Breakdown of individual scores of thermal sensation for selected values of the PMV index—from ISO (1984)—and indices indicating the percentage of dissatisfied individuals.

PMV	0	-1	-2	-3	PPD	PPD_{max}
+2	5	20	45	30	75	95
+1	27	48	20	5	25	73
0	55	40	5	0	5	45
-1	27	48	20	5	25	73
-2	5	20	45	30	75	95

of PMV: the one-before-last column indicates the value of the PPD index which, as said earlier, was evaluated by considering only those who scored ±2 and ±3 as dissatisfied. The last column shows the percentage of dissatisfied persons—denoted by PPD_{max}—obtained by including in the dissatisfied group also those who scored ±1: it is surprising that for PMV = 0—a condition for which, on the average, a sensation of comfort is reported—the percentage of dissatisfied persons rises from 5 to 45%.

DISCUSSION

This analysis does not indicate that the PMV-PPD method cannot be used. The purpose of this paper was not to suggest that scarce attention should be paid to the parameters of air-conditioned environments, advocating that there will be a high percentage of dissatisfied individuals. Our aim was to stress that inter-individual differences are large, and that the theory provides comfort conditions for the average man under ideal conditions.

The conclusion from this paper is that clothing is the individual element of fine regulation which is available to the subject. This awareness must be acknowledged and enhanced in those working environments where there are no other means for individual adjustments of the temperature level. To a certain extent, clothing adjustment is used by subjects instinctively. In fact, those prone to feeling cold wear heavier garments than those who tend to feel warm. Such relatively simple concepts must be widely spread and, for example, small cloth-lockers must be made available at the workplaces where a certain number of garments of different thermal insulation can be kept, so as to allow a fine adjustment of individual responses.

Once this habit becomes widespread, with a correctly operated air-conditioning facility the percentage of dissatisfied individuals can practically drop to zero.

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COMPENSATION OF ASYMMETRIC RADIANT HEAT LOSS TO COLD WALLS BY DIFFERENT HEATING SYSTEMS—ANALYSIS WITH THERMAL MANIKIN

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Poor thermal insulation of the external walls often causes thermal comfort complaints in winter due to the local discomfort effect caused by asymmetric heat radiation. There seem to be two solutions for the elimination of this unpleasant local discomfort effect: better insulation of the walls or a more effective kind of heating. In regard of the latter, a series of laboratory tests have been carried out in the Hungarian Institute for Building Science. In the course of the tests, comparisons were made of rooms with one or two outer walls with different insulation capacities (U = 0.6, 0.8, 1.0, and 1.2 Wm^{-2} K^{-1}) and of the changes in the heat transfer of the human body, with the help of a thermal manikin (ÉTIman), a multimember-type aluminum radiator, a radiant panel, floor heating, and wall heating. The results have definitely proved that radiant heatings (panel, wall, and floor heating) exert a more favourable effect on the heat loss of the human body as compared with the traditional multimember-type heating devices.

INTRODUCTION

The information on heating methods can be distinguished based on the effect of the temperature distribution in the heated enclosure (Kollmar and Liese 1957; Wenzel and Müller 1967) or the impact on the thermal comfort of the occupants (Olesen and Thorshavge 1979; Langkilde et al. 1985; Fanger et al. 1980).

During the recent decade, efforts to conserve energy have dominated the field of heating design in Hungary and many other countries. The local discomfort effect caused by asymmetric thermal radiation is considered an important item. The significance of this problem is judged differently because there are fundamental differences in the quality of the thermal insulation of the external walls in different countries. While, for instance in the Scandinavian countries, the overall heat transfer coefficient (the U-value) of the external walls is in the range of 0.25-0.3 Wm^{-2} K^{-1}, the present Hungarian standard prescribes 0.7 Wm^{-2} K^{-1}, and actual values for buildings built 15-20 y ago are 1.2-1.4 Wm^{-2} K^{-1}. Therefore, in winter the poor thermal insulation leads to low temperatures of the internal surface of these walls. Consequently, close to these surfaces the radiant heat loss of the occupants increases causing a local discomfort sensation at certain parts of their body (Bánhidi et al. 1985). Furthermore, next to the cold structure there is an unpleasant feeling, sometimes called radiation draught.

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Obviously, this problem can be eliminated by thermal insulation and by reduction of the infiltration of outdoor air through the windows. These methods are widely used in Hungary. However, there are several limitations to their application due to their costs, inadequate energy savings, technical difficulties, molding, growth of fungi, and condensation problems.

Therefore, the application of new methods has become necessary. A promising method targets the reduction of the radiant heat loss of the human body by proper selection and arrangement of the heat emitters. In heating design, the heat emitters are routinely located in front of cold external walls and below the window. The heat emitters located this way warm up the room air, warm up infiltrating outdoor air, increase the temperature of internal surface of external wall and window, and compensate for part of the radiant heat loss of the human body by the radiant component of their heat emission.

It appears logical to make use of these two last functions in compensating for the radiant heat loss of the human body. This compensation strategy allows the selection of a heating method and a heat emitter based on thermal comfort without increasing the heating requirements.

Accordingly, a comprehensive research project is planned having the following three phases. Phase one consists of the comparison of different heating methods based on heat transfer from the human body, using the thermal manikin technique. The second phase is similar to the first, repeating the above tests with human test subjects. The third phase compares the results of the first two phases in order to draw conclusions concerning the applicability and accuracy of the manikin tests for the prediction of human thermal comfort response and reaction.

This paper presents the results of the first phase concerning convective and radiant heat emitters.

TEST METHOD

The tests were carried out in the test room (5 m × 3 m) of the Microclimate Laboratory of the Hungarian Institute for Building Science (ÉTI). One end wall (3 m × 3 m) and a major part of one adjacent side wall were covered with flat aluminum box panels, in which water was circulated to simulate different cool internal surface temperatures. The end wall enabled the simulation of a window and wall ensemble. The ÉTIman was set in the corner of these two temperature-controlled wall surfaces. The layout of the test room is shown in Fig. 1. The ÉTIman is a full-scale doll. It is a complex system consisting of a thermal measurement system, two-processor control and

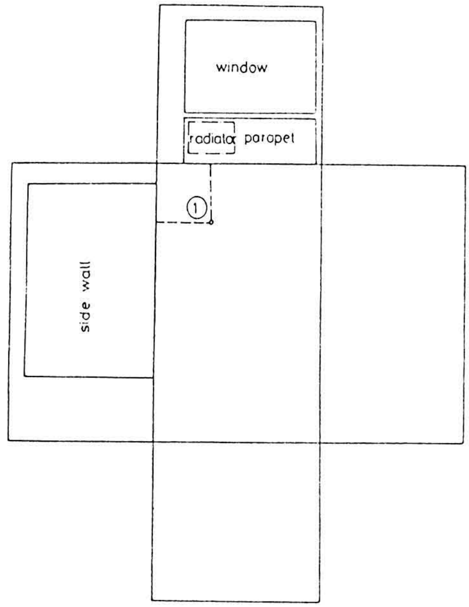

Fig. 1. Layout of the testroom.

measurement data-recording system and a data-processing and displaying computer system. Its operation is similar to the Voltman (Wyon 1982), though there are some differences in the mechanical construction of the measuring body. The surface of Étiman is divided into 18 segments, each kept at the same surface temperature as the corresponding part of a human body. Fig. 1 shows the manikin sitting in front of a heating radiator. The system permits the collection of a great deal of information. During this study, three sets of data were collected, as follows: (1) heat loss per unit surface area of the different parts of the body, assigned as P_i(Wm^{-2}; i = 1, 2, ..., 18; (2) thermal resistance of clothing covering the body parts, assigned as Clo_i; i = 1, 2, ..., 18): (3) equivalent homogenized temperature, that is the "perceived" temperature, as the different body parts feel, assigned as EHT_i (°C); i = 1, 2 ..., 18).

For each of these parameters a mean value was computed for the whole body and as counted surface, assigned as P_{tot} (Wm^{-2}), Clo_{tot} (clo) and EHT_{tot} (°C).

Tested combinations of radiator and cool wall surface

Taking into account typical Hungarian conditions, the following U-values were assumed for external building shell components: 3.0 $Wm^{-2} K^{-1}$ for windows, 0.6, 0.8, 1.0, and 1.2 $Wm^{-2} K^{-1}$ for walls and parapet. For reference temperature, the following values were assumed: outside ambient temperature t_o = -2.0°C (average outdoor temperature in Hungary in January); room air temperature: t_a = 18, 20, 22°C, as prescribed in the Hungarian code of practice for different premises in residential and public buildings; relative air humidity 50% at an air velocity of 0.1 ms^{-1}.

Inside surface temperatures of window (t_k) and wall (t_w) were calculated by

$$t_{k(w)} = t_i - U_{k(w)} \frac{t_i - t_o}{h} \tag{1}$$

where

h = 8 $Wm^{-2} K^{-1}$ (heat transfer coefficient)
t_i = inside air temperature, °C
t_o = outside air temperature, °C
$U_{k(w)}$ = overall heat transfer coefficient of the window or the wall $W/m^{-2} K^{-1}$.

The computed set of basic data are presented in Tables 1 and 2, respectively.

Table 1. Inside surface temperature of window (t_k) as a function of the room air temperature (t_a) and the U_k-value of the window.

t_a °C	U_k $Wm^{-2}K^{-1}$	t_k °C
18	3	10.5
20	3	11.75
22	3	13.0

Table 2. Internal surface temperature of wall (t_w) as a function of the room air temperature (t_a) and the U_w-value of the wall.

t_a °C	U_w $Wm^{-2}K^{-1}$	t_w °C
18	1.2	15.0
18	0.8	16.0
20	1.2	16.7
20	1.0	17.25
20	0.8	17.8
20	0.6	18.35
22	1.2	18.4
22	0.8	19.6

Table 3. Heating energy (Q) of heaters depending on air temperature (t_a) and external walls.

number of external walls	t_a °C	Q W
1	18	890
1	20	940
1	22	990
2	18	1260
2	20	1400

Test arrangement

The body centre of the ÉTIman was positioned at 1 m from the two adjacent cold walls, that is, from the cooled aluminum panels, facing the window and with its back to it, alternately. The ÉTIman was sitting on an open-back wooden chair. The total heat resistance of clothing and chair was 0.8 clo.

When simulating a room with one external wall only, four different heating methods were tested:

1) aluminum radiator (normal, multimember type);
2) radiant panel;
3) floor heating;
4) wall heating by coil embedded into the internal surface layer of the external wall panel (Macskasy 1975).

With two external walls, two different heating methods were tested, as follows:

1) aluminum radiator and
2) wall heating.

Table 3 shows the energy of the heaters, as well as the air temperature for these cases.

Beside of testing the above heating alternates, measurements were also performed for a situation without any kind of heating, constant temperatures of air and inside surfaces, and in both positions of the manikin, i.e., facing and backing the external wall.

EVALUATION METHOD OF TEST RESULTS

The Predicted Mean Vote (PMV) and Perceived Percentage of Dissatisfied (PPD) values were determined by calculations according to ISO standard 7730 (1984).

PMV is the vote vote of people in a given indoor environment according to their subjective thermal comfort sensation. It is determined by measurements with the participation of thousands of test subjects during several years by Fanger (1972). PPD indicates the predicted percentage of occupants dissatisfied at with the thermal comfort at a given PMV value.

In addition, the following three values were calculated from the test results and used for evaluation:

1) total heat transfer from the unit body surface of body (P_{tot} Wm^{-2});

2) total equivalent homogenized temperature of the body which describes the temperature sensed by the body as the temperature of the ambient microclimate (EHT_{tot} °C);

3) asymmetry of the thermal comfort sensation (μ) which is the standard deviation of EHT_{tot} of EHT_i values:

$$\mu = \frac{\sum_{i=1}^{18} (EHT_i - EHT_{tot})^2}{17} \quad (2)$$

EVALUATION OF TEST RESULTS

The results of the calculations and measurements are shown in Tables 1-4. The test results proved that deviations are small. There were about 1-3 Wm^{-2} between calculated PMW and PPD values (measured as P_{tot} and EHT_{tot}) and in calculated and measured "μ" values for all combinations of the tested air room temperature (t_a) with the evaluated surface temperature (t_w).

Therefore, it can be concluded that variation in the thermal insulation of the external wall in the indicated range of Table 2 had little effect on the thermal comfort sensation.

The effect of the heat emitter types and their arrangement is much higher on the heat transfer from the body (4-10 Wm^{-2}). According to the test results, the effect of the heat emitter on the total heat transfer from the body (P_{tot}) and the "effective sensible ambient" temperature (EHT_{tot}) are multiples of that of the U-value of the wall.

Comparing the four heating methods, tested for the case of simulating one external wall, and for both ÉTIman positions from the aspect of the P_{tot}, their values were found in the following succession of heating methods in ascending order:

panel radiator;
wall heating;
aluminum radiator;
floor heating.

For the case of simulating two external wall tests, the values in ascending order were:

wall heating;
aluminum radiator.

There were no changes in the case of two external walls, and the best result was achieved with a steel-panel radiator. These results correspond to the case when the ÉTIman was set in front of and rather close to the heat emitter. Obviously, the higher the surface temperature of the heat emitter was, the larger the reduction of the radiant heat transfer was from the body of the ÉTIman. This explains how the panel radiator could "overtake" floor heating. If there was a bigger distance between the heat emitter and the body, the order could have been somewhat different; determination of which would have required further testing. It is logical to assume, however, that even in this case, wall heating, floor heating, and panel radiators, in spite of their lower surface temperatures, would likely overtake any multimember-type aluminum radiators.

Ranking the tested heating methods from the aspect of EHT_{tot} for one external wall gives the following order:

panel radiator;
wall heating;
floor heating;
aluminum radiator.

Table 4. Acceptable reduction of room air temperature for different criteria if compensation of cold radiation provided by panel radiators (°C).

	1 external wall		2 external walls	
manikin position	facing window	with its back to window	facing window	with its back to window
		Criteria		
P_{tot}	1.5	2.5-3.0	1.1-1.5	2.5
EHT_{tot}	2.0	2.0-2.5	1.1-1.5	2.3
u	0.3-0.5	3.0-4.0	1.0-2.0	3.0

When floor heating and aluminum radiator (column type) changed place, there were no changes in the case of the two external walls.

Ranking the tested heating methods from the aspect of the asymmetry of the thermal radiation (μ), provides the same order as in the case of P_{tot}.

Smaller differences were observed in the case of the ÉTIman having its back to the heat emitter than when facing it. This is explained by the larger dimension of "naked" surface of covered ones in the latter case.

Compared to the reference situation (no heat emitter, constant air temperature), the application of the best heating method made acceptable reductions of the room air temperatures (Table 4). This occurred in accordance with the above order. The values for P_{tot}, EHT_{tot}, and μ will only be the same as in the reference situation, when the values of the air temperature are lower than those given in the tables. The tests showned that, by using appropriate heaters, the heat losses of the different unclothed parts of the body may be reduced by 5-25 Wm^{-2}, and those of the clothed parts 0-8 Wm^{-2}, as compared to the values in the reference measurements.

Finally, it can be concluded that the heat loss on the surface of the ÉTIman is influenced by the same factors as the surface of the human body, i. e., the heat insulation of the clothing and chair, the air temperature, air velocity, and the heat radiation emanating from and going back to the surrounding surfaces.

Thus, the ÉTIman is applicable to qualify the indoor thermal comfort in different situations and different heating methods. Unacceptable indoor climate situations, when people feel cold at the legs or neck, can be reliably detected by the thermal manikin. The ÉTIman is sensitive to draught, cold radiation, and other discomfort effects.

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THE THERMAL FACTORS CRITICAL FOR DESIGN OF HVAC SYSTEMS

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The major aim of a building is to provide a healthy and comfortable environment for the occupants. For this purpose, it is preferable if the influence of the building and installations on human comfort can be predicted already at the design stage. This paper discusses the problems in predicting the thermal environment. The requirements for a comfortable thermal environment based on existing standards are presented, followed by a discussion on different methods for predicting the relation between design of building, heating, and air-conditioning systems, and the thermal environment. This indicates that while surface, radiant, and air temperatures may be predicted in the design state, it is often not possible to predict air velocities and vertical air temperature gradients. Finally, the question of which factors are important in the design and development of new heating and air-conditioning systems are discussed.

INTRODUCTION

The main purpose of most heating and air-conditioning systems is to provide an acceptable thermal environment for human beings. Based on many years of research, international standards have been established which quantitatively specify requirements for acceptable thermal environments. (ASHRAE 1981; ISO 1984; NKB 1981). The best and most efficient way is to consider those requirements as early as possible in a building or developing process. At the design stage, it is, then, desirable to predict the indoor thermal climate that will result from a given combination of building construction, heating and/or air-conditioning system, and outdoor climate.

In existing building codes or standards for sizing the heating and air-conditioning systems, very few requirements have been listed for the indoor thermal environment. Mostly, it is only required that, at a given outdoor design temperature, the heating and/or air-conditioning system should be able to keep the indoor temperature above (heating period, winter) or below (cooling period, summer) a certain value. Until recently, the indoor temperature in existing codes has been regarded as air temperature. In new standards and codes, however, it is discussed to introduce the operative temperature. Several large computer programs (Kusuda 1976; LBL 1980) exist that can be used to predict heating and cooling loads, indoor air temperatures, surface temperature and humidity, both in steady-state and non-steady-state conditions. These programs are, however, often difficult and expensive and are mainly used to calculate energy consumption for large buildings.

If in the future the architect and engineer are to take into account all the requirements for an acceptable thermal environment, it is necessary that the appropriate tool in the form of predictive calculation procedures are available. In the 1970s and beginning of the 1980s the computer programs dealing with buildings and heating and air-conditioning systems focused mainly on the prediction of the energy costs. This is still an important factor, but the requirements for an acceptable environment must, in the future, get a much higher priority.

The cost of energy for heating and cooling of an office in modern buildings is only a small percentage of the costs for salaries and office facilities. This means that, if the heating and air-conditioning system is designed to minimize energy costs at the cost of the thermal comfort of the occupants, the savings will readily be lost by a decrease in the performance of the occupants (more sick leave, dispute about conditions, etc.).

The following sections consider, in turn: the critical factors and requirements for an acceptable thermal environment; factors that can be taken into account at the design stage; and finally, the most important factors for design and development of new systems.

REQUIREMENTS FOR AN ACCEPTABLE THERMAL ENVIRONMENT

The following requirements are included in an international standard, ISO 7730 (ISO 1984) and similar requirements may be found in ASHRAE standard 55-81 (ASHRAE 1981) and NKB guidelines (NKB 1981). A first requirement for an acceptable thermal environment is that a person feels thermally neutral for the body as a whole, meaning he does not know whether he would prefer a higher or lower ambient temperature level. This is evaluated by the Predicted Mean Vote (PMV) index (Fig. 1). This index gives a number on a seven-point thermal sensation scale (+3 Hot, +2 Warm, +1 Slightly warm, 0 Neutral, -1 Slightly Cool, -2 Cool, -3 Cold).

The quality of the thermal environment may also be described by the Predicted Percentage of Dissatisfied (PPD) index. This index is directly a function of the PMV value (Fig. 1).

The PMV-PPD index integrates the influence of the following factors by standardized equation (ISO 7730 1984):

Personal factors:

Activity level M (met, W/m^2)

Thermal insulation of clothing I_{cl} (clo, m^2 °C/W)

Environmental parameters:

Air temperature t_a (°C)

Mean radiant temperature $\bar{t}_r$ (°C)

Air velocity v_a (m/s)

Air humidity (water vapour pressure) p_a (Pa)

A PMV value = 0 is equivalent to thermal neutrality. In ISO 7730, the recommended limits for an acceptable thermal environment are:

$-0.5 < \text{PMV} < 0.5$

$\text{PPD} < 10\%$.

Figure 2 illustrates the use of recommended limits for a typical winter situation (heating period, clothing insulation ~1.0 clo) where the occupants have light, mainly sedentary work with an activity level of 1.2 met (office, school). The recommended operative temperature range is 20-24°C. In summer (clothing insulation 0.5 clo) the corresponding interval is 23-26°C.

Thermal neutrality as predicted by the comfort equation or described by the PMV-PPD indices is not the only condition for thermal comfort. A person may feel thermally neutral for the body as a whole, but

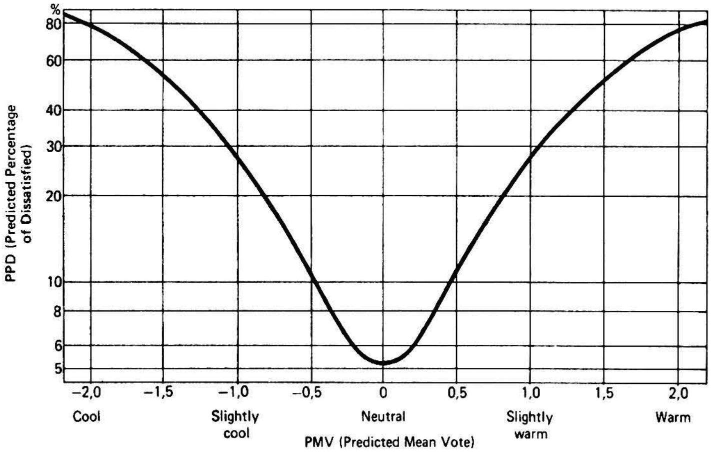

Fig. 1. Relation between the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) indices.

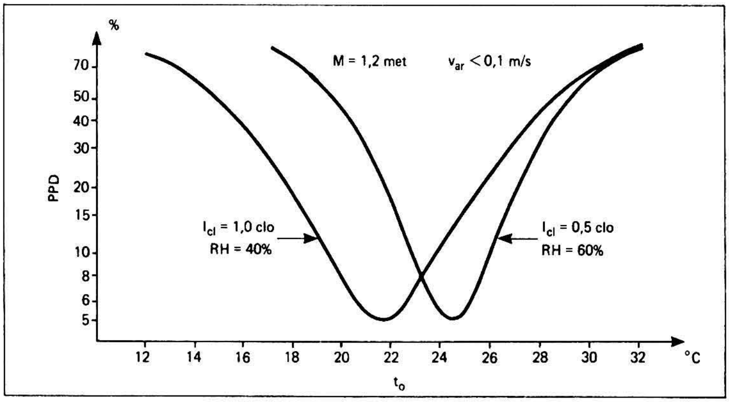

Fig. 2. Relation between operative temperature and the Predicted Percentage of Dissatisfied (PPD) value.

may not be comfortable if one part of the body is warm and another cold. It is therefore a further requirement for thermal comfort that no local warm or cold discomfort exists at any part of the human body. Such local discomfort may be caused by an asymmetric radiant field, by a local convective cooling (draught), by contact with a warm or a cold floor, or by a vertical air temperature gradient.

In ISO 7730, the recommended limits for avoiding local discomfort for people occupied with light, mainly sedentary work (1.2 met) are as follows:

The radiant temperature asymmetry (Δt_{pr}) from windows or other cold vertical surfaces shall be less than 10°C (in relation to a small vertical plane 0.6 m above the floor).

The radiant temperature asymmetry (Δt_{pr}) from a heated ceiling must be less than 5°C (in relation to a small horizontal plane 0.6 m above the floor).

Mean air velocity (3 min) v_a shall be less than 0.15 m/s during winter (heating period), i.e., operative temperature between 20 and 24°C.

Mean air velocity (3 min), v_a, less than 0.25 m/s during summer (cooling period), i.e., operative temperatures between 23 and 26°C.

Vertical air temperature difference between 1.1 and 0.1 m above floor (head and ankle level) shall be less than 3°C.

Surface temperature of the floor shall normally be between 19 and 26°C, but floor heating systems can be designed for 29°C.

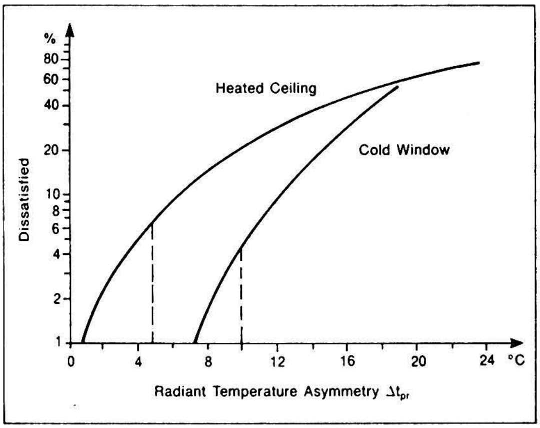

Fig. 3. Relation between the radiant temperature asymmetry and the expected number of dissatisfied persons (Fanger et al. 1985).

The following limits for temperature ramps and cycling temperatures have been specified in ASHRAE 55-81:

by temperature ramps a rate of change of 0.5°C/h is recommended,

by cycling temperatures the rate of change shall be less than 3.5°C/h with a peak to peak amplitude less than 3.5°C.

The above requirements are based on several research results (Berglund and Gonzalez 1978a; Berglund and Gonzalez 1978b; Fanger et al. 1980; Fanger 1982; Fanger et al. 1985; Fanger and Christensen 1986; Fanger et al. 1988; Griffiths and McIntyre 1974; Olesen 1977; Olesen et al. 1979; Olesen 1985; Rohles et al. 1980). In several studies, the relation between the percentage of dissatisfied persons and the different local thermal discomfort parameter has been established. This relation is shown in Fig. 3 (Fanger et al. 1985) for radiant temperature asymmetry, in Fig. 4 (Olesen et al. 1979) for vertical air temperature differences, and in Fig. 5 (Olesen 1977) for floor temperatures. The requirements for air velocity are, in existing standards, based on a mean air velocity and an air temperature range (Fig. 6). New research results (Fanger et al. 1988) have, however, shown that fluctuation of air velocity

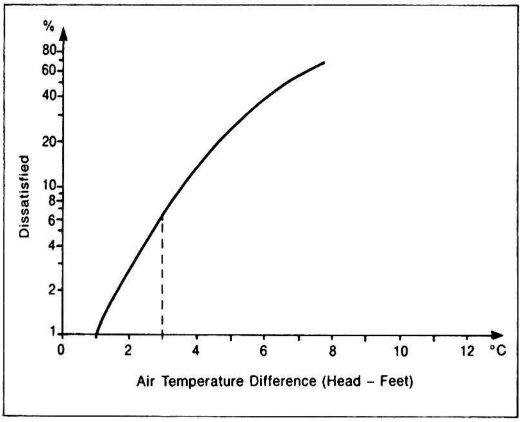

Fig. 4. Relation between the vertical air temperature difference and the expected number of dissatisfied people (Olesen et al. 1979).

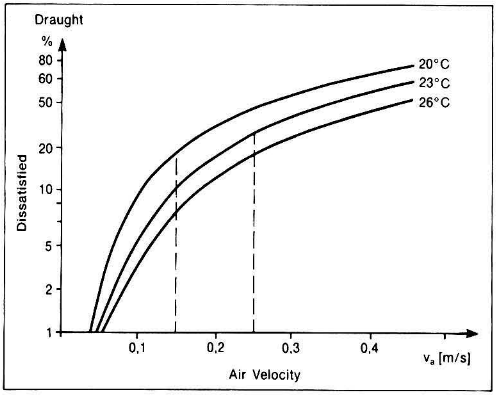

Fig. 5. Relation between the air velocity (medium turbulence) and the expected percentage of people, feeling draught (Fanger and Christensen 1986).

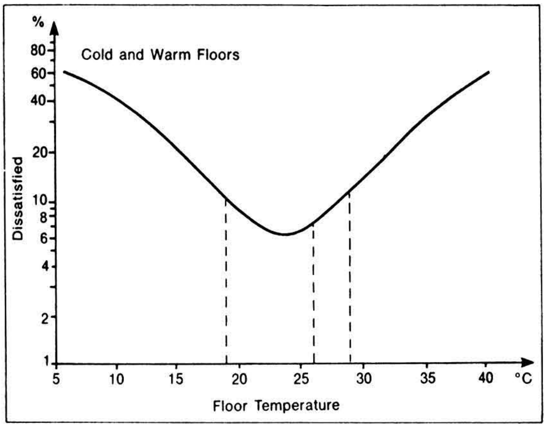

Fig. 6. Relation between the floor temperature and the expected percentage of dissatisfied people (with shoes) (Olesen 1977).

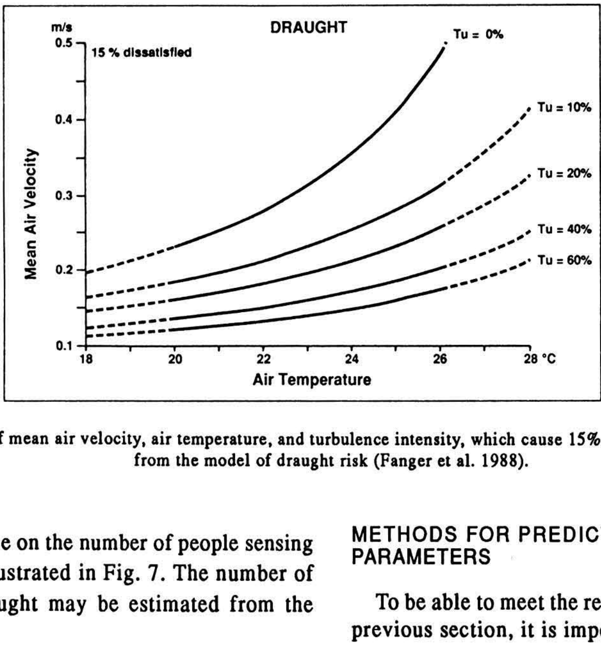

Fig. 7. Combinations of mean air velocity, air temperature, and turbulence intensity, which cause 15% dissatisfied people. Calculated from the model of draught risk (Fanger et al. 1988).

also has an influence on the number of people sensing draught. This is illustrated in Fig. 7. The number of people feeling draught may be estimated from the equation:

Percentage dissatisfied =

$$(34-t_a)\,(v_a - 0.05)^{0.6223}\,(3.143 + 0.3696 \cdot SD) \tag{1}$$

where

v_a = mean air velocity (3 min) m/s

SD = standard deviation of air velocity (3 min) m/s

t_a = air temperature, °C.

METHODS FOR PREDICTING THE THERMAL PARAMETERS

To be able to meet the requirements outlined in the previous section, it is important to try to predict the parameters critical for human comfort already at the design stage.

The PMV-PPD Index can be calculated from the six parameters (activity, clothing, air temperature, mean radiant temperature, air velocity, humidity). The two personal factors, activity and clothing, are fixed by taking into account the use of the room/building and the time of year.

Air temperature and surface temperature may be estimated by setting up a heat balance equation for the room/building. This consists of a heat balance for each of the surfaces, including walls, floor, ceiling, windows, and heated surfaces. It takes into account the internal heat exchange by radiation to other surfaces, convection to the air, conduction through the construction, and external heat exchange to the outside or neighbouring rooms. A heat balance for the air is established by taking into account the convective heat exchange to all surrounding surfaces, heat exchange by infiltration air, and ventilation and heat input from internal sources (people, machines, etc.). This is the basis of the equations which are being used in existing computer programs.

The humidity (vapour pressure or relative humidity) may be calculated from similar equations based on air infiltration, ventilation and internal sources (people, cooking etc.).

The mean radiant temperature is then calculated from the calculated surface temperatures and the corresponding angle factors for a person (Fanger 1982, NKB 1981, Olesen 1983).

The air velocity is not calculated in the above-mentioned computer programs. Normally, it is assumed to be less than 0.1 m/s. There exist, however, some large models for the prediction of the air velocity distribution in ventilated spaces (Nielsen 1976; Nielsen et al. 1978). These programs are very difficult and expensive to run and are not usable in a normal design procedure.

The calculation mentioned above may be done for both steady-state and non-steady-state conditions by taking into account the heat capacity of a building. In the latter case, it is then also possible to calculate temperature ramps or cycling temperatures due to change in outside conditions or changes in internal loads.

The radiant temperature asymmetry is calculated in the same way as mean radiant temperature by use of the surface temperatures and angle factors to a small plane element (ASHRAE 1981; ISO 1985; NKB 1981; Olesen 1983).

The floor temperature is calculated from the heat balance equation of the floor (heat exchange to internal air and surfaces, heat conduction through the floor construction, heat exchange with the ground, cellar or lower rooms). For a floor heating system, the design heat loss per m^2 of heated floor surface has to be taken into account.

The air velocities (draught) are, as mentioned earlier, difficult to predict at the design stage. For evaluating the draught-risk, it is not only the air velocity but also the air temperature and the air velocity fluctuations (standard deviation) which have to be estimated. Air velocities may be caused by ventilation systems or by thermal convection currents. Methods exist for predicting the air temperature and air velocity of down draught from cold surfaces like windows and walls (Shillinglaw 1977). The design of outlets and their position are often studied in full-scale models; but this is only economically feasible for greater building projects. There is a need for usable methods for predicting air velocities.

Vertical air temperature differences are also difficult to predict in the design stage. Most often a uniform temperature distribution is assumed in a room.

The physical parameters like air temperature, surface temperature, mean radiant temperature, plane radiant temperature, and humidity may be estimated at the design stage. However, it is not yet possible to predict the air velocity and air temperature distribution in a usable way.

A simplified calculation method for predicting the indoor thermal climate at the design stage has been presented by Olesen (Olesen 1983).

DEVELOPMENT AND DESIGN OF NEW HEATING AND AIR-CONDITIONING SYSTEMS

An acceptable thermal environment can be fulfilled by the proper design of a building and the proper use of existing heating and air-conditioning systems. However, there is no single satisfactory system. A case-by-case decision must be made on the building design and the use of the building.

From the requirements it is seen that the design shall try to provide conditions as uniform as possible, meaning no radiant asymmetry, low air velocities, and uniform temperature distribution. This is not only accomplished by the design of the heating and air-conditioning system, but, what may be more important, by the design of the building. In many cases, a heating or air-conditioning system may compensate for thermal problems caused by the design of the building.

Radiant asymmetry is mainly caused by large windows (cold in winter, direct sunshine in summer). This may be avoided by the use of multi-pane windows (double or triple), high insulative windows (gas filled) and, in some extreme cases, by heated windows. This will at the same time reduce the risk for unacceptably high air velocities due to down draught along the colder window surface. Also, a proper position of the heater (panel heater) may compensate for the cold radiation from a window.

The risk of too high vertical temperature differences is normally greater in poorly insulated houses and in rooms heated mainly by convection. In these cases, low temperature radiant heating systems will normally result in a uniform temperature distribution.

Low temperature heating systems are beneficial in many ways due to the uniform conditions which are normally obtained. However, there are also advantages in relation to the energy consumption. Lower supply temperatures will result in higher efficiency of the boiler and lower heat loss in the supply coils.

Probably the most difficult task is to design ventilation systems with low, uniform air velocities. One development in this direction is the use of displacement ventilation. The risk here is, however, that the air temperatures along the floor will be too low.

Verifying the advantage of new designs, may not always be possible by use of calculation methods at the design stage, as indicated above. The only way to perform the verification is by measurement of the thermal parameters. This is also possible with existing measuring equipment which fulfills the requirements in ISO 7726.

CONCLUSION

The requirements for an acceptable thermal environment are well known. For the design of buildings and heating and air-conditioning systems, it is possible to predict the thermal parameters at the design stage. There is, however, a need for better methods to predict the air temperatures and air velocity in a room by a proper design. It should also be possible to fulfill the requirements for an acceptable thermal environment using existing heating and air-conditioning systems.

In the future, these requirements should be included in building codes or codes for the design of heating and air-conditioning systems. Also, it should be specified in any building contract which requirements for the thermal environment are the basis for the design. Then, in any later dispute, it will be much easier to verify if the requirements have been fulfilled.

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LABORATORY STUDIES ON THE RELATIONSHIP BETWEEN FUNGAL GROWTH AND ATMOSPHERIC TEMPERATURE AND HUMIDITY

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The effect of air temperature (4-30°C) and relative humidity (RH 11-96%) on the growth of two common fungi *Aspergillus fumigatus* and *Penicillium* sp. was studied in the laboratory. A short period of favorable conditions was sufficient to start fungal growth. Temperature was not a limiting factor for fungal growth on building materials, because fungi grew at even below 10°C. The relative humidity of air had no direct influence on the growth of fungi. Fungi may grow at very low levels of air humidity if water is available on the surface. Thus, repeated or persistent moisture condensation or water leakage is sufficient for fungal germination and growth on building materials.

INTRODUCTION

Mold growth in buildings has mainly been studied in warm and humid climates (Lumpkins and Corbit 1976; Mansmann 1978; Solomon and Mathews 1978). In such conditions, it is not necessary to distinguish between air humidity and moisture of surfaces and structures. In the Scandinavian winter the intake air must be heated by 20-50°C which reduces its relative humidity (RH) to <10-20%. Therefore, the indoor air RH may be very low during cold periods in the winter. Although mold problems in buildings are associated with humid environment, visible fungal growth on building structures has been detected in Finnish homes even in the winter, when air humidity was low (Nevalainen et al. 1991). In these cases, building structures have been moisturized by water leaks or condensation on cold surfaces. This indicates that on moist surfaces mold growth is possible also in dry air. In this study, we have investigated this phenomenon under laboratory conditions, where air relative humidity and temperature could be individually controlled.

Fungi are capable of growing on nutritionally marginal substrates (Solomon 1975; Solomon and Burge 1984). Germination time and growth rate of a fungus strongly depend on temperature and availability of water and nutrients on a surface (Ayerst 1969; Gervais et al. 1988). However, the effect of one factor cannot be entirely distinguished from the others. Fungi can grow on building materials, but nutritional conditions are not optimal on them. To ensure homogeneity and availability of nutrients, we have used culture media instead of building materials in this study.

In previous laboratory studies, usually only water activity of the culture media has been adjusted (Ayerst

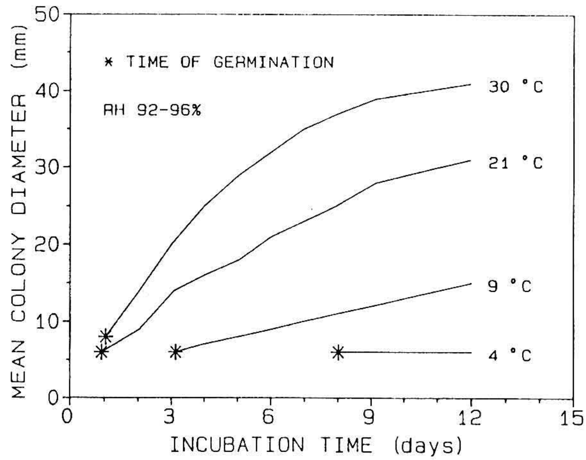

Fig. 1a. Germination and colony size of *Aspergillus fumigatus* as a function of time and temperature at RH 92-96%.

1969; Magan and Lacey 1984). In some experiments the effect of humidity (RH above 78%) on the fungal growth has been studied (Mislivec and Tuite 1970; Mislivec et al. 1975), but then both air humidity and water activity of the medium have been regulated. Because we were unable to find any information about the influence of air RH alone, we have investigated here on a wide RH-range, how air temperature and humidity affect fungal development.

MATERIALS AND METHODS

The growth of two common fungal strains, *Aspergillus fumigatus* and *Penicillium* sp., was studied in humidity chambers. The fungi were precultured on modified Hagem agar (Modess 1941), *A. fumigatus* at 40°C and *Penicillium* sp. at 19-22°C, in the dark for 7 d. Spores were washed off from both cultures with 0.02% Tween 80 detergent. The suspensions were then centrifugated at 2700 G for 30 min at 4°C.

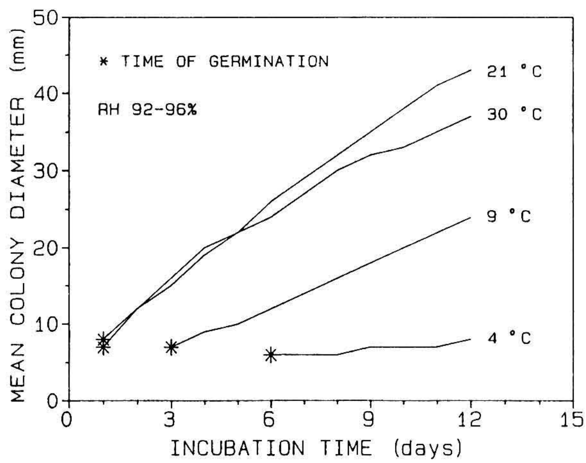

Fig. 1b. Germination and colony size of *Penicillium* sp. as a function of time and temperature at RH 92-96%.

Table 1. Initial growth rates of *Aspergillus fumigatus* and *Penicillium* sp. at various temperatures relative to the optimum temperature.

T (°C)	Growth Rate at T Relative to Growth Rate at the Optimum T	
	A. fumigatus (%)	*Penicillium* sp. (%)
4	0	0
9-10	18	52
9-22	40	100
30	100	85

The spores were resuspended in fresh sterile 0.02% Tween 80 (Curran 1980), and 20 µL of spore suspension (10^5 spores/mL) was inoculated to Hagem agar plates which had been stabilized in 4-L glass chambers for 24 h. The RH inside these chambers was regulated with saturated aqueous solutions of LiCl, $MgCl_2$ 6 H_2O, $Mg(NO_3)_2$, NaCl or KNO_3. The corresponding RH-levels at temperatures used were 11, 32-34, 51-59, 75-76 and 92-96% (Greenspan 1977).

The plates were incubated in the chambers in the dark for 12 d at four temperatures 4, 9-10, 19-22 and 30°C. The germination was noted, when the fungal colony was visible to the naked eye. Upon, this the colony diameters were measured daily during the incubation.

RESULTS AND DISCUSSION

At 4°C, *A. fumigatus* did not germinate and the germination of *Penicillium* sp. took about 7 d. Both fungi germinated within 3-4 d at 9-10°C and within 1-2 d at temperatures above 19°C. Both fungi grew at 9-10°C, but not at 4°C. Figures 1a and 1b illustrate the effect of temperature on germination and growth of both fungi at RH of 92-96%. Initial growth rates at various temperatures relative to growth at optimum temperature are presented in Table 1. The

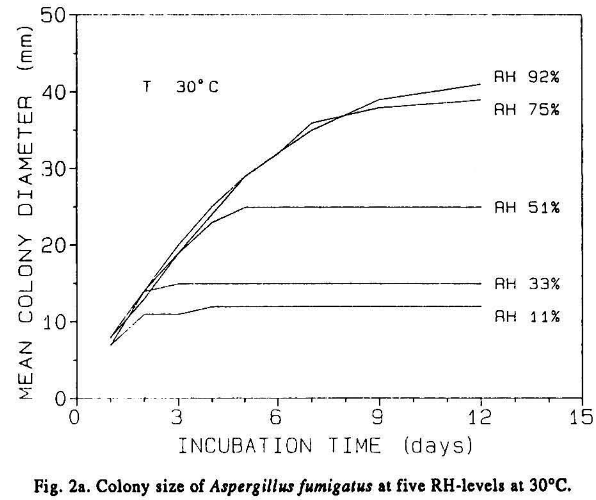

Fig. 2a. Colony size of *Aspergillus fumigatus* at five RH-levels at 30°C.

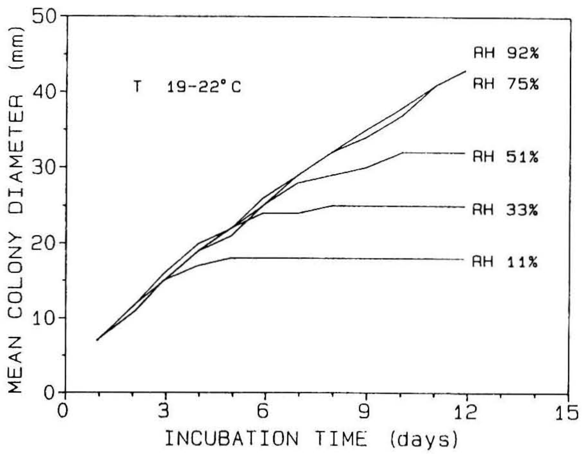

Fig. 2b. Colony size of *Penicillium* sp. at five RH-levels at 19-22°C.

colony growth rate increased with increasing temperature. *A. fumigatus* grew fastest at 30°C and *Penicillium* sp. at 19-22°C.

Figures 2a and 2b present the colony growth of *A. fumigatus* and *Penicillium* sp. at five RH-levels at the maximum growth temperature. At first the fungi grew linearly, but later the growth ceased rapidly. This indicates that the growth of both fungi was independent from air humidity as long as the moisture content of the medium remained above some critical level. The drier the air the faster this level was achieved.

These results are not directly applicable to field conditions, because there were enough nutrients for fungal growth on the medium and the fungi did not need to compete for living space with other microbes. However, this study supports the field observations of mold growth on building structures in the winter (Nevalainen et al. 1991). The results show that fungal growth is possible at 10°C, which means that even the lowest temperatures in building structures may allow their growth. Although the growth is slow under such conditions, fungi may accumulate considerably during years and decades in the life of a building.

This study also confirms the idea that fungal growth is not directly controlled by air RH as long as there is a sufficient amount of moisture available on the given surface. Therefore, mold growth on wetted building structures is possible even when the air humidity is low.

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THE INTERACTION OF NOISE AND MILD HEAT ON COGNITIVE PERFORMANCE AND SERIAL REACTION TIME

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In a 2x2 factorial design two noise levels (38 dBA and 53 dBA) were crossed with two temperature levels (19°C and 27°C). A total of 64 subjects completed a 2-h, 20-min session, working with mental arithmetic, a recognition task, hidden geometrical figures, proofreading, verbal fluency, and the five-choice serial reaction task. In a pre-test session, exactly 24 h before the experiment proper, subjects worked with parallel versions of the very same tests in 38 dBA and 20°C. Multivariate analyses of variance were performed on the difference in performance between the two sessions. Results indicated an antagonistic interaction between heat and noise on the hidden figures test. For the recognition task, noise biased the response criterion towards being stricter. On the five-choice task, the higher temperature increased the rate of responding without increasing errors. Results are discussed in terms of arousal and overload theories.

INTRODUCTION

Two stressors affecting the same psychological mechanism should yield an interaction, whereas two stressors affecting different mechanisms should not. Tapping the same underlying mechanism should show up as an antagonistic (canceling effects) or synergistic (more than additive) interaction. Effects routed along different paths would be indicated by additive or parallel effects. Thus, studies of the interaction between two different kinds of stimulation may yield valuable theoretical insights into the mediating psychological mechanisms.

Explanations of an interaction between heat and noise on performance have often employed an arousal theory including the inverted U-hypothesis and Easterbrook's (1959) cue-utilization hypothesis (Hockey and Hamilton 1983). The inverted U-hypothesis states an inverted U-shape relationship between arousal and task performance. Persons who are either above or below some optimal arousal point will suffer performance decrements. Furthermore, increased task difficulty moves the optimal arousal point downwards on the arousal continuum. Easterbrook's (1959) cue-utilization hypothesis proposed an explanation for why high arousal levels impede performance. The explanation is that high levels of arousal narrow the focus of attention so that only the cues that are perceived to be central to task performance are attended to. If these cues indeed are the central ones, performance will improve. If not, performance will deteriorate.

From this theoretical perspective, and if noise is assumed to increase arousal and mild heat to decrease it, an antagonistic interaction between the two would be predicted. This interaction would be more pronounced on more difficult tasks.

However, things probably are more complex than that since the arousal-theory suffers from many ambiguities and short-comings (Hockey and Hamilton 1983). Among them are, whether the arousal concept is multidimensional and the problem of finding a data-independent location of the optimum level. An alternative to the arousal theory is some variation of the attentional overload theory or a cognitive strategy theory (Cohen et al. 1986). A prediction from the latter two theories would be that two environmental stressors do not interact with each other, unless some drastic change in cue-selectivity or cognitive strategy has taken place and "redefined" the situation for the subjects.

As an empirical generalization, interactions between heat and noise have been questioned (Broadbent 1971; Hockey 1979; Hockey and Hamilton 1983; Jones 1983; Poulton 1966). Hockey and Hamilton (1983), for instance, stated that heat does not normally interact with either noise or sleep loss. The argument is that heat may be affecting another psychological mechanism than noise, within the inverted U, cue-utilization, arousal theory framework, and/or that the arousal concept is not unidimensional.

The empirical evidence for any conclusions on interactions between heat and noise is sparse. Poulton and Edwards (1974) investigated tracking, vigilance, and a five-choice task under combinations of mild heat (34°C vs. 19°C) and continuous low frequency noise (102 dBC vs. 80 dBC). They reported that the combined effect of heat and noise on tracking and vigilance was smaller than their sum, i.e., an antagonistic interaction. Bell (1978) in a study of a dual task, found performance decrements associated with high noise (95 dBA white noise bursts vs. 55 dBA continuous background noise) and high temperature (35°C, 29°C vs. 22°C) on the subsidiary number processing task, but no interaction between them and no effect on the primary pursuit rotor task. Viteles and Smith (1946) reported no effect of noise (72 dB, 80 dB, and 90 dB) and an effect of temperature only at the highest level (37°C) for a group of Naval recruits who worked for seven weeks on seven demanding tasks. However, in a reanalysis of the Viteles and Smith's data , Wilkinson (1969) found a significant positive effect of noise at the intermediate temperature (31°C) level, and a significant negative effect of noise at the highest temperature. Wyon (1970) had 12-y-old boys perform various tasks at 20°C, 23.5°C, and 27°C in quiet and noisy conditions. The noise had no reliable effect on most of the tests, but an open-ended creativity task yielded better performance at 27°C in the quiet, while no effect of temperature was found in noise. Thus, for some cognitive tasks there may be an antagonistic interaction between noise and heat.

On the five-choice serial reaction task, a counteracting effect of heat and noise was reported by Wyon et al. (1978). At 30°C, car-factory noise of 85 dBA, in contrast to background noise of 50 dBA, increased the proportion of coordination errors. According to Wyon (1984), this was true for the subjects who found the tasks difficult and the 30°C condition comfortable.

The present study was designed to further explore interactions between mild heat and noise on several cognitive performance tasks and the five-choice serial reaction task. From the perspective of a dearousing effect of mild heat and an arousing effect of noise, it was predicted that the more demanding tasks would show an antagonistic interaction between noise and heat.

The choice of the temperature levels in the present study (19°C and 27°C), was guided by Wyon (1970) who summarized a series of studies on the effects of heat on school performance. His conclusion was that mild heat, such as 27°C, was dearousing and too high for optimum performance which occurs at around 20°C.

The type of noise chosen was continuous ventilation noise. One of the reasons for this choice is the wide-spread subjective complaints of noise from heating, ventilation, and air-conditioning equipment in offices (Keighley 1970). However, studies demonstrating performance or learning effects of ventilation noise at the levels generally encountered in, for example, offices (<60 dBA), seem to be lacking.

To make the experiment as sensitive as possible for performance effects, it was designed as a within-subject experiment with two sessions. In the first session all subjects were exposed to 19°C and 38 dBA noise, while working on the various tasks. In the second session, 24 h later, they worked on parallel versions of the same tasks in a 2 × 2 factorial design where 19°C and 27°C were crossed with ventilation noise of 38 and 53 dBA. In an effort to make the situation as demanding as possible for the subjects, presentation rates for a mental arithmetic task were tried out individually. Further, time of day, age, and sex distributions were kept constant across conditions.

METHOD

Apparatus

Air temperatures were controlled by a computerized climate system, and relative humidity was set to the range of 80-90% Rh. The noise was produced by a commercial heat-exchanger and was adjusted to yield 38 dBA (54 dB lin) or 53 dBA (68 dB lin). The noise had its maximum energy content in the 250 Hz octave band and lower.

Subjects

A total of 32 males and 32 females aged 18-59 with mean ages of 30.7 and 31.5 y respectively, completed the whole experiment. Approximately half of the subjects started their session at 9:30 a.m., the other half around 1:00 p.m. Each session lasted for about 2 h, 20 min. Subjects used their own clothes, and were, if necessary, asked to take off any heavy sweaters or the like to ensure that the insulation value of their clothes would correspond to ordinary indoor use.

Tasks

During both sessions the subjects worked on six tasks in the following order: mental arithmetic together with recognition, proof-reading, hidden figures, verbal fluency, and the five-choice serial reaction task.

Mental arithmetic. At the start of Session 1, an individually-fixed, inter-trial interval for a mental arithmetic task was tried out. The criterion was set to 25-40% incorrect responses, and the interval was kept constant for both sessions. The task was a three-step addition or subtraction task, presented on a CRT.

Recognition. The subjects were informed that during the arithmetic task, words would be flashed on the screen from time to time. A total of 50 words was flashed, for 1 s each, between two arithmetic trials, separated by at least 40 s. At the end of the arithmetic task, the subjects were presented with a set of 100 test words. In replying to the test words, the subjects had to make a choice between the alternatives: 1) Yes, I am quite sure this word has appeared; 2) Yes, I am fairly sure this word has appeared; 3) No, I am fairly sure this word has not appeared; and 4) No, I am quite sure this word has not appeared. This permitted an ROC analysis (Gardner and Boice 1986; McNicol 1972) of d' and the natural logarithm ln of β.

Proof-reading. Subjects were given 30 min to indicate errors in a fairly complicated text of approximately 2500 words presented on paper, which was prepared to contain 40 simple and 40 complex errors. Simple errors were defined as detectable when focusing on the word containing the error or its two adjoining words. A complex error could be discerned only when keeping more of the sentence in focus.

Hidden geometrical figures. A set of 16 complex geometrical figures were presented on a sheet to the subjects. At the top of the page, five simple figures were shown, and the subjects were given 20 min to identify which one of the simple ones reappeared in the complex ones with the same size and orientation.

Verbal fluency. During 5 min, subjects were asked to make up as many "words as possible for things" with the restriction that the word must start with one or the other of two specified consonants. The number of different words was scored in addition to a sum quality-weighted score for each word. The quality score for each of the words, the subjects came up with, was obtained by the formula $x = \log(64/n)/\log(2)$, where n is the number of persons responding with the word in question and 64 the actual number of subjects in the experiment. That is, higher quality scores were given for words that a certain subject was alone in generating.

Five-choice serial reaction. With a stylus the subject taps five circular brass targets (19 mm in diameter), arranged in a pentagon with a side of 50 mm. Tapping any target extinguishes the current signal lamp in a corresponding pentagon arrangement of lamps, and one of the other four goes on in a random order. Tapping the wrong target is recorded as a "choice error"; hitting the facia is recorded as an "aim error". With a probability of 5% a delay of 0.2 s is introduced and is reported by the subject by pressing a button. Responses were normalized to 1000 responses. This task lasted for approximately 17 min.

Statistical analyses

Each of the six tests constituted its own set of data and the differences in responding from Session 1 to 2 were entered together in a multivariate analysis of variance (MANOVA, software SPSS-X 2.2). In the analysis, noise and temperature manipulations were the between-subjects factors. In the result section below, F-ratios (F), degrees of freedom, and the associated probability values (p) are given for the analyses of variance.

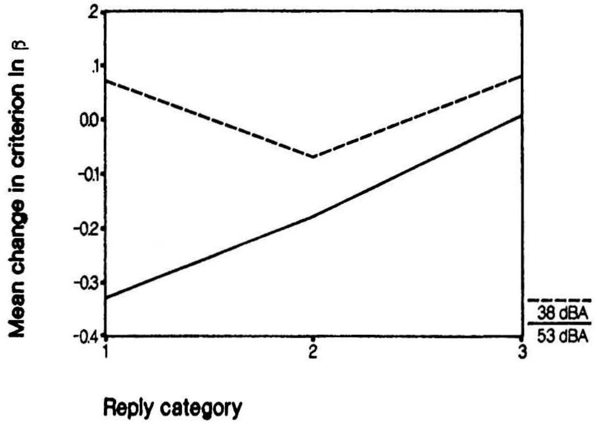

Fig. 1. Mean change in response criterion (ln β) from Session 1 to 2. Negative figures indicate a change towards stricter criteria.

RESULTS

Effects of noise and temperature

For the mental arithmetic task, no significant differences were obtained. An overall multivariate test of the ln β-values for the recognition task in the three first reply categories, as shown in Fig. 1, yielded an effect of noise, $F(3, 58) = 3.23$, $p = 0.029$. A univariate follow-up test indicated that only the difference for reply category No. 1 was of significant size, $F\ (1, 60) = 8.47$, $p = 0.005$. The response criterion became stricter for reply category No. 1 for the 53 dBA-group than for the 38 dBA-group, implying a stronger bias towards saying "non-signal".

The number of correctly identified hidden figures in Sessions 1 and 2 are shown in Fig. 2. The MANOVA indicated a significant interaction Noise × Temperature on the difference between the sessions, $F(1, 60) = 4.18$, $p = 0.045$. Follow-up one-tailed t-tests with pooled error terms for the differences between the 53 dBA/27°C-group and the 53 dBA/19°C-group, $t(60) = 1.65$, $p = 0.052$, and the 38 dBA/27°C- group, $t(60) = 1.60$, $p = 0.057$, just fell short of the 5%-level. Thus, the results indicate an

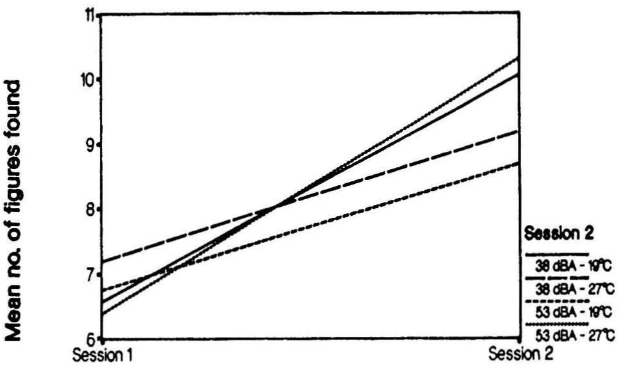

Fig. 2. Mean number of correctly identified hidden figures in the two sessions.

antagonistic interaction between noise and heat to the effect that the slightly negative effect of adding one of the stressors is counteracted by adding also the other. Noise and heat seem to cancel each other when applied together, and to have negative effects when applied separately.

The statistical tests for proof-reading and verbal fluency did not yield any significant differences with respect to changes in responding from Session 1 to 2.

For the five-choice task, data from the first session were missing for one subject. An overall multivariate test for the difference in responding from Session 1 to 2 yielded $F(8, 52) = 11.72$, $p < 0.000$. Separate univariate tests showed significant F-ratios for Response rate, $F1(1, 59) = 93.01$, $p < 0.000$; Hesitation errors (>1.5 s) $F1(1, 59) = 20.09$, $p < 0.000$; Extra button presses $F(1, 59) = 4.00$, $p = 0.05$; Reaction time $F(1, 59) = 40.96$, $p < 0.000$; Reaction time at extra button press (not all subjects did that) $F(1, 40) = 10.15$, $p = 0.003$.

Means are shown in Table 1. Taken together, the results for the five-choice task point to a facilitation effect of mild heat. Responding gets faster without increasing errors. Rather, hesitation errors and extra button presses decrease with mild heat.

Other results

As an additional check of the results, the significant effects reported above were entered in a supplementary analysis of variance where time of day and sex were added as between-subject factors. However, time of day and sex did not further specify the significant effects.

DISCUSSION

As regards the hidden figures task, the antagonistic interaction between heat and noise can be explained by the inverted U-hypothesis and Easterbrook's cue-utilization hypothesis, if it is assumed that mild heat is dearousing and noise arousing, and that the 19°C/38 dBA group is in the vicinity of an optimal level of the inverted-U function. Thus, from the arousal theory, the cancelling-out of noise and heat effects on the hidden-figures task makes sense.

To explain the antagonistic interaction between noise and heat from an overload or cognitive strategy theory is more difficult. One possibility though, is that subjects who experienced failure with the tasks in Session 2 that preceded the hidden-figures task would be overloaded or induced to change strategy on the hidden-figures task. However, the regression of the increase in percentage of correctly solved arithmetic tasks from Session 1 to 2 on the increase

Table 1. Means of significant changes between the sessions for the five-choice response measures at 19°C and 27°C.

	Session 1		Session 2		
Response measure	(19°C	27°C)	19°C	27°C	*p*
Response rate	801.3	792.7	811.5	1,125.1	0.000
Hesitation errors (>1.5 s)	199.5	267.8	205.0	53.7	0.000
Extra button presses	8.4	17.5	8.5	11.8	0.05
Reaction time (RT)	1.29	1.32	1.26	0.90	0.000
RT extra button press (n=44)	2.56	2.88	2.04	1.74	0.003

Note: Response rate, hesitation errors, and extra button presses are normalized to 1000 responses. The p-values refer to the difference in change from Session 1 to 2 between the temperature groups.

in number of hidden figures found, was insignificant, $F(1, 59) = 0.73$, $p = 0.395$, as was the regression on ln β, $F(1, 59) = 0.03$, and $p = 0.860$. Thus, an explanation of the results for ln β and the hidden figures test in terms of a cognitive overload or a change in cognitive strategy, does not seem likely.

The response criterion ln β for reply category No. 1 in the noise group changed in the direction of being stricter. This means that subjects exposed to noise became more conservative about reporting signals or more biased towards saying "non-signal". Assuming that the lower noise level is located around the optimal level of the inverted U, the higher noise level can be regarded as over-arousing and is thus expected to induce "tunnel vision" or reduced "cue-utilization" (Easterbrook 1959).

The results for the five-choice task point to a facilitation effect of mild heat on frequency of responding, including a decrease in hesitation errors and extra button presses (Grether 1973). From the point of view that 20°C is around the optimum arousal level for this task, this result looks more like an arousing rather than a dearousing effect of mild heat.

In summary, effects of low-intensity noise and mild heat were demonstrated for a cognitive task and five-choice serial reaction time. An interaction between noise and mild heat was indicated for one of the difficult cognitive tasks. The arousal theory, despite its shortcomings, is a likely candidate to explain some of the results.

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EMISSION OF BACTERIA FROM AIR HUMIDIFIERS

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An experimental study was undertaken to determine the emission of bacteria from two different types of air humidifier. In one of the humidifiers, which is of spray type, the air is humidified by very small droplets of finely dispersed water being sprayed by nozzles into the air stream. The other humidifier is of evaporative type, in which the air is humidified by water being evaporated from a humid contact body. The emission of bacteria from the humidifiers was studied by adding *Pseudomonas aeruginosa* to the humidifier water. In addition, the emission of bacteria was simulated by metering polystyrene particles with a diameter of 2 µm into the humidifier water. The carry-over factor, defined as the ratio of the bacteria concentration in the humidified air to the bacteria concentration in the humidifier water, was found to be about 10^{-7} for the spray-type humidifier and about $5 \cdot 10^{-10}$ for the evaporative humidifier of standard design. A modified evaporative humidifier was found to have a carry-over actor of less than $5 \cdot 10^{-12}$ when tested with particles.

INTRODUCTION

The air humidity that should be maintained indoors for hygienic reasons is the subject of considerable interest. The relative humidity of 40-60% has been recommended (MTI 1986; Sterling et al. 1985). However, to save energy, the indoor air humidity is now usually appreciably lower during the cold season of the year, when space heating is employed.

If the air supplied to a building is humidified, micro-organisms may give rise to hygienic problems. This occasionally occurs when micro-organisms are entrained by the air from humidifiers included in the air handling system. The problems arising from the use of humidifiers are generally caused by bacteria. Complaints are generally in the form of fever reactions, although these are usually of short duration.

Whenever the emission of bacteria from air humidifiers has given rise to hygienic problems, this was usually due to high bacteria concentrations in the humidifier water, and the fact that the water was sprayed into the air stream in droplet form (MTI 1986). The risk of the emission of bacteria is consequently highly dependent on the type of humidifier used and the conditions under which the humidifier operates. Recirculation of the water in an air humidifier promotes the growth of bacteria. The bacteria may also grow more quickly in the humidifier water as a result of high contents of organic dust in the air flowing through the humidifier.

The number of bacteria emitted from an air humidifier during a certain period of time depends mainly on how much water leaves the humidifier in droplet form during that time. If the bacteria concentration in the humidifier water and the quantity of water leaving the humidifier in droplet form per unit of time are known, the bacteria concentration in the humidified air can be calculated. But determining the amount of water in droplet form that leaves an air humidifier is a difficult metrological problem.

Few experimental results from laboratory tests on humidifiers have been reported. Only one study by Völksch et al. (1987), in which bacteria tests on aerosol humidifiers and evaporative humidifiers were carried out, should be mentioned in this context. During these tests, the bacteria concentration in the air was measured by means of a slit sampler, and measurements were made at a distance of 1 m from the humidifiers. The results obtained show that the bacteria concentration in the air increased substantially when the aerosol humidifier was started. On the other hand, when the evaporative humidifier was in operation, the total bacteria concentration in the air decreased somewhat.

Several field studies aimed at determining the bacteria concentrations in premises, in which the air is humidified by different types of humidifier, have been reported. The bacteria concentrations in air handling systems were studied, for example, within the framework of a major Finnish project concerned with the quality of the indoor climate (MTI 1986). A result of general interest in this connection is the fact that no increased bacteria concentrations could be demonstrated in buildings with air humidification (Pitkänen et al. 1985). The bacteria emission from evaporative humidifiers has also been studied in conjunction with the Finnish indoor climate project. It was found that this type of humidifier did not cause any significant increase in the bacteria concentration of the air, in spite of high bacteria concentration in the humidifier water. According to the report, the explanation is assumed to be that no solids are emitted from the surfaces of an evaporative humidifier to the air.

In this study, different methods were employed for determining the emission of bacteria from two common types of humidifier, i.e. the spray type and the evaporative type. Entirely different principles are employed in these two types of humidifier, and their bacteria emission properties may be different. Since the water is supplied in droplet form in the spray-type humidifier, some of the particles and bacteria present in the humidifier water may be transferred to the humidified air. On the other hand, this type of carry-over should be low in an evaporative type of humidifier.

An important element of the study was to determine the carry-over factor for the two humidifiers, which is defined as the ratio of the bacteria concentration in the humidified air to the bacteria concentration in the humidifier water. Knowledge of the carry-over factor for a certain type of humidifier then allows an assessment by relatively simple water analyses of the bacteria concentration that can normally be expected in the humidified air.

Another important task in the project was to compare different methods of sampling the bacteria in the air stream. A cyclone sampler, an All Glass Impinger-30 and an Andersen sampler were therefore used to determine the bacteria concentration in the humidified air.

EXPERIMENTAL METHODS AND PROCEDURES

In laboratory tests, the emission of bacteria from the two air humidifiers was determined by adding known quantities of test bacteria to the humidifier water. The emission of bacteria was also simulated by the addition of solid particles to the humidifier water. Probes for isokinetic sampling were used for taking air samples at a number of sampling points.

The test bacteria experiments in this study were preceded by preliminary tests with two different types of bacteria, in order to determine their survival in the water systems of the humidifiers.

The design of the humidifiers used in the tests is shown in Fig. 1. The spray-type humidifier was the type KDQS and the evaporative humidifier was the type KDQA (Fläkt AB). Both humidifiers are of standard design, although a somewhat modified version of the evaporative type was also tested. (In the modified version, the humidifier fills were extended downwards in order to reduce the distance between the fills and the water surface in the water tray to zero. This distance is about 35 mm in the standard evaporative humidifier.)

The spray-type humidifier is equipped with a bank of 14 nylon nozzles and double stainless steel droplet eliminators. During the tests, the spray-type humidifier was run with recirculated water, and the air flow rate was 1.15 m^3/s, which corresponds to an average air velocity of 2.7 m/s (across the effective area). The water volume in the humidifier water tray is normally 110 L.

In the evaporative type, the air is humidified by wet fills made of corrugated aluminium sheet with a surface layer of hygroscopic aluminium oxide. Circulating water from a water tray with a volume of 20 L

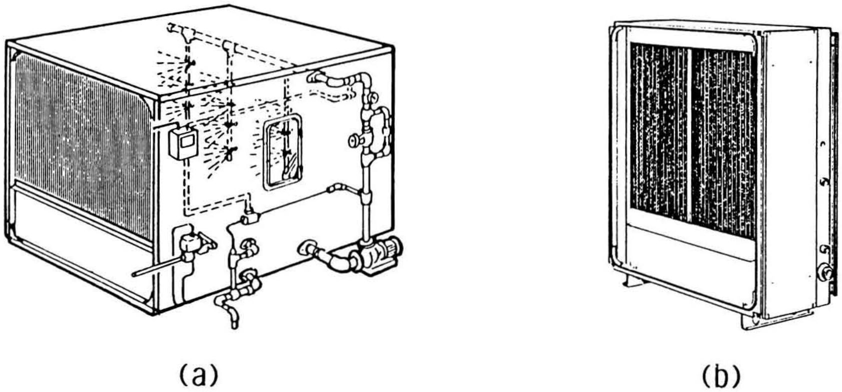

Fig. 1. The humidifiers used in the tests: a) spray type and b) evaporative type.

is distributed over the fills. The emission of bacteria from the evaporative humidifier was studied at an air flow rate of 0.63 m^3/s, which corresponds to an average air velocity of 3.0 m/s.

In all tests, the two humidifiers were run at basically the same humidification rate, i.e. ~ 90%, and the water supplied to the air normally amounted to ~ 2.5 g/kg of dry air.

Air handling system

Special test rigs were set up for studying the bacteria emission from the air humidifiers. Unit sections from a standard air handling unit were principally used. Air was supplied to the humidifiers from the test room, through a measuring device for determining the air flow rate, and through intake sections and a filter. Unit sections with various measurement probes were installed downstream of the air humidifiers. The air from the test rigs was discharged from the building through fans and control dampers. The test rig for the spray-type humidifier is shown schematically in Fig. 2.

Filters

The filter located upstream of the spray-type humidifier was a grade F95 fine filter. Bacteria measurements were significantly facilitated by employing a filter with a high collecting efficiency, since the filter collected a large proportion of the background bacteria in the air drawn from the premises. Efficient

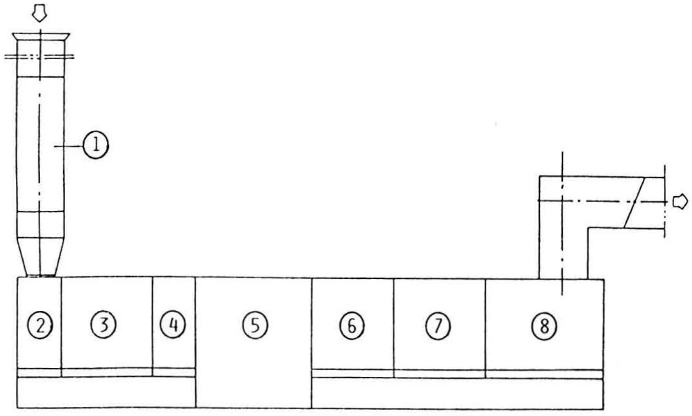

Fig. 2. Test rig for spray-type humidifier: 1) air flow measuring device, 2) intake section, 3) filter section with F95 filter, 4) short empty section, 5) spray-type humidifier, 6) sampling section, 7) filter section and 8) fan section.

cleaning of the supply air also proved necessary for the particle measurements carried out in conjunction with the metering of solid particles into the humidifier water.

Two different filters were used for cleaning the supply air during the tests on the evaporative humidifier. A grade F95 fine filter was employed during the bacteria tests, whereas an HEPA filter was used during some of the particle tests. When the HEPA filter was used in conjunction with particle measurement, the air in the test rig was maintained at a higher pressure than that in the premises, and the air supplied to the evaporative humidifier was pre-filtered in one (or sometimes two) grade F95 fine filter.

Operation

During measurements in the test rigs, the air humidifiers were normally connected to the cold water mains in the test room, so that make-up water was automatically supplied to compensate for the water lost in humidifying the air. On the other hand, no continuous water bleed-off was used during the tests, in order to avoid reducing the concentration of the bacteria or particles added to the humidifier water. Such bleed-off is employed during normal operation of humidifiers, in order to avoid excessively high salt concentrations in the water.

Particle measurements

Solid particles were added to the humidifier water to simulate the emission of bacteria from the humidifiers being tested. The particles used in most of the humidifier tests were Dynospheres type SS-022-R (Dyno Particles AS) which are made of polystyrene with a density of 1.05 g/cm^3. The diameter of these spherical particles is stated to be 2.0 ± 0.1 µm.

Bacteria measurements

A suitable procedure for accurate determination of the bacteria emission from an air humidifier is to add test bacteria to the humidifier water and then measure the content of these bacteria in the humidified air. The bacteria selected for test purposes should be representative, particularly as regards the emission properties of the bacteria normally occurring in the water system of a humidifier. Above all, it is important that the test bacteria should be as similar as possible to the bacteria that may give rise to hygienic problems if they occur in high concentrations in the indoor air.

Klebsiella have been used earlier in air humidifier tests at the Fläkt laboratories. Some tests with this type of bacteria were also carried out in conjunction with this study. However, the tests demonstrated that the survival of *Klebsiella* in the humidifier water system is unsatisfactory. On the other hand, similar tests carried out with *Pseudomonas aeruginosa* gave acceptable results. This type of bacteria was therefore used for the final humidifier tests.

The bacteria emissions from the spray-type humidifier and the standard evaporative humidifier were studied by the addition of the selected test bacteria to the humidifier water in two extensive test series. The quantities of bacteria added resulted in contents ranging between 10^5 and 10^6 bacteria/mL of water. Several determinations of the bacteria concentrations in the air stream leaving the humidifiers were made during the tests.

It would appear that the most reliable results were obtained when sampling was carried out with the cyclone sampler (Henningson 1981). In this sampler, airborne bacteria are collected in the liquid film on the wall of the cyclone (see Fig. 3). The bacteria concentration in the collecting liquid can then be determined by cultivation, which was carried out on CLED agar for the bacteria used in the tests.

Samples were taken with the cyclone sampler in the centre of each measurement section in the two test rigs, and the sampling time was 30-60 min. Totally, four tests were carried out for each type of humidifier. In all cases the sampling flow was 75 L/min.

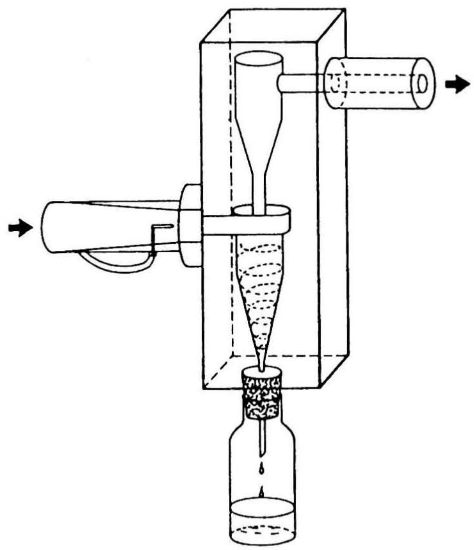

Fig. 3. Cyclone sampler (Swedish Defence Research Establishment).

Table 1. Measured content of particles ranging in size between 1.4 and 3 μm when plastic particles were added to the humidifier water.

Humidifier type	Particles added 10^{12} m^{-3} of water	Number of measurements	Particle content in the air (particles/m^3)
Spray (standard)	1.04	15	$1.04 \cdot 10^5$
Evaporative (standard)	5.6	78	540
Evaporative (modified)	5.6	90	<30*

*Lowest measurable particle content during the tests.

RESULTS

A large number of particle measurements were carried out by an optical particle counter (Royco type 245) when polystyrene particles were added to the humidifier water. Table 1 shows the mean contents of particles, ranging in size between 1.4 and 3 μm, in the air. The tabulated contents have been reduced by the measured background contents of particles on each occasion. Measurements were made at nine points, uniformly distributed across the cross-section of the test rigs. The distance between the spray-type humidifier outlet and the measurement section was 230 mm, whereas the distance between the evaporative-type humidifier outlet and the measurement section was 380 mm.

Table 2 shows the measured concentration of test bacteria during the two test series. The carry-over factor f_b for test bacteria is also given in this table, based on the results obtained. For the first test series on the spray-type humidifier, for instance, the carry-over factor was calculated according to

$$f_b = 2.0 \cdot 10^4 / (2.4 \cdot 10^5 \cdot 10^6) = 0.8 \cdot 10^{-7} \quad (1).$$

Table 2. Measured concentrations of test bacteria in the humidified air when sampling with the cyclone sampler.

Humidifier type	Bacteria added $10^6 \cdot mL^{-1}$ of water	Bacteria concentration in the air (number/m^3)	Carry-over factor for test bacteria
Spray (standard)	0.24	$2.0 \cdot 10^4$ -	$0.8 \cdot 10^{-7}$ -
Spray (standard)	0.12	$2.0 \cdot 10^4$ $1.7 \cdot 10^4$	$1.7 \cdot 10^{-7}$ $1.4 \cdot 10^{-7}$
Evaporative (standard)	0.9	$3.9 \cdot 10^2$ $4.8 \cdot 10^2$	$4.3 \cdot 10^{-10}$ $5.3 \cdot 10^{-10}$
Evaporative (standard)	1.1	$6.1 \cdot 10^2$ $8.6 \cdot 10^2$	$5.5 \cdot 10^{-10}$ $7.8 \cdot 10^{-10}$

DISCUSSION

The size and density of the particles used are considered to be representative of the bacteria usually occurring in air humidifiers. By adding such particles to the humidifier water, it should therefore be possible to obtain a relatively good assessment of the bacteria emission from different types of air humidifier. However, such tests must ultimately be confirmed by using the appropriate bacteria, since in addition to their size, the surface properties and geometrical shape of the bacteria undoubtedly have an effect on their emission from the water.

The plastic particles added to the water must be traced in the air stream downstream of the humidifiers, and this can be achieved only if the content of other particles is low. If the background content of particles is maintained at a very low level, the testing procedure will be significantly simplified, since the content of the added particles can then be measured directly in the air stream by means of an optical particle counter. At higher background particle contents, the plastic particles should preferably be collected on a membrane filter. The number of plastic particles can then be counted selectively in a light microscope, even if many other particles have been collected on the filter. However, the method is very time-consuming.

It will be noted from Table 1 that the measured particle content in the air downstream of the spray-type humidifier was $\sim 10^5$ particles/m^3 of air at a humidifier water particle content of $\sim 10^{12}$ particles/m^3. At a humidifier water particle content which is about five times higher, the particle content in the air downstream of the standard evaporative humidifier is ~500 particles/m^3 of air. The particle emission from an evaporative humidifier thus appears to be about 1000 times lower than that from a spray-type humidifier.

The modified evaporative humidifier was tested at a humidifier water particle content of $5.6 \cdot 10^{12}$ particles/m^3. In spite of this high particle content in the water, the particle content in the air downstream of the humidifier was not measurable. In this case, the particle content was lower than the lowest content that could be measured, i.e. ~30 particles/m^3 of air. The modification to the evaporative humidifier thus appears to have reduced the particle emission about 20-fold, or possibly entirely eliminated it.

Knowledge of the particle content in the humidified air and the particle content in the humidifier water provides a measure of the particle emission from the humidifiers being tested. It is advisable to specify the particle emission as a carry-over factor, defined as the ratio of the particle content in the air to the particle content in the water. Both of these particle contents should be specified for the same unit of volume, e.g. as the number of particles per m^3.

If the carry-over factor for particles is designated f_p, this can be calculated as follows for the standard spray-type humidifier

$$f_p = 1.04 \cdot 10^5/1.04 \cdot 10^{12} = 1.0 \cdot 10^{-7} \qquad (2)$$

For the standard evaporative humidifier, the corresponding value will be

$$f_p = 540/5.6 \cdot 10^{12} = 9.6 \cdot 10^{-11} \qquad (3)$$

Only the upper limit of particle emission could be determined during the tests on the modified evaporative humidifier. In this case, the carry-over factor can be expressed as follows:

$$f_p < 30/5.6 \cdot 10^{12} = 5.4 \cdot 10^{-12} \qquad (4)$$

The method of testing can probably be improved significantly, so that even lower carry-over factors can be determined, although it is doubtful whether this would be of any practical importance.

It may be of interest to compare the carry-over factors for bacteria specified in Table 2 with the carry-over factors obtained during the tests using plastic particles. According to Table 2, the carry-over factor for bacteria is an average of $1.3 \cdot 10^{-7}$ for the spray-type humidifier and $5.7 \cdot 10^{-10}$ for the evaporative humidifier, whereas the tests using plastic particles gave corresponding carry-over factors of $1.0 \cdot 10^{-7}$ and $1.0 \cdot 10^{-10}$ respectively. Good agreement between the two test methods was thus obtained for the spray-type humidifier. The difference between the results obtained on the evaporative humidifier may possibly be partially explained by the fact that sampling with the cyclone sampler was carried out at only one point (in the centre of the measurement cross-section), whereas particle measurements were carried out at nine measurement points.

The results obtained when sampling by means of the impinger (AGI-30) displayed wide scatter. The measured bacteria concentrations are also generally lower than those measured when sampling with the cyclone sampler. An estimate of the carry-over factor gives $f_{bi} \cong 1.7 \cdot 10^{-8}$ for the spray-type humidifier and

$f_{b2} \cong 1.2 \cdot 10^{-10}$ for the evaporative humidifier (apart from one value which is about 10 times higher than the mean value of the others). Both of these carry-over factors are lower than those obtained when sampling with the cyclone sampler. However, the ratio of the carry-over factors for the two humidifiers, i.e. $1.4 \cdot 10^{2}$, agrees somewhat better with the results obtained with the cyclone sampler, which gave $f_{b1}/f_{b2} = 2.3 \cdot 10^{2}$.

The bacteria concentrations measured when sampling with the Andersen sampler appear reasonable when compared to the results when sampling with the cyclone sampler. However, the scatter of the results is very wide. No accurate determination of the bacteria emission from the humidifiers can therefore be made on the basis of the results obtained with the Andersen sampler.

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THE EFFECT OF AIR HUMIDIFICATION ON DIFFERENT SYMPTOMS IN OFFICE WORKERS — AN EPIDEMIOLOGIC STUDY

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The effects of air humidification were studied in the Pasila Office Center, a modern eight-floor office building of 2150 workers in Helsinki, Finland. The occurrence of symptoms and complaints among the workers in the humidified part of the building (n = 122) was compared to the symptoms and complaints of workers in similar nonhumidified rooms (n = 132) in February, March, and April. The workers in the humidified part reported significantly less dryness of skin, throat and nose, and nasal obstruction as well as sensation of air dryness compared to those in the non-humidified part. There was no evidence of humidifier fever symptoms during the study period.

INTRODUCTION

Sensation of dryness is one of the most frequent complaints concerning indoor air quality in Finland during the heating season. The indoor air in the Nordic countries during the winter can be extremely dry, with a relative humidity below 10% during the coldest period. Air humidification in mechanically ventilated buildings is seldom used because of its expense.

Relative humidity affects man directly by causing humidity-dependent sensations on skin and mucous membranes and indirectly by changing the indoor air quality and the properties of furniture and building materials. It has been postulated that, during a cold winter, dry indoor air would cause drying of nasopharyngeal mucosa and deterioration of the ciliary function and thereby would increase the occurrence of respiratory infections (Lubart 1962; Arundel et al. 1986). Experimental studies on the effects of relative humidity on the function of the respiratory tract have given controversial results. In one experiment, the ciliary function of the human nose was considered to be as efficient at 9% relative humidity as at 50% (Andersen et al. 1974). In another experiment, the ciliary function of a rat bronchial preparate was reduced by 80% when the relative humidity was decreased from 50% to 5% at 37°C (Horstman et al. 1977). Linn et al. (1985) found that asthmatic bron-

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Study population

Three questionnaires were sent to all workers in the building in February, March, and April of 1985. They inquired about symptoms, diseases, complaints, and attitudes towards working conditions, health behaviour, and details of the home environment. Overall response rates in the three questionnaires were for February, March, and April 81%, 70%, and 71%, respectively. The study population in the first cross-sectional analysis (February) consisted of 122 workers in the humidified area and 135 workers in the non-humidified area. Those members of the study population, 78 (69%) workers in humidified and 100 (74%) workers in nonhumidified area who completed both the second and the third questionnaire, formed the study populations in the second and the third cross-sectional analyses.

Methods

Indoor air measurements. Air flows were measured in February 1985 in a random sample of 410 offices in the exhaust air registers with a calibrated Wallac anemometer whose accuracy is better than 15%. The mean of the measured airflows in a given ventilation zone was used to estimate the airflow in other offices of the zone. Room temperature and relative humidity were measured in the same offices in February, March, and April of 1985 with VAISALA HMI-31 capacitive sensors whose accuracy is ± 0.3°C for temperature and ± 2% for relative humidity. Temperatures in each office of the humidified and nonhumidified study area were also measured in March 1987.

The concentrations of chemical and biological factors, particles, ions, and radon were also measured in a small number of nonhumidified offices. Air samples were taken into a TENAX adsorbent with a high volume air pump. The samples were analysed by gas chromatography. Formaldehyde was measured with the standardized chromotropic acid method (SFS 3862). The carbon dioxide concentration was measured with a BINOS infrared analyser and was recorded 24 h/d. The particulate samples were collected by the two fraction method between 8 a.m. and 4 p.m. using a Nuclepore filter. A gravimetric measurement of the mass concentrations was carried out. Bacteria and fungal spores were collected with an Anderssen collector in one humidified office and seven non-humidified offices.

Exposure. Worker's exposure to air humidification/dry air was assessed based on the location of his/her office room.

Outcomes. The occurrence of symptoms during the previous 7 d was inquired about and the subjects were also asked to specify if the symptoms were experienced mostly at home, mostly at work, or equally at home and work. The occurrence of a symptom mostly at work or equally at home and work would add 1 point in the respective component of the summation score. The symptoms occurring mostly at home were not included in the summation. The inclusion of symptoms occurring equally at work and at home was justified because part of the effect of the office environment could be subacute and thus taking place also at home. Inquiring about the previous 4 weeks or 12 months it was asked how many times the symptoms had been experienced at home and at work. Occurrence once would add 1 point in the summation score, twice 2 points, three or more separate times 3 points, and continuous occurrence 4 points. Five different summation scores were used: (1) The SBS score describing the total amount of symptoms during the previous 7 d associated with SBS (nasal, eye, skin and mucous membrane symptoms, lethargy, and headache), range 0-6; (2) the dryness score of dryness symptoms experienced during the previous 7 d (throat, nose, eye and skin dryness, and obstruction of nose), range 0-5; (3) the humidifier fever score of symptoms experienced during the previous 7 d (lethargy and headache), range 0-2; (4) the humidifier fever score of symptoms experienced during the previous 4 weeks (fever, lethargy, headache, and musculoskeletal symptoms), range 0-16; and (5) the humidifier fever score of symptoms experienced during the previous 12 months (fever, lethargy, headache, and musculoskeletal symptoms), range 0-16.

The SBS score was the same used earlier by Jaakkola et al. (Jaakkola 1986; Jaakkola et al. 1987; Jaakkola et al. 1989; Jaakkola et al. 1988). The dryness score describing the dryness symptoms was formed of the symptoms suggested by Robertson et al. (1985) as consequences of low relative humidity. The humidifier fever scores were based on the information received from humidifier fever epidemics in office buildings (Wadden and Scheff 1983). The symptoms of the previous 7 d were asked in every questionnaire. The symptoms of the previous 12 months were recorded only in the first questionnaire and of the previous 4 weeks in the second and third questionnaire.

Statistical methods. The results were compared between the workers of the humidified and nonhumidified area (χ^2-test, t-test). The association of the summation score with potential confounders and the distribution of potential confounders in humidified and nonhumidified areas were also studied in bivariate analyses (t-test, χ^2-test). Finally, the mean SBS scores in the two areas were compared after adjusting for exposure to tobacco smoke, attitudes towards atmosphere at work, and history of allergic disease (asthma, allergic rhinitis, or allergic eczema) in the analysis of covariance. Logistic regression models were fitted to estimate the adjusted relative risk (odds ratio) of having dryness symptoms and humidifier fever symptoms when working in nonhumidified vs. humidified area. The outcome scores were dichotomized for the analysis: dryness score (0 = one or no symptoms, 1 = more than 1 symptoms), 7-d-humidifier-fever-score (0 = no symptoms, 1 = symptoms), 4-week and 12-month-humidifier-fever-score (0 = five or less symptoms, 1 = more than five symptoms). The estimated relative risks were adjusted for all the potential determinants of the outcome.

RESULTS

The ventilation rates in the building were large on the average, 7-70 L/s · person (mean 26 L/s · person). In the study, area temperatures were 19-24°C (mean 22.4°C) in the nonhumidified offices and 21-24°C (mean 22.0°C) in the humidified offices. Relative humidity in the humidified spaces was kept in the range of 45-55% ± 5%. The relative humidity did not vary between nonhumidified offices at any time, and was 10-20% in February and 20-25% in March and April.

The concentrations of indoor air pollutants measured in the nonhumidified offices were far below the values known to cause adverse health effects. The mean carbon dioxide concentration was 420 cm^3/m^3 and did not exceed 950 cm^3/m^3. The concentration of formaldehyde was 47 $\mu g/m^3$ in an office with typical furniture, textiles, and ventilation rate. The maximum concentrations of organic gases were: ethanol 98 $\mu g/m^3$ (mean 73 $\mu g/m^3$), hexane 10 $\mu g/m^3$ (mean 9 $\mu g/m^3$), acetone 33 $\mu g/m^3$ (mean 32 $\mu g/m^3$) and toluene 165 $\mu g/m^3$ (mean 107 $\mu g/m^3$). Bacteria concentrations in the nonhumidified offices were 4-2229 cfu/m3 and 152 cfu/m^3 in the humidified office. Concentrations of fungal spores were 4-77 cfu/m^3 in the nonhumidified offices and 14 cfu/m^3 in the humidified office.

The adjusted mean SBS score was greater in workers of the nonhumidified than in the humidified area. In February it was 2.84 vs. 2.48, in March 3.07 vs. 2.36, and in April 2.79 vs. 2.21, although the difference was statistically significant only in March (Table 1).

The occurrence of dryness symptoms in the humidified and the nonhumidified areas is presented in Table 2. The prevalence of dryness symptoms was systematically greater among workers of the nonhumidified area in every month. The difference was greatest for pharyngeal and nasal symptoms. The adjusted relative risk (odds ratio) for dryness symptoms associated with work in nonhumidified vs. humidified rooms for three months is given in Table 3. Working in a nonhumidified room was a statistically significant determinant of dryness symptoms every month.

The adjusted relative risk (odds ratio) for humidifier-fever symptoms due to work in the humidified area (coded 1) vs. nonhumidified area (coded 0), controlling for other determinants of the symptoms, was estimated in logistic regression models (Table 4). The point estimate for risk of humidifier fever caused by humidification was in all but one case greater than one. The lower limit of the 95% confidence interval is greater than one for symptoms occurring during the previous 12 months.

The distribution of answers to the question "Is the humidity of air in your working room suitable in winter?" in the workers of the nonhumidified and humidified areas is given in Table 5. There was a

Table 1. Adjusted mean SBS score (range 0-6) in nonhumidified and humidified rooms. Analysis of covariance with covariates: exposure to tobacco smoke, atmosphere in the working environment and history of asthma, allergic rhinitis, or allergic eczema.

	Nonhumidified	Humidified
February (n=254)	2.84 (n=132)	2.48 (n=122)
March (n=176)	3.07 (n=98)	2.36 (n=78)
April (n=176)	2.79 (n=98)	2.21 (n=78)

Analysis of covariance: * $p < 0.05$.

Table 2. Dryness symptoms in the nonhumidified and humidified rooms during the previous 7 d in February, March, and April.

	Nonhumidified		Humidified		
	n	%	n	%	
Dryness of skin					
February	66	48,9	56	45,9	
March	57	57,0	31	39,7	*
April	47	47,0	31	39,7	
Dryness of eyes					
February	22	16,3	19	15,6	
March	23	23,0	14	17,9	
April	23	23,0	15	19,2	
Dryness of throat					
February	67	50,4	40	32,8	**
March	49	50,0	19	24,4	***
April	39	40,0	17	21,8	*
Dryness of nose					
February	76	57,8	49	40,2	**
March	61	62,0	30	38,5	**
April	55	56,0	26	33,3	**
Obstruction of nose					
February	74	54,8	55	45,1	
March	53	53,0	23	29,5	**
April	47	47,0	26	33,3	

t-test: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

Table 3. Adjusted relative risk (odds ratio) for having more than one dryness symptom when working in nonhumidified (coded 1) vs. humidified office (coded 0). Logistic regression model with sex and attitude towards working environment as covariates.

	Adjusted odds ratio	$CI_{95\%}$
February (n=252)	2.1	1.3-3.6
March (n=174)	4.1	2.0-8.7
April (n=174)	2.0	1.0-3.9

Table 4. Adjusted relative risk (odds ratio) for occurrence of humidifier fever symptoms due to work in humidified office. One week symptoms (0 = no symptoms, 1 = 1 to 2 symptoms) covariates: sex, subjective possibility of controlling work, atmosphere of working environment and temperature. Four weeks and one year symptoms (0 = 0 to 5 symptoms, 1 = 6 to 16 symptoms) covariates sex and atmosphere of working environment.

	One week		Four weeks/12 months	
	Adj.odds ratio	$CI_{95\%}$	Adj.odds ratio	$CI_{95\%}$
February	1.4	0.8-2.4	1.9	1.1-3.2
March	1.1	0.6-2.1	1.2	0.6-2.3
April	0.7	0.3-1.3	1.1	0.6-2.2

Table 5. Distribution of answers to the question "Is the humidity of air in your working room suitable in winter?" among workers in nonhumidified and humidified rooms in February, March, and April.

	Nonhumidified		Humidified	
	n	%	n	%
February				
"Yes."	17	13,0	74	69,2
"Sometimes feeling dry."	50	38,2	20	18,7
"Always feeling dry."	64	48,9	13	12,1
Total	131		107	***
March				
"Yes."	15	15,2	50	74,6
"Sometimes feeling dry."	48	48,5	10	14,9
"Always feeling dry."	36	36,4	7	10,4
Total	99		67	***
April				
"Yes."	21	21,0	51	73,9
"Sometimes feeling dry."	49	49,0	13	18,8
"Always feeling dry."	30	30,0	5	7,2
Total	100		69	***

χ^2-test : *** $p < 0.001$

statistically significant association between the sensation of dryness and working in the nonhumidified area for every month (χ^2-test: $p < 0.001$).

DISCUSSION

The objective of the study was to evaluate the effect of humidification on human health and comfort. The study population was obtained from the Pasila Office Center. The basic idea was to choose a group of workers from similar humidified and nonhumidified rooms and compare the symptoms and complaints between the two groups.

Thorough characterization of offices and HVAC systems in the building was made and the most comparable humidified and nonhumidified spaces were chosen. There were some differences between the offices of the two areas: (1) The HVAC system performed differently, (2) the mean number of persons per office was greater in the humidified area due to two large drawing halls of 30-40 workers in each, and (3) the mean temperature differed between humidified (22.0°C) and nonhumidified spaces (22.4°C) by 0.4°C. These differences are potential sources of bias, which have to be taken into account when evaluating the results.

The two groups were comparable with respect to age, sex, and smoking habits. The repeated questionnaires in February, March, and April give information on the seasonal variation and consistency of possible differences in symptoms and complaints.

More SBS symptoms were recorded in the nonhumidified than in the humidified rooms for all of the three cross-sectional studies, although the difference was statistically significant only in March. The occurrence of dryness symptoms was also associated with working in the nonhumidified area. The risk for more than one dryness symptom was significantly higher in the nonhumidified area for the three months. The prevalence of every individual dryness symptom was greater in the nonhumidified area. The difference was statistically significant in the dryness of throat and nose. Dryness symptoms form a main part of the SBS score used in the study.

There were no significant differences between the two groups in the occurrence of humidifier fever symptoms during the previous week and during the four weeks. However, working in a humidified area was found to be a significant determinant of humidifier-fever symptoms in the previous 12 months. Originally, the questionnaire was not designed for detecting cases of humidifier fever and the score used in the analyses may be insensitive. The cut-off points used in the logistic regression model are arbitrary and not based on the most adequate clinical signs and symptoms. On the other hand, the measured concentrations of microbes in the indoor air and the ventilation system were very low. Further, there had not been any clinical cases of humidifier fever registered by the local occupational health center. It can be concluded that during the research period from February to April 1985 no evidence of humidifier fever occurred.

Complaints of the dryness of indoor air were clearly more frequent among workers in nonhumidified than in humidified offices in all three cross-sectional analyses. The knowledge of the presence or absence of humidification has possibly an effect on the complaints which cannot be separated from the physiological effects of relative humidity. However, the difference in the amount of complaints was large: in February, only 13.0% of the workers in the nonhumidified area were satisfied with the humidity compared with 69.2% in the humidified area. The small difference (0.4°C) in the mean temperature between the areas could not explain the difference in the sensation of dryness (Jaakkola et al. 1991).

According to our results, humidification reduces the symptoms which are associated with the sick building syndrome. Especially, dryness symptoms of the nose and throat are affected. Humidification clearly reduces the sensation of air dryness. The physiological effect cannot be separated from that of the knowledge of the presence or absence of humidification. Pragmatically, the effect of humidification during cold winter seems to be positive: workers in humidified rooms express less symptoms and complaints than workers in nonhumidified rooms. Well maintained humidification apparatus do not cause humidifier fever.

Our results indicate that further research is needed on the effect of indoor air humidification on human health and well-being in the Nordic countries like Finland where extremely low indoor air humidity during cold winters can have adverse health effects.

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ATTITUDES AND COMPROMISES AFFECTING DESIGN FOR THERMAL PERFORMANCE OF HOUSING IN AUSTRALIA

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This paper gives a brief outline of some of the findings of a study of thermal preferences in housing in South and central Australian climates, where both summer and winter thermal performance need to be considered in design, and where the normal pattern of heating and cooling equipment use is intermittent. The study aimed to discover a range of design data relevant to housing in climates and situations such as these, where designers may need to make compromises in design for good thermal performance. A central question was what periods should be taken as high priority design times in designing for thermal performance. Data collection was by mail survey and by electronic devices called comfort vote loggers. The paper shows how the complexity of the thermal design problem and the need for compromises in design affect the nature of applicable data. It shows how systematic study of thermal preferences in the field can help to bridge the gap between approaches which model thermal performance of buildings and assess performance against some measure of thermal satisfaction, and approaches which recommend built solutions for various climates on the basis of interpretation of how physical science suggests that traditional buildings perform in those climates.

INTRODUCTION

Designers who aim to produce thermally satisfactory housing for climates with both summer and winter design times face very different problems from designers for climates where either cold or hot conditions predominate. In housing design for climates with both summer and winter design times, designers must usually design for good thermal performance at several different times of day and year. The design which is appropriate for one time may be quite inappropriate for another time. For example, heavyweight walls that stabilize internal temperatures may improve comfort in uncooled buildings on summer afternoons, but be inappropriate for hot summer evenings and nights (Walsh et al. 1982; Coldicutt and Williamson 1988).

A major concern is how, in principle, to provide knowledge for application in design for any climate and thermal design problem where compromise is an issue. This compromise could be between thermal performance at different times of year, or between performance with and without mechanical cooling, or between thermal performance and other design aims. These situations are only partly a product of climate, as they can also be influenced, for example, by economics, by aspects of lifestyle, and by the nature and availability of heating and cooling equipment. In the following, these situations will be referred to as compromise situations.

Literature on design for these situations covers two extremes. Certain studies interpret the application of physical sciences to the thermal performance of traditional buildings in a particular climate. Other studies present or are based on methods dealing with modelling of buildings' thermal performance. In the latter cases, the acceptability of performance may be assessed according to thermal response criteria which may be based on climate chamber or field studies. There are also many intermediate examples of studies, many of which use a bioclimatic chart (Olgyay 1963) as a basis for proposing appropriate strategies for various climates. A well-known intermediate example is Watson and Labs' "Climatic Design" (1983). Most approaches have a common theme in that they give some explanation of the physics of heat. To discuss the strengths and weaknesses of the various approaches, it is useful to take extremes of the types of approach.

Saini (1980) provides an Australian example of the type which interprets traditional buildings. It explains how various characteristics of the buildings affect performance, but does not generally provide quantitative evaluation. If the cultural, economic, and physical contexts in which the buildings were created are identical to those relevant to the design, this approach can present information in a form which appears to be readily usable by designers. It can take account of the complexity of the potential factors influencing compromises in design. However, this type of approach commonly fails to take full account of currently available heating and cooling equipment, and this limits applicability in cultures where equipment is an option. For example, Saini considers "artificial control of indoor climate" briefly, only after building design has been discussed, and thus the bulk of the information on building design takes no account of heating or cooling equipment.

In the climates under study in this paper, choice of whether or not to install cooling equipment and what type of cooling to use have major implications for other aspects of housing design for good thermal performance. For example, they affect the choice of materials, both resistance and "thermal mass" being relevant (Williamson and Coldicutt 1986; Coldicutt and Williamson 1988). Since the choice of materials in turn affects the decision of whether and how to cool mechanically, the design decision-making process is a complex one which needs to treat the effects of equipment in an integrated way.

A further weakness of these approaches which interpret traditional buildings is their predominantly prescriptive nature. If, for any reason, designers cannot readily comply with the recommendations, these approaches usually do no more than explain what will be better or worse. They give no means by which designers can make quantitative evaluations of the effects of non-compliance and partial compliance. For a compromise situation it is not enough to know that improvement X will make the building better on hot days and worse on hot nights. The designer is likely to want to know how much better and worse, and how much this matters to the occupants. An evaluative approach is called for.

Modelling building performance can overcome some of these problems. Thermal performance computer programs, which have been validated for similar buildings in similar climates, provide a powerful tool to aid design decision-making (Williamson 1982). An evaluative approach can be adopted and many alternatives can be compared systematically. However, in climates and situations where some thermal discomfort is to be accepted at some times and, hence, compromise is required, the utility of these computer packages depends on the availability of knowledge about the thermal requirements of the occupants.

One approach to providing this knowledge is to use a noncontextual model of thermal sensation and satisfaction, such as the International Organization for Standardization (ISO) predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) (ISO 7730 1984). However, this approach is limited in that it provides no means of defining acceptability (or satisfaction) in a way which takes account of context (Coldicutt et al. in press). For example, in some hot climates, economic influences and acclimatization both appear to affect acceptability (Williamson et al., in press), but neither is taken into account in the ISO approach. It might be possible to take account of them by selecting an appropriate PPD, but this requires contextual information not considered in the ISO formulae.

Many field studies have brought the application of noncontextual approaches into question (Humphreys 1975; De Dear and Auliciems 1985). Field studies have themselves produced recommendations on thermal requirements, a recent example being a proposal by Auliciems (1990) which gives thermal neutralities recommended for a range of times of year and climates in Australia. However, this too can be criticized for failing to take account of potential contextual influences such as cultural and economic factors. More importantly, it presents information only on neutralities, and not on acceptable limits. If a designer is trying to make decisions on compromises of the type illustrated above, information on acceptable limits is needed (Williamson et al. in press).

The present paper reports aspects of a study which attempted to overcome these problems and to provide information for design of housing in South and central Australia. The paper is concerned with the nature of appropriate knowledge and with the knowledge itself. So far as the authors could discover, for such a broad topic, currently available approaches, such as the Watson and Labs example mentioned above, do not appear to provide evaluative approaches which take account of relevant aspects of context such as economics and other nonthermal influences on choice and use of equipment. Attempts have been made to deal with compromise (Koenigsberger et al. 1973) but these appear to take account of only a narrow range of contextual influences.

This paper draws its conclusions from an empirical study in three climates, and aims to provide design data for these cases. It could not be assumed that current approaches defined knowledge in ways which are appropriate to compromise situations. Hence the study was an exploratory one, as it was recognised that the problems would not be overcome easily. A variety of data-gathering instruments was considered appropriate; both qualitative and quantitative data were sought. To maintain sizable subsamples (for example, houses with insulated ceilings), large samples were used, except where use of expensive equipment, the comfort vote loggers, made this infeasible.

The study sought context-specific knowledge regarding design times and thermal preferences. Knowledge of priorities of design times should help designers to make compromises where design for good thermal performance at one time of day and year conflicts with design for another time. For example, if hot nights (sleeping) is considered the most important design time, and no mechanical cooling is to be used, a well ventilated lightweight building with only reflective foil laminate insulation might be chosen, though it would not be the best solution for summer daytime or winter nights (Walsh et al. 1982; Coldicutt and Williamson 1988).

Knowledge of thermal preferences is also important. It is useful to conceptualize three sets of preferences which relate to thermal attributes of environments:

1. Preferences regarding attributes of the climatic environment—the air temperature, radiation, humidity, and air movement;

2. Preferences regarding attributes of the built environment—the buildings, heating and cooling equipment, and other material means by which the first set of preferences can be addressed;

3. Preferences regarding attributes of the human environment—this very broad set includes all ways in which people's attitudes, beliefs, and behaviour affect their thermal preferences; an everyday example is customs and preferences regarding clothing; a broader example is the ways in which societies make decisions about addressing thermal preferences.

Thermal preference is thus defined as having an unusually broad meaning (Auliciems 1981). Preferences are by their nature difficult to determine. They may be expected to change over time, under the influence of, for example, changing lifestyles or rising energy costs. Despite these problems, it is important for designers of thermally good housing that attempts be made to identify thermal preferences as here defined, as otherwise, in the absence of a particular client/occupier, the designer is forced to guess what thermal preferences are likely.

METHOD

The locations studied were Alice Springs, Adelaide, and Port Augusta (Fig. 1). Alice Springs and Port Augusta are small towns, with about 12 000 and 19 000 persons, respectively, on their electoral rolls. Adelaide is an extensive city of about one million people, with considerable climatic variations from one part of the city to another, and so an area of Adelaide close to the Bureau of Meteorology was chosen for the study.

Figure 2 illustrates the types of houses in these three locations. They are mainly freestanding single-storey buildings, usually with individual heating and cooling systems for which the occupants pay the running costs. Many are either owned by their occupants or occupied long-term by tenants of a government housing authority.

Aspects of the climates of the three locations are shown in Fig. 1 and Table 1. Alice Springs and Port Augusta have hot, dry, sunny summers, with Alice Springs having longer summers, hotter nights, and fewer mild summer days than Port Augusta. Adelaide's summers are less extreme, but also have some hot weather. Alice Springs has short, sunny, dry winters with cold nights. Port Augusta and Adelaide have cool to mild winters, with Adelaide's being longer and wetter—an average of 16 days on which rain occurs in July (ABOM 1975).

Information was gathered by a mail survey, and by comfort vote loggers (Williamson and Coldicutt 1988;

Williamson et al. 1989). Questionnaires were sent to 1900 households in each of the three locations. Half were sent in winter (1986) and half in the following summer, to allow for any seasonal effects. Households were selected randomly from electoral rolls which include all Australian citizens over the age of 18 y. An exception to the otherwise random selection was that, as far as possible, only those living in houses, not flats, were selected, by omitting addresses which had dual numbering, such as 4/32 Smith St. The response rate to the survey was 47.4%.

Comfort vote loggers are electronic instruments which record house occupants' votes on a thermal sensation scale and their reported clothing levels, activities, relative air movement, and identification. Whenever an occupant enters a vote, temperature and humidity are recorded automatically by the logger. Comfort vote loggers were installed in the living zones of approximately 20 houses in each of the three locations. These households were selected by taking the first available from those who responded to an invitation sent with one quarter of the mail surveys. Loggers were used for approximately three weeks in summer in each location.

The questionnaire (Williamson et al. 1989) contained 43 questions. Of these, 24 were concerned with matters of fact regarding the construction materials of the respondent's house, its age, the various heaters and coolers in the house, the rooms in which they were used, and the times of the day when they were normally used. Some questions were concerned with the house occupancy (for example, whether the house was owner-occupied or rented and how long the respondent had lived in it). The questions which related to heaters and coolers and their use are shown as the headings to Tables 3 to 8. Eight questions were aimed at eliciting the respondent's degree of satisfaction with the climate, the house's heaters and coolers, and some aspects of the house's design, such as, for example, its windows. The remaining questions, approximately the final quarter of the questionnaire, were concerned with eliciting the respondent's ideas on the type of house he or she would consider to be ideal for the local climate.

Since thermal preferences, and hence design times, are difficult to determine, the survey was designed to approach this central question from a number of angles. One key question, referred to henceforth as the "design times" question, was "Imagine that you were choosing a house that would be ideal for the [Alice Springs] climate. You would need to think about what it would be like inside the house at particular times of the year and times of the day. Listed below are some times that you might want to take into consideration. Please indicate which of these times would be most important to consider:

Cold winter nights when you're in bed
Hot summer afternoons
Hot summer evenings
Hot summer nights when you're in bed
Cold winter mornings at getting-up time
Cold winter evenings
Hot humid weather
Any other times?........"

The list of times was developed from an analysis of group discussions conducted early in the project. All times of the day and year that were mentioned in connection with thermal discomfort were included.

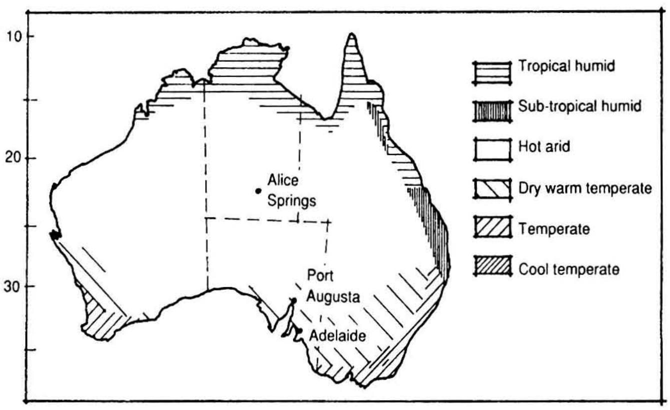
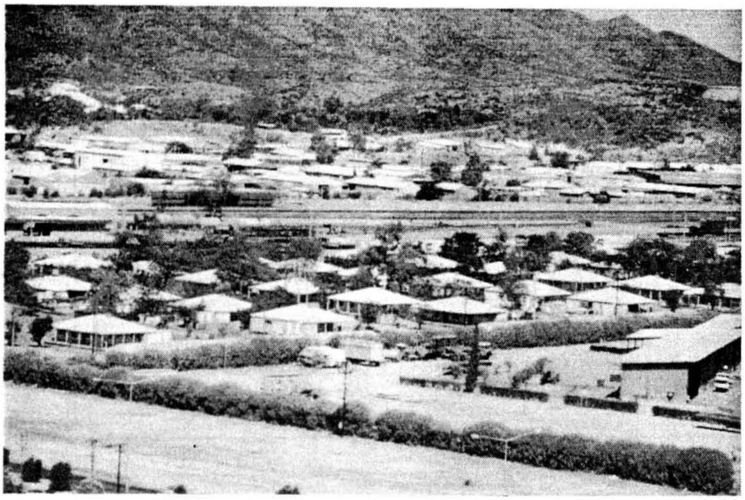
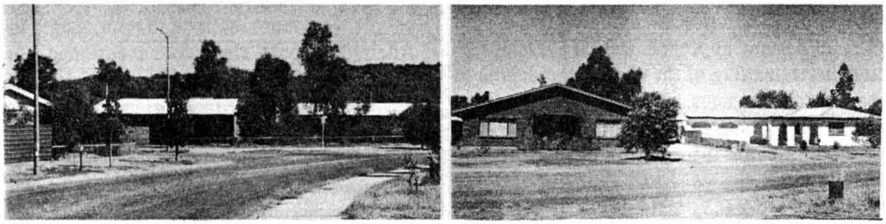


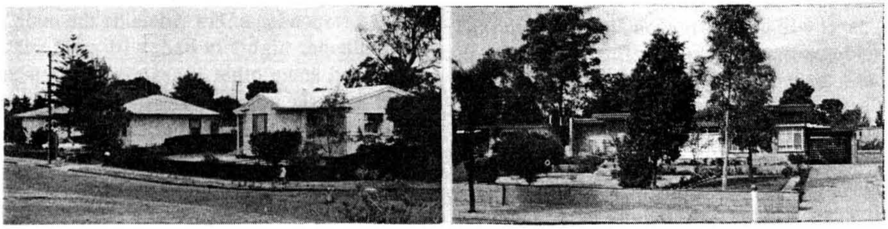
Fig. 1. A broad classification of Australian climates (Drysdale 1975).



Alice Springs



Alice Springs



Port Augusta

Adelaide

Fig. 2. A range of houses in the locations studied (1. and 2. Alice Springs; 3. Port Augusta; 4. Adelaide)

Table 1. Climatic data for hottest and coldest months (ABOM 1975).

Location	Month	Daily max temp. (C) 86%ile	Mean	14%ile	Daily min temp (C) 86%ile	Mean	14%ile	3pm mean rel humid (%)
Alice Springs	Jan	40.6	36.6	32.6	26.7	22.2	17.3	19
Port Augusta PO	Jan	41.6	33.1	26.7	23.9	19.8	16.1	30
Adelaide(Kent Town)	Jan	35.8	29.3	23.7	21.6	17.3	14.0	33
	Feb	36.8						
Alice Springs	Jul	24.1	19.3	15.3	9.3	4.5	0.2	30
Port Augusta PO	Jul	18.3	16.2	14.4	9.4	6.9	4.4	51
Adelaide(Kent Town)	Jul	17.7	15.1	12.8	10.1	7.5	4.2	60

The questions relating to existing house construction, heaters, coolers, and use patterns provide basic information which is an important starting point in design as it helps to describe thermal preferences.

Another important approach was the attempt to gain some understanding of the occupants' degree of discomfort at various times. Though the comfort vote loggers were the main source of such data, the survey also collected relevant information by the question "At what times of the year and times of the day is your house very uncomfortable....fairly uncomfortable....?"

RESULTS

This paper will concentrate on results which show how data regarding contextual influences can be obtained and made available for designers. The complete findings are given in the research report by Williamson et al. (1989).

People gave a wide variety of answers to the question about times when the house is very uncomfortable. However, summer afternoons were mentioned often for all locations, with the distinction that for Adelaide people usually referred to mid-summer or hot summer days, whereas in the other two locations people were more inclined to refer simply to summer. Adelaide people also often mentioned hot summer weather in general, without specifying the time of day. The main other times given were summer evenings and nights (Adelaide and Port Augusta) and winter mornings (Alice Springs).

Answers to the design times question (Table 2) bear an interesting relationship to these findings. For Alice Springs, times most commonly given were hot summer afternoons and hot summer nights in bed, but three other times were also given by more than 50% of the respondents. For Adelaide the main time was hot summer nights in bed, with cold winter evenings and some other times also as important. For Port Augusta, hot summer afternoons, evenings, and nights in bed were all important. In all locations, cold winter nights in bed were mentioned least often. In all locations, there was an average of three times given per respondent. The similarities and differen-

Table 2. Design times (% of cases).

	Alice Springs	Adelaide	Port Augusta
Cold winter nights when you're in bed	19	16	13
Hot summer afternoons	61	46	67
Hot summer evenings	53	52	57
Hot summer nights when you're in bed	60	66	63
Cold winter mornings at getting-up time	50	43	36
Cold winter evenings	50	57	37
Hot humid weather	39	33	27
Any other times?........	1	1	1

Table 3. "What kind of heating do you use in your house?" (% of cases).
Note: Tables 3-8 are condensed and/or abbreviated to concentrate on main response categories.

	Alice Springs	Adelaide	Port Augusta
Gas space heater	18	40	7
Built-in electric	4	3	10
Portable electric	42	68	64
Reverse cycle airconditioning	3	28	30
Open fire	13	28	6
Slow combustion stove etc.	18	17	13
Kerosene heater	9	5	7
Built-in oil heater	31	8	5
None	1	0	1

Table 4. "What rooms do you usually heat?" (% of cases).

	Alice Springs	Adelaide	Port Augusta
Whole house	12	4	8
About half house - living areas	42	37	33
Living room	46	58	59
One bedroom	8	13	6
All bedrooms	3	4	2
Kitchen	10	28	26

Table 5. "At what times of day or night do you usually use heaters?" (% of cases).

	Alice Springs	Adelaide	Port Augusta
All the time, day and night	7	6	3
All the time, except overnight	4	11	6
Afternoons	5	13	8
Evenings until bedtime	83	82	87
Over night	9	3	3
Mornings	25	24	27

ces between the times given in answer to these two questions can be better understood knowing the heating and cooling patterns in each location.

Responses to questions concerning heaters and their use are described in Tables 3, 4, and 5. In all locations a wide variety of heaters was used, with rooms most commonly heated being in the living zone of the house, and ranging from one room to about half of the house. Daily use patterns were also similar in all locations, by far the main time being evenings till bedtime, with mornings next. Few houses were heated all the time. In Alice Springs and Port Augusta, the mean number of days per year reported on which heaters were usually used was about 70; in Adelaide it was 104. There were hardly any houses in any location with no form of heating.

With existing cooling, there were more differences between the three locations. In Alice Springs, almost every house had evaporative cooling, mainly ducted and used as the main cooler. No house in the sample was without mechanical cooling of some kind. Mean days of reported use of main coolers was 145/y. Most commonly the whole house was cooled, and by far the most common daily use pattern was "all the

Table 6. "What coolers, if any, do you use in your house?" (% of cases).

	Alice Springs	Adelaide	Port Augusta
Portable fan or fans	17	48	35
Ceiling fan or fans	14	21	17
Evaporative cooler	99	18	27
Refrigerative airconditioner	8	50	78
None	0	8	1

Table 7. "What rooms are cooled by your main cooler(s)?" (% of cases).

	Alice Springs	Adelaide	Port Augusta
Whole house	80	11	29
About half house - living areas	11	29	29
Living room	7	49	38
One bedroom	3	25	20
All bedrooms	5	10	9
Kitchen	4	17	17

Table 8. "At what times of day or night do you usually use your main cooler(s)?" (% of cases).

	Alice Springs	Adelaide	Port Augusta
All the time, day and night	46	9	26
All the time, except overnight	26	12	21
Evenings until bedtime	22	53	35
Over night	11	18	19
Mornings	17	32	28

time". The Adelaide houses had a greater variety of coolers, particularly refrigerative coolers and fans. Some houses (8%) had no coolers at all. Mean days of reported use of main coolers was 40/y. The most common area cooled with main coolers was one living room but a variety of other patterns, including one or more bedrooms and the living half of the house, were also common. The most common daily use patterns were evenings till bedtime and afternoons. Port Augusta showed an even greater variety of cooler use patterns. Broadly, these fall between the Alice Springs and Adelaide patterns, as is shown in Tables 6 to 8.

These cooler and heater use patterns throw some light on the differences between answers to the "design times" question (Table 2) and the "house very uncomfortable" question. The most striking difference between answers to the two questions occurred for Adelaide, where winter evenings were given as a main design time, but were not often mentioned as times when the house was very uncomfortable. In view of the common daily use pattern of heating in the evening it is not surprising that this time is recognized as a main design time but is not reported as a time of major discomfort.

In designing the research, there was some concern as to whether respondents would give reliable responses to any "design times" question. It was thought that recent experience, including weather and type of house occupied, might affect responses. The research report (Williamson et al. 1989) shows that there were only slight differences between summer and winter responses regarding main design times. Nor did the type of house occupied appear to have any strong effect on responses, although interpretation of this is complex. It seems that answers to the "design times" question can provide data which are sufficiently reliable for use in design, provided that findings are interpreted as giving approximate relative importance.

Other survey questions help to explain the use patterns of equipment and the choice of type of equipment. Running costs were a major concern, especially for heaters; non-monetary costs, such as equipment noise, were also important in some cases.

Further data on thermal preferences and design times are provided by answers to other questions in the survey. For example, a question on likely window opening habits for a house that would be ideal for the climate shows that many respondents in all locations like having windows open for ventilation or for a breeze. Among reasons for keeping windows closed, dust or pollution stand out as important in the dry climates of Alice Springs and Port Augusta. These preferences could have a major influence on building design and choice of equipment.

The Design Data Sheet shown as Fig. 3 summarizes the findings for Adelaide for the main summer design times. It includes findings not discussed in this paper, such as data collected by comfort vote loggers and information from responses to questions regarding sun penetration. These findings are reported fully by Williamson et al. (1989). Briefly, the temperature and humidity data are taken from comfort vote logger records. While collection of accurate data in the field presents many difficulties, it seems unlikely that the mean temperatures of 2°C above neutralities (see footnote in Fig. 3) would be explained by such potential inaccuracies in data collection.

The type of design information shown on the design data sheet (Fig. 3) is different from the two broad types discussed in the introduction: interpretation of traditional buildings and modelling of building performance assessed against some measure of thermal satisfaction. The design data sheet appears to overcome some of the problems of both these approaches. Its numerical data and some of the information on coolers are intended for use in an approach which models building performance, as computer simulation is a useful design aid in that it allows for evaluation of many alternative designs. The data sheet also provides descriptive data regarding thermal preferences (for example, preferences for sun penetration), and some other contextual data. The attempt is to gain the advantage of approaches based on traditional buildings, while taking account of currently available equipment and current costs and lifestyles. For brevity, only key contextual data are shown in Fig. 3; further details are given by Williamson et al. (1989).

For other design times other design data sheets are required: for example, for Adelaide, one is needed for summer nights during sleeping hours and one for winter evenings and mornings. Only limited thermal preference data regarding these times were collected.

CONCLUSIONS

This study has shown how research which addresses design problems can help to bridge the gap between two current approaches to providing thermal design data, while providing an evaluative rather than a prescriptive approach. The resulting design data are context-specific in all respects — climate, place, time, and culture. Hence, they will not necessarily be strictly applicable to future housing design, and should be interpreted to take account of changes in relevant influences, such as energy costs or public concern regarding energy use. The design data sheet is intended to help designers to take account of the conflicting influences and compromises which are a part of building design.

For the locations studied, in houses without mechanical cooling, a compromise is likely to be necessary between the lightweight, well ventilated building suitable for rapid cooling on hot nights and the well insulated, well sealed building, with high internal mass, suitable for other important design times. Where mechanical cooling is used, as is most likely in Alice Springs where evaporative cooling is common, this must also be taken into consideration in the design of buildings. Its use has major implications for choice of materials (Williamson and Coldicutt 1986).

The study of thermal preferences as defined in this paper is providing a useful starting point for design of houses for good thermal performance in climates which have several different design times. However, more work remains to be done in this complex field of study. The empirical approach reported in this paper has limitations for analysing the nature of knowledge appropriate for application in design. Theoretical approaches also need to be investigated.

Main design times: afternoons and evenings

COOLING
- The majority of households have and want airconditioning - most refrigerative, some evaporative.
- Some households want ceiling fans only; very few want no mechanical cooling at all.
- Usual cooler use period: afternoons, and evenings until bedtime.
- Area cooled: ranges from one living room to the living half of the house.
- Context: these thermal preferences have arisen in houses which could be expected to have maximum temperatures (without cooling) several degrees higher than would be expected in thermally well designed houses (Coldicutt el al., 1988); if thermal performance of housing were improved, preferences for cooling might be reduced.

SOLAR RADIATION
- Little information is available regarding preferences for direct solar radiation. Most househols are satisfied with the summer sun penentration in their current house; this seems to imply that some sun is acceptable. It seems that preferences range from wanting to keep sun out in summer to wanting plenty of sun all year except in hot weather. The main time when sun exclusion is preferred is summer afternoons.
- For design, this suggests that fixed shading devices excluding all direct solar radiation in summer will be satisfactory to some, while others will prefer at least some adjustable devices, to exclude sun in hot weather but admit it in cooler summer weather.

AIR TEMPERATURES		
- 50 percentile neutral temperature*		21.5 C
- upper limits of acceptable# temp	- 10 %ile	22.0 C
	- 20 %ile	23.5 C
	- 50 %ile	27.5 C
	- 80 %ile	32.0 C
HUMIDITY - The average humidity in houses in summer is approximately		45 %
CLOTHING - Average clothing levels are approximately		0.6 clo
ACTIVITY - The above temperatures apply to people sitting or doing light work		
MEAN RADIANT TEMPERATURE is assumed equal to air temperature		
AIR MOVEMENT - The above temperatures and humidity are predominantly associated with low air speeds (less than 0.1m/s), but, especially in warmer conditions, some use is made of higher air sppeds.		

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* mean of temperatures at which occupants would not want to be either warmer or cooler; actual mean temperatures are some 2 C above this: it connot be assumed that occupants are willing or able to afford money and/or other costs of achieving neutral temperatures

\# the "acceptable" bands of temperatures are taken as including slightly cool, neutral and slightly warm

Fig. 3. Design Data Sheet.
Adelaide Plains thermal preferences in hot-weather-living areas.

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HOUSING ENVIRONMENT: FLATS AND HEALTH

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The effect of the housing environment on the frequency and duration of acute respiratory diseases was investigated in children aged one to two years. The increase in the number of days of illness correlated with the following factors: position of the flat towards the main road, strong exposure of the house to wind, and number and size of the windows in the children's room, non-adjustibility of the temperature of the radiator, draught in the flat, lacking possibility of cross ventilation in the flat, bathroom and kitchen without windows, and predominant vacuum cleaning in the flat, in contrast to combined wiping and vacuum cleaning. In addition to the factors mentioned above, the morbidity rate was increased by combined window and forced ventilation, in contrast to mere window ventilation and by staying outdoors at the weekend for less than two hours. Additional studies are necessary before a causal relationsship can be established.

INTRODUCTION

Although people spend the major part of their time in their homes rather than at work or with other activities outside their home, this sphere of living is still insufficiently investigated.

There are only a few studies on the influence of hygienic and socio-economic factors of the housing environment on the frequency of acute respiratory diseases (ARD). Some studies deal with the effects of increased NO_2-concentrations due to gas-fired cooking devices. Either no effects (Melia 1982) or an increase in the number of ARD cases (Colley and Reid 1970; Dodge 1982) were found.

The relationship between smoking in the domestic environment and relapsing ARD in children, however, has been widely demonstrated (Lorenz and Passauer 1987).

After studying 399 homes in Massachusetts, Tuthill (1984) found no connection between wood-burning stoves in homes and ARD. However, the number of ARD cases was considerably higher in children exposed to formaldehyde(s). Sources of formaldehyde(s) were materials used for remodeling the flat, for isolating the walls, and upholstered furniture.

Excessively high or low temperatures in rooms are regarded by several authors as being favourable to ARD in children (Seidel and Völksch 1974; Schrader et al. 1976; Wirsing et al. 1985.)

Because newborns and infants are developing (Opitz and Völksch 1973), a relatively narrow range of temperature is suggested to assure the feeling of comfort. This range is supposed to be 20-22°C (Wirsing et al. 1985). Schrader et al. (1976) suggested a higher ARD morbidity rate in tele-heated rooms as compared to rooms heated by a stove. They rationalized children's ability to adapt to changing temperatures.

An increased flow of air in the home can contribute to an increased ARD morbidity rate. During the cold season, the air at the inside surface of the window cools down and sinks to the ground. The movement of the air at ground level increases and reaches around 0.1 m/s when doors and windows are closed. When the french window is opened, values of 0.4-0.5 m/s are reached and when the windows are opened the values rise to 0.4 m/s. In case of outside wind, when the windows were open, values of more than 1 m/s could be measured under the doors. This particularly impacts infants who live and play on the floor (Gross 1977).

In a Finnish study, the number of siblings, the number of rooms in a flat and their furnishing, type of home (flat in a new building and terraced house, and the socio-economic status of the family were correlated with ARD frequency. This study demonstrated a positive correlation between the socio-economic standard and the occurrence of feverish infections (Stahlberg 1981). This finding is in agreement with another investigation which shows that a higher educational level improves the ability to identify inflammatory diseases (Monto and Ullmann 1974). Colley et al. (1973) found the lowest ARD rate in the upper middle class and the highest in the lower working class. However, Passauer and Wiedemann (1989) found a higher ARD rate among parents with a university education. Bjerregard (1988) examined 310 children in the town of Upernavik and found less ARD in children of low socio-economic groups as compared to higher socio-economic groups. However, his results were statistically not significant.

These studies deal with ARD morbidity using single parameters of the problem. Possible interrelations with variables were either not studied or were given little attention. Therefore an investigation was necessary comprising as many of the known or supposed factors influencing the development of ARD as possible.

The study required a group that was

1) not exposed to any additional, superimposing influences of the work and its environment,

2) stayed prevailingly in the same residential district,

3) responded to slight environmental changes with typical, easily measurable reactions,

4) was large enough to allow a representative statement on various environmental effects, and

5) had a uniform age structure.

METHODS AND PROCEDURES

To satisfy these conditions, we selected 970 children, aged 1-2y, attending day-nurseries in three municipal districts of Berlin. The random sampling included approximately 30% of the children of a specific age. The parents belonged to the lower and middle socio-economic population. The drop-out rate was less than 5% but not all questions were answered by all parents. The reliability was tested by repetition of the questioning with a random sample of the investigated children. The criterion chosen to indicate the environmental influence on health was being ill or not with ARD within six months (verified by the pediatricians of the day-nurseries). The investigation was aimed at determining risk factors of ARD and at deriving therefrom measures for the improvement of the housing environment.

We compiled 100 variables which might possibly influence the morbidity of ARD in children and worked out a standardized questionnaire, suitable for electronic data processing. The variables were as follows:

Occupational activity of parents
Vocational training of parents
Age of parents
Working time of parents
Marital status of parents (married, single, divorced)
Type of dwelling house
Distance of house from road traffic
Location of flat with regard to a green area
Heating of - children's room
- living room
- kitchen
- bathroom
Adjustibility of radiators
Cleaning of radiators
Wind speed in housing environment
Age of house
Number of floors in house
Location of flat in house
Number of rooms
Size of flat
Height of rooms
Number of outer walls of rooms and thickness of outer walls
Heat insulation
Children's room - size of floor area
- size of outer wall area
- size of window area
- number of windows
- direction of windows
- type of window
- type of window frame

- location of child's bed with regard to outer wall

Number of children in flat
Number of children in children's room
Number of persons in flat
Existence of a balcony or a loggia
Existence of a lift
Can flat be reached by lift or not?
Kitchen with or without window?
Type of stove in kitchen
Temperature in living room during colder season
Temperature during colder season in children's room
Are there appliances for regulation of humidity in room?
Draught in rooms
Principle of ventilation in flat
Functioning efficiency of ventilation
Frequency of ventilation
Cleaning of rooms
Humidity in flat
Possibility of cross ventilation in flat
Cold floors in flat
Time children spend outdoors
- during week - at weekend

Sleeping hours of child during night
- during week - at weekend

Staying in weekend house
Smoking of parents
Domestic animals in flat
Performance of measures to keep fit
Eating of fruit and vegetables
Vitamin C intake.

These variables were correlated with the number of days of illness and the number of ARD cases within the six months immediately before the investigation.

The statistical assessment was conducted using the χ^2-test, Hotteling T^2-distribution, and a multivariable discriminant analysis (Ahrens and Läuter 1981).

RESULTS

A significant statistical correlation with ARD morbidity in the analysis of two-dimensional frequencies could be verified by the χ^2-test with a probability of error of 5%. A multivariable discriminant analysis demonstrated a statistically significant correlation with ARD morbidity but did not reach the significance level for the following variables: On which floor is the flat, lift, type of heating system, size of the childrens's room, height of the rooms, and area of the outer walls, thickness of the outer walls of the rooms and direction of the children's room.

In this discriminant analysis using 19 variables, characteristics were established to separate the two groups of cases (≤20 days of diseases, <20 days of disease). The process included reduction procedure of variables using intermediate steps of extension.

With regard to the influence of the flat and the housing environment on the number of days children were sick with ARD, the following factors were found to be of importance:

1) Position of the flat towards the main road (Table 1),
2) stronger exposure of the house to wind (Table 2),
3) more than one window in the children's room (Table 3),
4) size of the windows in the children's room (Table 4),
5) on-adjustability of the temperature of the radiators (Table 5),
6) draught in the flat (Table 6),
7) lacking possibility of cross-ventilation in the flat (Table 7),
8) location of bathroom and kitchen in the flat (Table 8),
9) predominantly vacuum-cleaning of the flat in contrast to the combination of wiping and vacuum-cleaning (Table 9).

Discriminant analysis used to determine the order of significance of variables and the number of days of illness resulted in the following, in descending order:

1) Exposure of flat to wind
2) Cross-ventilation of flat
3) Temperature control of radiators
4) Position of flat towards road.

In an examination of the influence of the environmental factors on the rate of ARD (1st group 1-3 diseases, 2nd group 3 and more diseases) in the previous six months, the same parameters were found to be valid. However, the following factors raised the rate of ARD further:

1) combined window and forced ventilation in contrast to mere window ventilation,
2) staying outdoors at the weekend for less than 2 h.

Discriminant analysis resulted in the following optimum list:

1) Ventilation principle of flat
2) Temperature control of radiators
3) Room cleaning
4) Exposure of flat to wind

Table 1. Position of the flat towards the road.

Position of flat	0-20 days of illness	>20 days of illness	Number of infants examined
1. Main road <10 m away	50 52.1 %	46 47.9 %	96
2. Main road >10 m away	85 52.8 %	76 47.2 %	161
3. Minor road	196 57.1 %	147 42.9 %	343
4. Resident road	119 65.0 %	64 35.0 %	183

(significant differences between 1. and 4. as well as between 2. and 4.)

Table 2. Exposure of the flat to wind.

Exposure to wind	0-20 days of illness	>20 days of illness	Number of infants examined
1. None	81 62.3 %	49 37.7 %	130
2. Low	209 63.5 %	120 36.5 %	329
3. High	203 51.3 %	193 48.7 %	396

(significant differences between 1. and 3. as well as between 2. and 3.)

Table 3. Number of windows in the children's room.

Number of windows	0-20 days of illness	>20 days of illness	Number of infants examined
1. One window	393 59.4 %	269 40.6 %	662
2. Two windows	66 46.8 %	75 53.2 %	141

Table 4. Size of the window(s) in the children's room.

Size of the window(s) in m^2	0-20 days of illness	>20 days of illness	Number of infants examined
1. 1.0 - < 2.4	213 59.50 %	145 40.50 %	358
2. 2.4 - < 3.8	159 58.67 %	112 41.33 %	271
3. 3.8 - < 5.8	44 51.16 %	42 48.84 %	86
4. 5.8 - 6.6	12 40.00 %	18 60.00 %	30

(significant differences between 1. and 4.)

Table 5. Temperature control of the radiators.

Temperature control	0-20 days of illness	>20 days of illness	Number of infants examined
Possible	365 59.2 %	251 40.8 %	616
Not possible	20 40.0 %	30 60.0 %	50

Table 6. Draught in the flat.

Draught	0-20 days of illness	>20 days of illness	Number of infants examined
1. No draught	103 66.4 %	52 33.6 %	155
2. Draught despite closed windows	127 54.0 %	108 46.0 %	235

Table 7. Cross-ventilation in the flat.

Cross-ventilation	0-20 days of illness	>20 days of illness	Number of infants examined
1. Yes	309 61.8 %	191 38.2 %	500
2. No	181 52.2 %	166 47.8 %	347

Table 8. Location of kitchen and bathroom in the flat.

Kitchen and bathroom	0-20 days of illness	>20 days of illness	Number of infants examined
1. Both rooms with windows	118 61.1 %	75 38.9 %	193
2. Bathroom without window(s)	214 59.3 %	147 40.7 %	361
3. Both rooms without windows(s) (Kitchen with window for passing meals through into the living room)	152 54.1 %	129 45.9 %	281

(significant differences between 1. and 3.)

Table 9. Room cleaning.

Way of cleaning	0-20 days of illness	>20 days of illness	Number of infants examined
1. Vacuum-cleaning	236 67.4 %	144 32.6 %	350
2. Wiping and vacuum-cleaning	105 80.8 %	25 19.2 %	130

DISCUSSION

This investigation did not confirm the positive correlations between gas cooking devices, smoking, socio-economic standards, and ARD.

More than one window in the children's room and an enlarged window area could possibly influence the children's health during the cold season due to low temperature and draught. This is supported by the positive correlation between draught and ARD morbidity.

Although the above mentioned results of the two-dimensional frequencies are statistically significant with regard to the influence on ARD morbidity, these correlations could not be confirmed by discriminant analysis. Obviously, these variables were considerably influenced by other ones. The influence of wind on ARD morbidity could be demonstrated by this study, the correlation between an increase in ARD morbidity, and the location of the flat on the main road could be caused by raised NO_2 and dust concentration from outdoors.

The correlation of ARD decrease with cross ventilation can be explained by a better chance of removal of viruses, bacteria, and gaseous pollutants from indoors.

When vacuum cleaning, particularly when vacuum cleaners have no bacteria-proof filters, the microorganisms on the floor are distributed into the air of the room.

A combined window and forced ventilation in contrast to mere window ventilation led to an increase in ARD morbidity. This is probably attributable to the inefficiency of the devices for forced ventilation.

Non-adjustability of the temperature of the radiator as a factor for increasing ARD morbidity seems to be logical. In such a case, excessive temperatures in the room during winter can only be lowered by permanently opening the windows.

Our results indicate that improvement of housing construction and town planning as well as hygiene of the housing conditions may lead to a decrease in the ARD rate.

It cannot be excluded, however, that the variables found to be relevant may be influenced by other variables. Therefore, it is necessary and planned to repeat the investigation, to include further variables not studied until now, and to use objective measuring data determined by architectural hygiene (such as data on the exposure of the house to wind or ventilation within the flat) before a causal relationship can be established.

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INDOOR FUNGI AS PART OF THE CAUSE OF RECALCITRANT SYMPTOMS OF THE TIGHT BUILDING SYNDROME

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As buildings are tightened to conserve energy, moisture and fungi as well as outgasing xenobiotics are trapped. It becomes necessary to have a method that will differentiate whether complaints blamed on poor indoor air quality are due to chemicals or molds, especially since many of the symptoms are identical. Patients whose symptoms were unrelieved by regular medical treatments were tested to the fungi chosen on the basis of previous research. Of 100 random cases out of 2000 that are annually asked to review their progress, 61% rated themselves as having markedly reduced symptoms while at the same time being able to reduce or completely discontinue all symptomatic medications. Case examples will demonstrate the diverse symptoms that improved, many of which had previously exhausted all that medicine had to offer. For some, double-blind placebo substitution was used and symptoms recurred. Upon reinstitution of injections, symptoms again were relieved. This therapy provides a method with potential to help differentiate whether complaints regarding indoor air quality are due to chemical hypersensitivty or an individual's mold sensitivity.

INTRODUCTION

Molds can produce some of the most potent toxins, hallucingens, and antibiotics known to man, while, at the same time, they are indispensible to the food industry (Beuchat 1978). They can thrive in conditions inimicable to many other living organisms (such as jet fuel lines) and, under certain climatic conditions, can produce billions of spores. During the height of the pollen season it is not unusual for the ratio of *Cladosporium (Hormodendrum)* spores to pollen to be 1000:1 (Lehrer et al. 1983). Fungi have been shown to produce many symptoms in the allergic individual (Holst et al. 1983; Mazar et al. 1981; Salvaggio and Aukrust 1981; Holst et al. 1990). Allergists usually test a patient's degree of sensitivity to the major molds, *Hormodendrum*, *Aspergillus*, *Alternaria*, and *Penicillium*, and test a dozen or fewer other fungi on an individual basis.

In a previous study (Terracina and Rogers 1982), substituting a medium of malt agar extract for Sabouraud's medium, increasing petri dish exposure time from 10 min to 1 h, and saving plates for up to three weeks to allow the slow growers to appear, resulted in a 32%-higher yield of fungi isolated and identified. It was then observed that the fungal flora was in a state of constant change, and that for best results, gravity plates should be placed during periods of human activity, between knee and shoulder height (Rogers 1983). A third paper updated fungal flora, revealing many fungi that were previously not monitored (Rogers 1984).

The purpose of this study was to determine the practical and clinical significance of incorporating these newly identified fungi into the regular pollen, dust, mite, and mold testing to determine if additional benefit in symptom improvement would occur. Since these people suspected their symptoms were worse indoors, and these fungi were isolated from indoor cultures, it was a logical next step to see if incorporating these into their testing (and treatment if the skin tests were positive) would provide symptom relief.

MATERIALS AND METHODS

Twenty-one fungi were selected for this trial and divided into mixes as shown in Table 1. The patients to be tested had a large range of symptoms, and most had undergone a variety of specialty and general workups, including conventional allergy workups. They were still not well. Since they spent the majority of their time indoors and suspected indoor air as a source of problem, they were skin-tested to these fungal antigens along with local pollens, house dust, and house dust mite, *Dermatophagoides pteronyssinus*, according to our previously published protocol (Rogers 1988). All antigens that were positive were included in the patient's prescribed medication to be administered by intradermal (skin) injection twice weekly for one month and then weekly thereafter.

Trichophyton, *Candida*, *Epidermophyton*, *Rhizopus*, and *Sporobolomyces* were tested individually.

At the beginning of the test period, patients were also placed on a major elimination diet which prohibited such commonly consumed foods as milk, wheat, corn, processed sugars, and ferments (bread, cheese, alcohol, vinegar, salad dressing, mayonnaise, ketchup, mustard, chocolate, and processed foods). They were allowed to eat foods they knew to be safe and that they did not normally eat more than once a week. This was done with the rational that elimination of ingested potentially cross-reacting fungal antigens and possible hidden food antigens might strengthen the therapeutic result. Questionnaires were mailed to patients yearly to evaluate their progress. They were asked to rate their symptoms according to whether they (1) were worse, (2) were the same, (3) experienced some improvement and rated themselves as less than 50% improved, still experiencing frequent symptoms and requiring chronic medications, (4) rated themselves as 50-75% improved with a definite reduction in symptoms and a marked reduction in medications, or (5) rated themselves as 75-100% better with no medications and with a marked reduction in symptoms.

Table 1. Components of mold mixes.

Mix A	*Aspergillus, Alternaria, Hormodendrum (CladosPorium), Penicillium*
Mix B	*Epicoccum, Fusarium, Pullularia (Aureobasidium)*
Mix D	*Fomes, Mucor, Poma, Rhodotorula*
Mix E	*Cephalosporium, Botrytis, Geotrichum, Helminthosporium, Stemphyllium*

RESULTS

Of 100 randomly selected subjects, 21% were male, 79% female. The age range was 12-66 y, and the duration of treatment by injection ranged from 1-10 y with an average of 5 y. Thirteen questionnaires were not fully answered, and so were not included in the statistics, even though all subjects were improved. None of the subjects felt worse, one person felt no change, and 15 thought they had some improvement, but not enough to decrease any medications, and definitely less than 50% improvement. Forty-five rated themselves as 50-75% improved with a marked reduction in symptoms and, consequently, a reduction in medication. Sixteen rated themselves as 75-100% better with no medications and indicated a marked reduction in symptoms. Thus 61% of 100 patients rated themselves as at least 50% improved with a marked reduction in symptoms. Consequently, they reduced medications or no longer needed medications.

CASE STUDIES

Since this program has been ongoing for over 10 y, and over 2000 patients have been successfully treated in this manner, a number of case examples will illustrate the improvement of a wide range of symptoms. Of the following cases, many were selected because of their uniqueness. They were not all part of the mailed questionnaire survey reported in this paper. They are by no means the entire program which covers over 2000 patients.

Certain patients (as designated) received double-blind substitution of their injections with placebo (normal saline). All of those worsened within two weeks and after re-institution of the injections, they again gained control of their symptoms. This also happened occasionally when they veered from the diet.

To obtain double-blind two-week substitution of active injections with the placebo, the syringes were prepared by the author without the knowlege of the patient or the nurse administering injections. This practice was a good way also for determining the time for discontinuation of the injections.

Chronic fatigue and nasal congestion

Twenty patients had complained of chronic fatigue and nasal congestion. Before the program, many related their symptoms to being inside a particular environment, usually home or office. All subjects rated themselves as at least 50% improved within four months of starting the program. However, many had a recurrence of symptoms if they were late for an injection. The time of symptom recurrence varied from one day to three weeks. Some were incapacitated by fatigue. For example, J.M. (30-y-old) had 5 y of symptoms. He had consulted several physicians for treatment of recurrent skin infections and chronic fatigue that left him unable to work. After 4 months of injections, he was so well that he was able to return to exercising, lifting weights, and teaching gymnastics.

Migraines

Four people with incapacitating migraines were also treated. One 48-y-old barber had a 6-y history of being bedridden 50% of the time with facial swelling, photophobia, tearing, glassy eyes, and a headache that left him threatening suicide. Narcotic analgesics, beta blockers, vasoconstrictors and antihistamines provided no relief. With the injections all symptoms ceased, and recurred only once in 3 y when he vacationed two weeks and missed one injection.

Eczema

Four people had intractable atopic dermatitis or eczema, and two had concomitant hyper-IgE. One of these, S.B., a 51-y-old teacher's aide, had received 15 y of conventional allergy injections which helped her nasal congestion partially, but did not improve her scaley, lichenified, cracked, bleeding, and brilliant red eczema. It involved the skin of her neck, upper chest and back, face, antecubital and wrist areas, and popliteal areas. It caused such constant pain that she rarely moved her neck if she could avoid it. Her skin burned more when in indoor environments which were perceived by her to have a musty odor. Her IgE was 75 082 I.U. (normal 14-100). After two months of injections her skin was clear of disease for the first time since it had begun, and in 8 months, her IgE was 30 006 I.U.

A 33-y-old snow ski laminator had facial, arm, torso and leg eczema since childhood. For the previous 11 y it was so severe that thick scales covered his body. He also suffered from chronic diarrhea and had been thoroughly examined and treated by four allergists and three dermatologists. He had used many dangerous medications to no avail, including high doses of steroids. He lived in the woods in a tight trailer and suspected that molds were part of his problem.

Laboratory findings revealed an IgE of 33 088 I.U., increased T-4 cells of 60.2% (normal 38-53%) and B cells of 18.9% (normal 7-11%), decreased T-8 cells of 10.3% (18-30%), and NK cells of 2.1% (6-13%). Unlike the typical patient with hyper-IgE syndrome, he had not had even one cold in the last 5 y. He also knew that milk caused severe exfoliation within a day, and his milk RAST (radio allergosorgent test) was moderately positive for milk. Within 13 d of participation in the program, his skin was totally clear for the first time in 11 y. His IgE dropped to 8809 I.U. after four months, and to 6456 after six months. After 1 y it was 2305 and after 2 y 1231. He has remained clear for over 6 y except for one time when a double-blind substitution of his injections was administered using normal saline placebo. It took two weeks to clear his symptoms again. His dermatitis flared up if he ingested certain foods to be avoided.

C.V., a 37-y-old housewife had 6 y of severe pustular erythematous eczema. Her IgE was unremarkable at 17. She knew her face would burn and tingle and erupt more when in indoor moldy environnments and in the fall. She has remained clear, except with dietary indiscretion or single-blind placebo substitution.

Asthma

Six cases of asthma included R.S., a 36-y-old woman who worked in the family-owned bakery. Wheat RAST was strongly positive and her IgE was 70 I.U. Cultures from her bedroom yielded 16 colonies of *Sporobolomyces*, 1 *Fusarium*, 48 bacteria, 2 yeasts and one sterile fungus. The bakery yielded 1 *Penicillium*, 1 *Rhodotorula*, 3 bacteria, and 4 *Sporobolomyces*.

After two months of the program, her asthma was clear and she has had no recurrence, needed no further asthma medications, and has continued to work in the bakery for the last 4 y.

S.K., a 57-y-old carpenter, was disabled by asthma who became visibly cyanotic just walking across the room. He was maximally medicated for asthma (maximum therapeutic blood levels of theophylline, inhaled beta-agonists, inhaled steroids, and inhaled chromolyn) including oral steroids. Pulmonologists had hospitalized him for bronchoscopies and bronchograms and his prognosis was guarded. His IgE was 5666 I.U. After 1 y with the program, his IgE dropped to 2146, and he no longer needed steroids and some of his other medications. After 2 y, his IgE was 1370 and his only medication was a few puffs of albuterol a week compared to daily.

M.G., a 26-y-old man, had 4 y of asthma, exhaustion, headaches, nasal congestion, and recurrent sinus infections. He could no longer run his 10 mi/d. His PEF (peak expiratory flow) was 37% of predicted normal level with 47% improvement post bronchodilator. He was able to resume cross country racing after three months of the program.

Urticaria

Five patients with urticaria (hives) included M.D., a 30-y-old patient with 5 y of chronic total body pruritis, headaches, and rhinitis. All symptoms were gone in two months of participation in the program. Likewise, K.L. had seven months of giant urticaria, 20 y of headaches, and perennial rhinitis. All were clear in two months.

Lupus

Three people were diagnosed with systemic lupus erythematosis. G.H., a 36-y-old restaurant manager, received this diagnosis from a major medical center and returned yearly, for 5 y, for an update. She required monthly 40 mg of injected steroids to function. In spite of this, she had a chronic erythematous (red), pustular malar rash, daily joint pain, asthma, irritable bowel, and chronic fatigue. In two months she was off all steroids, and well, and has remained medication- and symptom-free for 4 y.

Miscellaneous

C.H., an 8-y-old boy was receiving 10 mg of a commonly used amphetamine derivative, prescribed three times a day by the pediatric neurologist to subdue his hyperactivity. In spite of this, he would throw the iron at his father, pour hot water on his baby sister and was unteachable, with failing grades in school. Testing for molds by the provocation technique, previously described (Rogers 1987), enabled his behavior to be provoked and neutralized. He was placed on immunotherapy for the positive molds, and within one month he was able to discontinue the amphetamine, his attention span had improved to the point to where he was teachable, his behavior was markedly improved, he grew in height and his teeth erupted after a 2-y arrest. After four months of the program, the boy was earning high grades in school.

One year later, a placebo was substituted for two weeks, double-blind. Within two weeks, his mother came in wearing a black eye that he had given her in an unprovoked attack, and stated that his entire behavior had changed and it was as though he was no longer receiving his injections. Also during that period, the teachers had gone to the principal of the school requesting that he not return to the school for the following year, and the police had been to the house twice to warn his parents about not allowing him to use the phone to call them for fabricated emergencies. When his injections were reinstated, his former improvement returned.

M.E., a 68-y-old orthopedic surgeon, had experienced cardiac arrhythmia accompanied by diarrhea and weakness over the previous months. The weakness had become incapacitating to the point where he feared walking across a room. After one week of mold injections, he described himself as 80% improved over anything he had experienced over the last 10 y. Also 30 y of anosmia (inablity to smell things normally) had returned to normal.

Post-viral syndrome

Four patients who were diagnosed as having a flu, never recovered, and complained of persistent symptoms that were actually worsening.

W.B., a 41-y-old college professor and chairman of his department had developed what he thought was a flu 18 months prior, but it had never resolved. He complained of constant non-vertiginous dizziness, headache, and incapacitating weakness that would fluctuate in intensity without ever completely abating. His prior treatments included hospitalization with CAT scans of the brain and a lumbar puncture. He reported a distinct improvement after being tested with the mold extracts and receiving his first therapeutic injection. The second injection, a few days later, cleared all the remaining symptoms for the first time since the onset 2 y previously. His symptoms recur every fourth day and disappear within 30 min after an injection. He remains clear as long as he obtains his injection twice a week. Double-blind placebo substitution for his injections caused the symptoms to recur.

DISCUSSION

Sixty-one of 100 randomly selected ongoing patients rated themselves as at least 50% better with a marked reduction in symptoms and a partial or total reduction in medications. An obvious defect of the current study is that it does not allow for the number of dropouts. The case histories reported here represent another 55 patients who were successfully treated by this method. An obvious major flaw of this part is that it is in no way a statistically rigid study, nor is it randomly selected. Many of these people were blaming home or work environments for their recalcitrant symptoms, but were actually more suspicious of indoor chemicals as the cause and were surprised when the culprit turned out to be a much more easily remedied cause, mold allergy.

We have already reported the variety of symptoms that can be precipitated by indoor chemicals (Rogers 1989), including approaches for diagnosis of suspected chemically-induced symptoms (Rogers 1986; Rogers 1990). But when the symptoms go beyond what the individual can handle or when the problem creeps into the legal arena, a method is needed to separate chemically-induced from mold-induced symptoms.

This paper suggests a treatment method for a variety of disorders which have failed to respond to other forms of treatment, and/or which have been blamed on indoor chemicals. The indications of the specificity and appropriateness of the immunotherapy with fungal antigens were reinforced by the use of double-blind placebos and the serendipitous failures of patients who were unable to maintain what proved to be critical restrictive diets. It also demonstrates that mold sensitivity is responsible for a wider range of symptoms than is commonly perceived. Although more rigid studies are needed, this provides another tool to define, and in many cases treat, the cause of problems presumed to be secondary to poor indoor air quality.

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FIELD INVESTIGATION OF ODOR INTENSITY AND ACCEPTABILITY OF TOBACCO SMOKE IN AIR-CONDITIONED SPACES

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This paper presents basic data for estimating the degree of odor in the air obtained from the results of measurement in air-conditioned office spaces. The measurements were made in an office building in Tokyo on 4 and 5 August 1987. The occupants were asked to evaluate odor intensity on scale and acceptability and to answer some questions about odor, while concentration of carbon dioxide and particles in the air, air temperature and relative humidity were measured. The air was sampled four times a day. The air quality was voted on a scale and the acceptability was judged by the panel which consisted of four men and four women. The concentration of the odor was measured by a triangle test with sample bags. Though the concentrations of CO_2 and particles were low, the odor intensity judged by the panel was high. This is possibly due to background odor. The acceptance by the panel was less than 50%. About 30% of the occupants perceived tobacco smoke as a distinct source of odor.

INTRODUCTION

In Japan the ventilation requirements in offices are regulated by the Building Sanitation Management Standards Law for Maintenance of Sanitation in Buildings. The standard requires the concentrations of CO, CO_2, and particles in the air to be less than 0.010 mL/L, 1.0 mL/L, and 0.15 mg/m^3, respectively. It must be investigated, however, whether this standard can sufficiently cause the occupants to be satisfied with the indoor air quality or not.

The odor is one of the most important complaints about indoor air quality. Human bioeffluents and tobacco smoke are regarded as the main sources of indoor odor. The concentration of CO_2 can be used as an index of bioeffluents, and CO or suspended particles can be used as indices of tobacco smoke.

Regarding bioeffluents, Janssen and Grimsrud (1986) state that the concentration of CO_2 may be less than 1.0 mL/L when fresh air of 25.5 m^3/h · person is introduced. This value is consistent with the threshold value in the Ventilation Standard of ASHRAE 62-1981R (1986) and the Japanese Standard Law.

According to Yaglou (1937), tobacco smoke is inclined to mask other odors in smoking spaces. It was considered earlier, therefore, that ventilation requirements in office spaces where smoking was not prohibited, should be determined by the acceptability of tobacco odor. Both previous and recent studies on ventilation requirements and tobacco smoke by Yaglou (1937) and Cain et al. (1983) were performed in test chambers. From the results of Cain et al., it is known that 51.0 m^3 of fresh air per cigarette is required in order to keep a higher-than-70% acceptance by visitors. Thayer (1982) also developed a dilution index to show that 25.5 m^3/h of fresh air per person would satisfy more than 80% of the occupants, assuming that one-third of the occupants were to smoke 2.2 cigarettes/h. The data of Cain et al. apply to visitors, whereas the data of Thayer apply to occupants.

Occupants staying in the space for more than several minutes experience an adaptation to the odor, and their sensitivity to odor may decrease. Odor adaptation was investigated by Fanger and Gunnarsen (1988). They found that after an adaptation period, air polluted with human bioeffluents felt significantly better and air polluted with tobacco smoke felt somewhat better. It is considered necessary, therefore, that the indoor air quality must be evaluated by both occupants and visitors. The relationship between the odor intensity and acceptability was studied by Fanger and Berg-Munch (1983).

Another problem is that actual pollutants are usually more complex, as they comprise many kinds of sources. It may be difficult to apply the studies of Cain et al. (1983) directly to actual office spaces because these experiments were conducted in a controlled environment with low levels of background odor.

The aim of this study was to present basic data for evaluating the odor in office spaces by subjective experiments. In our field study, therefore, attempts were made to obtain the following three characteristics: (1) to obtain the odor intensity levels evaluated on Yaglou's scale by occupants and panel as visitors, (2) to obtain the acceptability judged by both of them, and (3) to obtain the odor units measured by the triangle test with sample bags.

PROCEDURE

The field investigations were conducted in an office building in Tokyo on August 4 and 5 1987. The office building with 22 stories was built in 1971 and was used as the headquarters of a computer company. In 1986, the sixth floor was renovated to facilitate individual control by increasing the number of air-conditioning zones. The furniture in the room was replaced as well. In Fig. 1 and 2, two plans of the sixth floor and the ninth floor are illustrated. Both spaces are of same size (32 m x 23.2 m x 2.5 m) with a volume of 1856 m^3 each.

The measurements on the sixth floor were performed on 4 August and those on the ninth floor on the following day. Concentrations of CO_2 and particles in the air, air temperature, and relative humidity were measured every hour from 9 a.m. to 5 p.m. at the measurement points as shown in Fig. 1 and 2.

The numbers of occupants in the east and west areas, as shown in Figs. 1 and 2, were counted every hour. Some of the occupants were asked to point out the origin of the odor (Fig. 3) and to vote on the odor intensity on Yaglou's scale (Fig. 4) and their acceptability of the odor (Fig. 5). At noon and 5 pm, the ash trays in the east area were gathered to count the number of cigarette butts.

At the measurement points, 30 L of the air were pulled into bags every two hours from 10 a.m. to 4

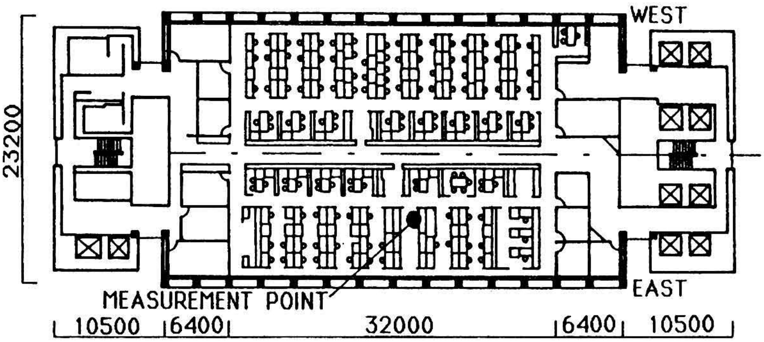

Fig. 1. Plan (sixth floor). Windows are faced east and west; two elevator cores are placed on north and south sides.

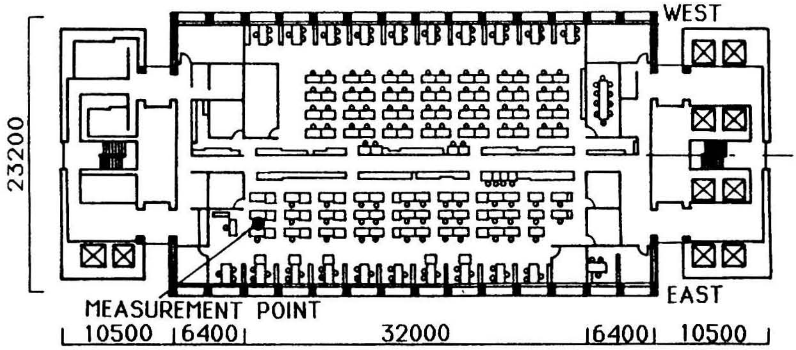

Fig. 2. Plan (ninth floor). It is similar to the sixth floor except that the ninth floor is not divided by partitions.

Questionnaire

1) sex ( ) male ( ) female

2) Do you smoke in this room ?

( ) yes ( ) no

3) How many cigarettes a day do you smoke ?

( ) about zero ( ) about five ( ) about ten
( ) about twenty ( ) about thirty ( ) about forty or more

4) What kind of cosmetics do you use today ?

( ) base (moisturizing lotion, emollient cream, astringent lotion, etc.)
( ) make-up (face powder, lip stick, eye shadow, etc.)
( ) fragrance (perfume, eau de cologne, etc.)
( ) for hair (hair oil, hair spray,etc.)
( ) deodorant (for breath, sweat, foot spray,etc.)
( ) none

5) During your daily work are you sensitive to the odor in this room ?

( ) yes ( ) no

If you answered "no", you need not answer the following questions.

6) What do you guess is causing the odor in this room ?

( ) tobacco smoke ( ) body odor
( ) cosmetics ( ) others ( ) indistinct

7) During your daily work do you feel that you are disturbed by the odor in this room ?

( ) yes ( ) no ( ) I am not sure

Fig. 3. Questionnaire for occupants.

How strong is the odor in this room ?
Please mark on the scale.

- None
- Definite
- Moderate
- Strong
- Very strong
- Overpowering

Fig. 4. Question sheet of odor intensity on Yaglou's psycho-physical scale for subjective judgment. For data analysis, the following numbers were assigned to the scale: 0 - none; 1 - define; 2 - moderate; 3 - strong; 4 - very strong; 5 - overpowering.

p.m. In a separate room, the panel was asked to judge the odor intensity on Yaglou's scale (Fig. 4) from the sampled air and vote on the acceptability by marking the sheet (Fig. 5). Then the panel took part in the triangle test to evaluate the concentration of the odor in the sample bags. This procedure was performed as soon as possible after sampling. The outline of the triangle test with the method to determine the odor unit is described in the Appendix.

Eight men and four women, 19-24 y old with a mean of 21 y, served on the panel. Their normal olfactory senses had been confirmed by a panel screening test. The four women joined the experiment on two days, while four men joined on the first day and the other four men on the second day. All of them were paid for their participation.

RESULTS

The results of the physical data in mean values are shown in Table 1. The air temperature was maintained between 23-26°C and the relative humidity between 54-60%. The concentrations of CO_2 and the particles in the air were maintained below standard values.

During lunch time there were less occupants on both floors. From 10 a.m. to 5 p.m., excluding lunch time, the mean values were 77.1 persons occupying the sixth floor and 55.5 persons occupying the ninth floor.

The number of the cigarette butts in the east area is shown in Table 2. On the sixth floor 23.5 cigarettes/h were smoked and on the ninth floor 15.8 cigarettes/h, which means the per-capita rates of 0.9 cigarette butts/h · person, respectively.

Odor intensity levels on Yaglou's scale, judged by the occupants, are shown in Fig. 6 and 7. The panel did not find significant differences in odor intensity among their four experiments made during the day.

Would you judge the odor in this room as acceptable ?

acceptable ☐

not acceptable ☐

Fig. 5. Question sheet of odor acceptability.

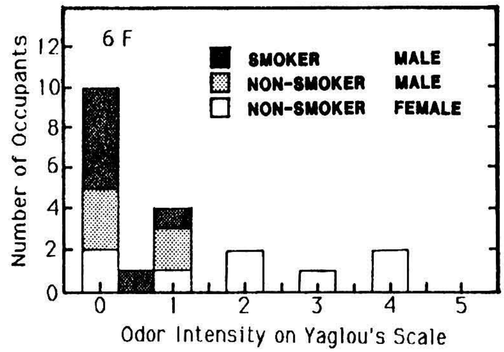

Fig. 6. Histograms of odor intensity on Yaglou's scale, judged by occupants on the sixth floor.

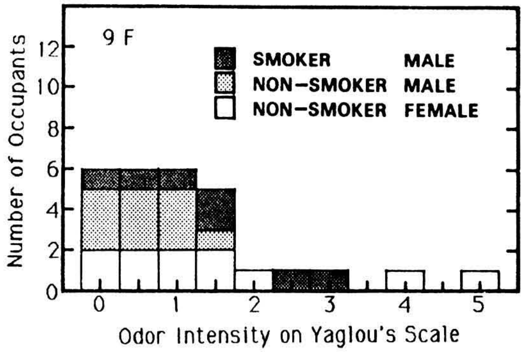

Fig. 7. Histograms of odor intensity on Yaglou's scale, judged by occupants on the ninth floor.

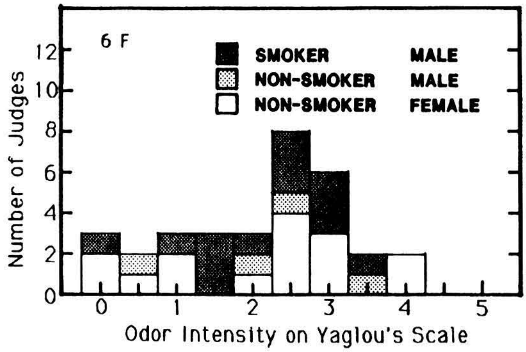

Fig. 8. Histograms of odor intensity on Yaglou's scale, judged by panel (sixth floor).

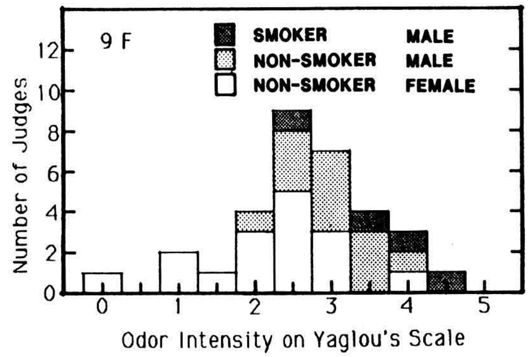

Fig. 9. Histograms of odor intensity on Yaglou's scale, judged by panel (ninth floor).

Those data were pooled as shown in Fig. 8 and 9. The average values of odor intensities judged by the panel were 2.1 on the sixth floor and 2.7 on the ninth floor. Meanwhile, the average value of odor intensities judged by occupants were 1.0 on the sixth floor and 1.1 on the ninth floor.

No women smoked on the sixth and ninth floors. The acceptability of the indoor air quality, judged by

Table 1. Mean values of physical measurements on the two floors.

Floor	Air temperature (°C)	Relative humidity (%)	CO_2 (mL/m^3)	Particles (mg/m^3)
6th	24.0	56.1	1.00	0.036
9th	25.8	58.2	0.94	0.037

Concentration of CO_2 of outdoor air was 0.40 mL/m^3

Table 2. Number of cigarette butts counted on the two floors.

Floor	Number of cigarette butts		
	9 a.m. - noon	noon - 4 p.m.	Total
6th	82	106	188
9th	64	62	126

Table 3. Acceptability voted by panel and occupants.

Floor	Acceptability	
	by panels (%)	by occupants (%)
6th	44.0	89.5
9th	32.0	92.9

Table 4. Results of the triangle test.

Floor	Number of correct detections	Number of uncertain detections	Total number	Odor units
6th	5	5	32	2.7
9th	5	3	32	3.1

the occupants and the panel, is shown in Table 3. Considerable differences were found between the acceptabilities judged by the occupants and judged by the panel as visitors.

The triangle test yielded the average odor values of 2.7 and 3.3 for the sixth and ninth floor, respectively, as shown in Table 4. However, both of these values were below the measurable limits of the triangle test and this difference may not be justified as significant. In fact, the triangle test is commonly used for measuring strong odors of concentrations ten times as high as the threshold.

The results of the questionnaire are shown in Table 5. Though most of the occupants used some kind of cosmetics, tobacco smoke was regarded as the main source of odor, disturbing 21-25% of the

Table 5. Answers by occupants to the questionnaire shown in Fig. 3.

	6th floor			9th floor		
	male	female	total	male	female	total
Answer	num.(%)	num.(%)	num.(%)	num.(%)	num.(%)	num.(%)
1)number	12	8	20	17	11	28
2)yes	7(58)	0(0)	7(35)	7(41)	0(0)	7(25)
no	5(42)	8(100)	13(65)	10(59)	11(100)	21(75)
3) 5/day	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
10	2(17)	0(0)	2(10)	0(0)	0(0)	0(0)
20	2(17)	0(0)	2(10)	5(29)	0(0)	5(18)
30	1(8)	0(0)	1(5)	0(0)	0(0)	0(0)
40	2(17)	0(0)	2(10)	2(12)	0(0)	2(7)
4)base	0(0)	7(88)	7(35)	2(12)	10(91)	12(43)
make-up	0(0)	8(100)	8(40)	0(0)	10(91)	10(36)
fragrance	2(17)	1(13)	3(15)	0(0)	6(55)	6(21)
for hair	9(75)	0(0)	9(45)	9(53)	4(36)	13(46)
deodorant	0(0)	0(0)	0(0)	0(0)	4(36)	4(14)
none	1(8)	0(0)	1(5)	3(18)	1(9)	4(14)
no answer	2(17)	0(0)	2(10)	4(24)	0(0)	4(14)
5)yes	1(8)	6(75)	7(35)	5(29)	6(55)	11(39)
no	11(92)	2(25)	13(65)	12(71)	5(45)	17(61)
6)tobacco	0(0)	6(75)	6(30)	3(18)	5(45)	8(29)
body odor	0(0)	0(0)	0(0)	0(0)	1(9)	1(4)
cosmetics	0(0)	0(0)	0(0)	1(6)	0(0)	1(4)
others	0(0)	0(0)	0(0)	0(0)	1(9)	1(4)
indistinct	1(8)	0(0)	1(5)	2(12)	0(0)	2(7)
7)yes	0(0)	5(63)	5(25)	2(12)	4(36)	6(21)
no	1(8)	1(13)	2(10)	3(18)	3(27)	6(21)
not sure	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)

1)sex 2)habit of smoking 3)number of cigarettes smoked a day
4)kind of cosmetics used 5)being sensitive to odor in the space
6)cause of the odor 7)being disturbed by the odor

occupants. The reason for the partial participation of the occupants was the permission of the company to distribute the questionnaire sheets only to the occupants working in the east area because of fear that the work might be disturbed. It was decided, however, that the data from 20 and 28 occupants were not too few for the purpose of our present study.

DISCUSSION

The panel reported a higher level of odor intensity on both floors than the occupants. However, we found low concentrations of CO_2 and particles. The concentration of CO_2 is related to body odor and the particle concentration is related to tobacco smoke. This discrepancy might be due to the presence of other chemicals, such as volatile organic compounds contributing to background odor, which were not measured.

The sixth floor had a lower odor intensity than the ninth floor (2.1 vs. 2.7). The difference was statistically significant (10% level). One explanation for the lower odor intensity on the sixth floor may be a new ventilation system. For example, it had a new filter plus an electrostatic filter to remove particles. These filters maintained particle concentrations at the same level as the ninth floor, even though the cigarette use was 50% higher. The second explanation for the lower intensity may be the difference in air distribution.

The sixth floor used a VAV system with a perimeter push-pull air barrier, while the ninth floor used conventional fan coil units and a duct system. The third explanation may be that the sixth floor had less pollution on the surface of furniture and building materials than the ninth floor. In addition, the 6th floor was divided by partitions of 1.2 m in height. This might have affected the air movement.

The panel and the occupants disagreed on the odor acceptability on the sixth and ninth floors. While the acceptability judged by the occupants on both the sixth floor and the ninth floor was about 90%, the acceptability judged by the panel was less than 50%. With a slightly high concentration of CO_2 in the outdoor air, the ventilation rates were calculated to be 28 m^3/h · person on the sixth floor and 31 m^3/h · person on the ninth floor, respectively, assuming CO_2 of 17 mL/h · person was produced. Based on the estimation of Cain et al. (1983), the sixth floor occupants would require 46 m^3/h per person, (1200 m^3/h for the floor) to dilute the tobacco smoke to the point that the odor level is acceptable to 70% of visitors. Similarly, on the ninth floor, 31 m^3/h would be required for a person to be consistent with the calculated ventilation rate. It was found, however, that only 32% of the panel accepted the odor on the ninth floor. One possible explanation is that the background odor was different between Cain's test chamber and the actual office space we investigated. On the other hand, Thayer's index gives the results similar to our study, where 90% of acceptability by occupants was obtained with the comparable amount of cigarettes/h. Therefore, since Cain did not use sample bags, it is suggested that the present procedure, in which the room air, sampled in bags, was brought to the panel to be smelled, might cause lower acceptability than by the occupants who smell the room air. Nevertheless, this procedure avoids the influence of visual stimulation such as the panel seeing people smoke cigarettes.

In addition, it was also found that the present value of acceptability judged by the panel was lower than the value estimated from the relationship between the odor intensity and acceptability proposed by Fanger et al., who asked panel to enter the room and evaluate the air. This also may be due to the difference in the two procedures. Furthermore, acceptability may depend on not only odor intensity but also odor quality. However, this cannot be measured with in the scope of our experimental design.

CONCLUSIONS

1. In the office space, where smoking is permitted, tobacco smoke is regarded as the main source of odor, disturbing 21-25% of the occupants.

2. The indoor air quality of an air-conditioned office space cannot be inferred only from the concentration of CO_2 or suspended particles. The background odor, depending on both the age and the type of ventilation system or furniture, and the air movement might also affect the indoor air quality.

3. From this investigation of office spaces, the odor units measured by the triangle test were found to be lower than the measurable limit, suggesting that the triangle test might not be useful for evaluating the indoor air quality of office spaces, though the values were found to be lower on the sixth than on the ninth floor on a relative scale.

4. While the acceptance by the occupants was about 90%, the acceptance by the panel was 44%. Based on the acceptance by the panel, office spaces with smoking levels of 0.6-0.9 cigarettes/h · person would require a higher rate of fresh air than the standard.

5. There is a possibility that the method of evaluating the air in sample bags caused a lower acceptance. Further investigation on this method of evaluation is required.

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APPENDIX

TRIANGLE TEST WITH SAMPLE BAGS

The triangle test to determine the odor units was introduced by the Institute of Environmental Pollution in Tokyo in 1977 as explained by the Environmental Agency of Japan (1978). Odor units are used widely to express legal limits for emission rates of odoriferous materials. In this test, six men and women are to be used as panel. Before the experiment, they must be screened because only persons with normal olfactory senses can be used.

Three sample bags, of which two are filled with odorless air and one with the sampled air diluted with odorless air, are to be provided to each member of the panel. Fig. A-1 shows the voting sheet. The panel is asked to vote which sample contains the odorant, guessing if there is any. The sampled air is to be diluted further in subsequent steps until none of the panel can make a correct detection.

> Which sample contains odor, 1 or 2 or 3 ?
>
> (If you can not determine with certainty, add "?" on the right of the number)
>
> 1 2 3 No comment

Fig. A-1. Voting sheet for the triangle test.

According to ASTM D1366-67a as adopted in the ASHRAE Handbook (1985), the odor concentration is expressed as the volume that the odorous material occupies when diluted to the odor threshold with non-odorous air. The numbers are called odor units and are equivalent to multiples of the threshold concentration. Odor units can be calculated from the number of dilutions and the mean ratio of correct detections of the triangle test. The mean ratio of correct detections M is expressed by the following equation:

$$M = (1.00 \times a + 0.00 \times b + 0.33 \times c) / (a + b + c) \tag{1}$$

where

- M = Ratio of correct detections
- a = Number of correct detections
- b = Number of erroneous detections
- c = Number of uncertain detections

When M is less than 0.58, the concentration of the diluted odor is less than that of the threshold. When M is greater than 0.58 another triangle test should be conducted with 1/10 of the previous concentration.

The odor units Y can be expressed by the following equation:

$$Y = t \times 10\,[(M_1 - 0.58) / (M_1 - M_2)] \tag{2}$$

where

- Y = Odor units
- t = Number of dilutions on the first triangle test
- M_1 = Rate of correct detections on the first triangle test (Number of dilutions = t)
- M_2 = Rate of correct detections on the second triangle test (Number of dilutions = $t \times 10$).

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A COMPARISON OF METHODS OF ASSESSING EXPOSURE TO ENVIRONMENTAL TOBACCO SMOKE IN NON-SMOKING BRITISH WOMEN

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Fifty-two non-smoking British women were recruited to wear personal monitors for nicotine and volatile organic compounds over a 24-h period in the autumn of 1989. The subjects also supplied samples of saliva for cotinine analysis, and answered questions regarding lifestyle and exposure to environmental tobacco smoke (ETS). The research indicates that exposure to ETS in free-living subjects is very low (mean nicotine exposure 2.3 µg m^3). Moreover, the greatest influence on exposure was living with a smoker, contact with smokers at work; leisure or travel having a minor impact. Salivary cotinine levels were found in subjects observed not to be exposed to ETS, hence somewhat questioning the validity of this measure for very low levels of exposure. Both of the objective measures of ETS exposure, nicotine and salivary cotinine levels, only correlated modestly with subjective assessments of exposure obtained by questionnaire.

INTRODUCTION

Environmental tobacco smoke (ETS) is the complex and dilute mixture of substances found in indoor air as a specific result of tobacco smoking. Through the 1980's, ETS has been the subject of much research, principally because of claims that exposure to ETS might be harmful to non-smokers (U.S. Surgeon General 1986).

An important consideration in any study of ETS, whether epidemiological, risk-assessment or laboratory-based research, is the determination of the populations' actual exposure to ETS (Proctor and Smith 1989). It is clearly not possible to absolutely measure a person's lifetime exposure to ETS and so estimates are based on either subjective or single point objective measures.

In epidemiology, the method of exposure assessment is either by questioning the spouse or a relative of the subject, or by reference to hospital records. This is likely to result in an indication as to whether the subject was exposed to ETS in the home, but is unlikely to produce an accurate assessment of actual exposure (Coultas et al. 1989).

In some studies of ETS and lung cancer, the number of cigarettes smoked by the spouse per day is used to segregate exposure levels in attempts to find dose-response relationships (Hirayama 1981; Trichopoulos et al. 1981; Garfinkel 1981; Chan and Fung 1982). Other studies (Correa et al. 1983; Miller 1984; Garfinkel et al. 1985; Kabat and Wynder 1984; Wu et al. 1985) also included questions about whether exposure had occurred at work (yes/no) and/or whether parents had smoked (yes/no). However, as Koo et al. (1987) suggest, these somewhat crude indices of exposure do not take into account that the degree of contact of the non-smoker with these smokers could be very low, or even nil.

Potential levels of exposure can be determined by fixed site monitoring. For this, typically time-weighted average concentrations of ETS related substances (usually nicotine and the contribution of ETS to respirable suspended particulates) are acquired in a certain type of environment. ETS levels will be dependant upon many factors, such as the rate of smoking, size of environment and ventilation conditions. Hence, for such measurements to be applicable to general populations, efforts must be made to ensure that the environments sampled are representative and that substances collected to assess ETS are specific (and do not include contributions from other sources) (Proctor 1988; Proctor and Smith 1989).

Even combining fixed site monitoring with time-activity considerations can be misleading. For example, exposure to ETS in the home will depend upon, to some extent, both the time spent in the same room as the smoker and the proximity of each contact. Hence it is likely that personal monitoring, where ETS substances are continuously measured close the breathing zone of the subject, will give a more accurate determination of exposure.

A further step is to measure the metabolite of an ETS related substance (such as cotinine, one of the metabolites of nicotine) in either plasma, urine or saliva (Haley et al. 1989a; Henderson et al. 1989). However, even these measures require careful interpretation, especially if single rather than cumulative samples are acquired, as there seems to be considerable inter-subject variability in nicotine metabolism (Wall et al. 1988), and because of the possible impact of the time of day of sample collection (Jarvis et al. 1987).

This study reports the findings of a comparison of three exposure assessment methods in a group of 52 free-living British non-smoking women. Each of the subjects was questioned on both, perception of exposure to ETS and on observation of cigarette smoking around them, whilst also wearing a personal monitor for airborne nicotine and supplying saliva for cotinine analysis. The personal monitor also allowed quantitation of exposure to volatile organic compounds (VOCs). Hence, for each subject, information was obtained on actual exposure, associated metabolite levels and perceived exposure to ETS. By comparing the data acquired from each of the approaches, the study allows an insight into the limitations of using any one of the exposure assessment methods in isolation.

PROCEDURAL CONSIDERATIONS

Sample selection

Subjects were selected independently by a market research agency (John Mumford Associates, London). The preset criteria was to acquire a sample balanced by living with a smoker or not and by working or not. An even distribution by age and social classification was also attempted for each sub group. All subjects were non-smoking women (at time of interview), living in either the Birmingham or Fordingbridge areas of England. All samples were acquired in November and December of 1989.

Some 70 subjects were studied, but 18 were rejected from the analysis because of either personal monitor failure or because insufficient saliva was collected. The remaining 52 were classified as in Table 1.

Table 1. Classification of sample.

	Total No. of	Age				Social Classification			
	Subjects	18-24	25-34	35-44	45-54	AB	C1	C2	DE
Smoking home/working	12	3	2	2	5	2	2	7	1
Smoking home/not working	11	3	4	2	2	3	3	4	1
Non-smoking home/working	12	1	5	1	5	0	6	3	3
Non-smoking home/not working	17	3	6	7	1	2	5	6	4

The subject acquisition was semi-random. For the selection of each subject, an area of social classification was identified prior to interviewers calling door-to-door, asking for non-smokers willing to partake in the study. Once a subject was identified, a date was set for the study day.

On the day of study, the interviewer arrived at a time convenient to the subject, instructed on the use of the personal monitor, placed, and switched the monitor on. At this time, a first saliva sample was taken. The subject then wore the monitor for 24 h (placing it at bedside when sleeping). Subjects also carried activity diaries where they noted times of leaving the house, traveling, working and when they were exposed to tobacco smoke. They also recorded the observed number of cigarettes smoked around them, separated by environmental type. After this 24-h period, the interviewer returned, switched off the monitor and took a second saliva sample. The subject was then questioned on the type of cooking, heating, and various lifestyle events relevant both to the monitoring period and in general.

Personal monitoring

The personal monitoring apparatus consisted of a sampling tube connected to a fixed volume diaphragm pump. The collection tube (ATD50 tube, Perkin-Elmer Ltd., U.K.) was a 9-cm-long stainless steel tube filled with about 0.2 g of Tenax TA adsorbant (30-60 mesh) (Chrompack, U.K.). Each tube had been thoroughly conditioned prior to use to ensure lowest possible background contamination. The tube was held close to the breathing zone by means of an SKC holder attached to a short chain worn around the neck. Subjects were instructed to ensure that the tube continued to protrude when overcoats were worn. The tube was connected by flexible tygon tubing to a sampling pump (SKC Model 224-4) held around the waist on a belt. These pumps have visible counters that indicate the volume sampled. The volume per count for each pump was calibrated (Gilibrator Automated Calibrator, Model D800286)) before and after sampling. Sampling pumps were tested prior to the study for retention of calibrated flow over 24-h periods. Similarly, breakthrough characteristics of the tubes under these conditions were tested. Typically, a total of 25 L was sampled using a constant flow rate over the 24-h period.

After sampling, the tubes were capped and stored in a freezer until transfer (cold) to our laboratory at the end of the study. Analysis of each tube involved procedures previously described in detail and validated for nicotine and VOC analysis (Thompson et al. 1989; Proctor et al. 1989). In brief, each tube was desorbed for 15 min at 240°C with helium gas flushing the released chemicals onto a cold trap containing a small amount of Tenax and maintained at -30°C. After this primary desorption, the trap was electronically heated to 240°C, effectively injecting the compounds on to the head of a 30 m, 0.32 μm I.D., DB5 capillary gas chromatographic column. This column separates the compounds of interest, which were subsequently detected, identified, and quantified using a bench-top mass spectrometer (Finegan Ion Trap Detector). Ion-specific detection was used for quantification (i.e., nicotine was quantified on the m/z 84 base peak of the mass spectrum). Calibration was achieved by injecting known quantities of nicotine and VOCs at five concentration levels on to clean Tenax tubes. Hence, standards followed the same analysis route as did the samples.

Salivary cotinine collection and analysis

Dental rolls (Claudius Ash and Sons, U.K.), were used to collect saliva. Subjects were asked to place a clean dental roll in their mouth, between their upper gums and cheek, for 30 min at the beginning (T_1) and again at the end (T_2) of the monitoring period. After this time, the roll was transferred into a coded vial subsequently placed in a cool box until the interviewer returned home, when it was then stored in a freezer.

At the end of the study, all saliva samples were transferred cold to New Cross Hospital, London, where they were analysed blind of subject information by an up-date of the method developed by Feyerabend et al. (1986). This involved basified extraction of the saliva collected by squeezing the dental roll, followed by analysis of the extract by capillary gas chromatography with nitrogen-phosphorus detection.

RESULTS AND DISCUSSION

The data are summarised in Table 2. Means, medians, and ranges are given for salivary cotinine values before (T_1) and after (T_2) the monitoring period, and time-weighted exposure concentrations for nicotine and some volatile organic compounds. Furthermore, both the subjects' observation of the number of cigarettes (including other tobacco products) smoked in proximity either at home or at work totalled to include travel and leisure and their subjective assessment of the extent of exposure to ETS, automobile exhausts, and general air pollution is given. The data set is summarised both for all subjects and segregated by smoking/non-smoking household and by subject working/not working.

Table 2. Summary of data for all subjects and segregated by smoking/nonsmoking household and by working/not working.

		Smoking Household/Working	Smoking Household/ Not Working	Non-smoking Household/ Working	Non-smoking Household/ Not Working	All Subjects
[1]Total number of cigarettes	Mean	7.4	6.6	5.4	0.4	4.5
	Median	5.5	5.0	2.0	0	2
	Range	1-25	1-30	0-50	0-2	0-50
[2]Number of cigarettes at home	Mean	4.7	6.3	0	0.2	2.5
	Median	2	4	0	0	0
	Range	0-25	1-30	0-0	0-2	0-30
[3]Number of cigarettes at work	Mean	1.5	0	5.4	0	1.6
	Median	0	0	2	0	0
	Range	0-10	0-0	0-50	0-0	0-50
[4]Salivary cotinine T_1 ($ng\ ml^{-1}$)	Mean	2.6	2.5	1.3	1.1	1.8
	Median	1.2	2.2	1.15	0.9	1.2
	Range	0.3-15.1	0.5-8.1	0.3-3.5	0.3-2.9	0.3-15.1
[5]Salivary cotinine T_2 ($ng\ ml^{-1}$)	Mean	1.7	2.2	1.3	1.1	1.5
	Median	1.3	1.5	1.0	0.8	1.1
	Range	0.1-5.3	0.2-9.0	0-4.4	0.2-3.7	0-9.0
[6]Nicotine ($\mu g\ m^{-3}$)	Mean	1.6	7.4	0.8	0.5	2.3
	Median	0	2.3	0.4	0	0
	Range	0-9.6	0-45.4	0-2.6	0-7.2	0-45.4
Benzene ($\mu g\ m^{-3}$)	Mean	15.7	21.6	60.7	13.2	26.5
	Median	13.3	13.4	15.5	10.4	12.8
	Range	3.2-48.7	5.2-103	0.7-510	0.2-32.1	0.2-510
Toluene ($\mu g\ m^{-3}$)	Mean	272	112	262	144	194
	Median	85	120	94	78	89
	Range	39-2191	22-208	0.4-1589	0.2-1264	0.2-1264

1 Total number of cigarettes is the subjects' assessment of the number of cigarettes smoked in proximity over the sampling period.
2 Number of cigarettes at home is the subjects assessment of the number of cigarettes smoked whilst at home during the sampling period.
3 Number of cigarettes at work is the subjects' assessment of the number of cigarettes smoked in proximity whilst at work during the sampling period.
4 Salivary cotinine T_1 relates to the sample taken at the onset of the sampling period.
5 Salivary cotinine T_2 relates to the sample taken directly after the 24 hour sampling period.
6 All VOC concentrations are time weighted averages over the 24 hour period and are given in $\mu g\ m^{-3}$, 0 is equivalent to a detection limit of 0.1 $\mu g\ m^{-3}$.

Table 2. Continued.

		Smoking Household/Working	Smoking Household/ Not Working	Non-smoking Household/ Working	Non-smoking Household/ Not Working	All Subjects
Ethylbenzene	Mean	10.2	10.1	12.5	11.1	11.0
(µg m^{-3})	Median	9.0	11.3	12.3	9.8	9.7
	Range	5.9-19.5	4.0-14.6	0.1-30.4	0.3-52.1	0.1-52.1
o-Xylene	Mean	12.1	10.2	13.7	9.5	11.2
(µg m^{-3})	Median	9.2	8.9	12.9	10.5	9.4
	Range	1.1-49.6	3.8-16.4	1.0-40.9	1.0-17.0	1.0-40.9
m/p-Xylene	Mean	37.2	30.6	47.9	34.0	37.2
(µg m^{-3})	Median	22.2	21.8	44.3	17.3	24.4
	Range	16.1-159	4.7-102	3.0-127	3.4-166	3.0-166
Styrene	Mean	3.2	3.0	9.5	2.9	4.5
(µg m^{-3})	Median	2.0	2.3	2.5	2.1	2.2
	Range	1.4-12.6	1.0-9.7	0.3-49.8	0.8-12.4	0.3-49.8
Chlorobenzene	Mean	0.2	0.2	0.2	0.5	0.3
(µg m^{-3})	Median	0.1	0.1	0.2	0.1	0.1
	Range	0.1-0.4	0.1-0.5	0.1-0.7	0.1-5.2	0.1-5.2
1,4-dichlorobenzene	Mean	8.8	12.2	12.8	1.5	8.1
(µg m^{-3})	Median	0.7	0.7	2.5	0.6	0.7
	Range	0.2-89.3	0.2-81.7	0.1-114	0.3-6.5	0.1-114
n-Octane	Mean	11.0	7.8	15.5	12.4	11.8
(µg m^{-3})	Median	9.1	5.9	7.4	7.0	7.0
	Range	3.5-32.7	1.7-22.2	0.1-55.3	2.4-77.4	0.1-77.4
N-Decane	Mean	16.2	21.8	67.2	27.6	32.8
(µg m^{-3})	Median	13.8	14.3	14.8	12.2	13.9
	Range	1.9-66.6	2.5-62.2	3.5-484	1.8-80.3	1.8-484
n-Undecane	Mean	8.4	9.9	29.7	10.5	14.3
(µg m^{-3})	Median	6.9	10.1	15.5	4.3	8.4
	Range	1.3-34.5	2.2-29.9	2.5-163	2.3-35.4	1.3-163
n-Dodecane	Mean	4.7	5.9	7.2	5.8	5.9
µg m^{-3})	Median	3.1	2.9	5.2	3.1	3.6
	Range	0.7-15.5	0.8-21.1	0.6-28.3	0.7-30.9	0.6-30.9
Limonene	Mean	18.4	16.9	13.4	15.9	16.1
(µg m^{-3})	Median	14.3	10.5	11.6	12.3	12.5
	Range	1.6-47.3	0.3-45.0	0.4-53.1	0.4-72.0	0.3-72.0

Table 2. Continued.

		Smoking Household/Working	Smoking Household/ Not Working	Non-smoking Household/ Working	Non-smoking Household/ Not Working	All Subjects
α-pinene ($\mu g\ m^{-3}$)	Mean	8.6	21.4	7.6	11.8	12.1
	Median	7.8	9.0	6.6	7.6	7.6
	Range	3.2-18.4	2.4-116	1.4-18.5	2.1-76.2	0.6-116
Chloroform ($\mu g\ m^{-3}$)	Mean	0.6	1.0	1.2	1.4	1.1
	Median	0.5	0.7	0.7	0.7	0.7
	Range	0.1-2.5	0.2-2.1	0.1-4.5	0.1-11.9	0.1-11.9
1,1,1-trichloro ethane ($\mu g\ m^{-3}$)	Mean	476	8.6	20.6	6.9	119
	Median	15.5	4.9	5.6	6.8	6.2
	Range	2.8-2507	2.0-45.5	1.3-172	0.1-15.1	0.1-2507
1,2-dichlorethane ($\mu g\ m^{-3}$)	Mean	0.2	0.4	3.7	0.4	1.1
	Median	0.3	0.4	0.4	0.4	0.4
	Range	0.1-0.5	0.2-0.6	0.1-40	0.1-1.4	0.1-40
Trichlorethene ($\mu g\ m^{-3}$)	Mean	9.1	8.3	10.2	6.9	8.5
	Median	8.7	7.2	7.8	5.4	6.5
	Range	1.0-31.2	2.0-20.1	0.4-4.5	0.1-11.9	0.1-31.2
Tetrachloroethene ($\mu g\ m^{-3}$)	Mean	3.6	3.3	14.0	1.9	5.4
	Median	1.6	2.0	2.4	1.4	1.9
	Range	0.9-12.4	0.8-13.9	0.2-76.8	0.1-6.0	0.1-76.8
Pyridine ($\mu g\ m^{-3}$)	Mean	0.8	1.6	0.8	0.5	0.9
	Median	0.5	0.8	0.4	0.3	0.5
	Range	0.2-2.4	0.4-8.9	0.2-3.8	0.2-2.2	0.2-8.9
[7]Assess ETS (1-5)	Mean	3.2	2.8	2.3	1.3	2.3
	Median	3	3	2	1	2
	Range	1-5	1-5	1-5	1-3	1-5
[8]Assess Car/bus (1-5)	Mean	3.1	2.4	2.6	2.5	2.6
	Median	3.5	2	2	2	2
	Range	1-5	1-5	1-5	1-5	1-5
[9]Assess all pollution (1-5)	Mean	2.7	2.3	2.6	2.2	2.3
	Median	2.5	1.0	2.0	2.0	2.0
	Range	2-4	1-4	1-5	1-5	1-5

7 Assess ETS is the subjects' assessment of exposure during the monitoring period to tobacco smoke in the air, scaled from 1 (none) to 5 (extreme).

8 Assess car/bus is the subjects' assessment of exposure to car and bus exhausts, scaled from 1 (none) to 5 (extreme)

9 Assess all pollution is the subjects' assessment of exposure to air pollution (other than car/bus exhausts), scaled from 1 (none) to 5 (extreme).

Representativeness of sample

It is clearly important to assess whether wearing the monitor influenced the behaviour of the subject and, hence, whether the results are typical. All subjects were questioned as to whether their lifestyle during the monitoring period was typical and all but one, who did not wish to be seen wearing the monitor, said that it was.

With regard to exposure to ETS, one check is to see whether salivary cotinine values taken at T_1 and T_2 were similar (i.e., exposure was similar both on the day of study and the previous day). The median difference between T_1 and T_2 was found to be zero (mean -0.2 ng mL^{-1}, lower quartile -0.4 ng mL^{-1}, upper quartile 0.4 ng mL^{-1}, range -9.8 to 2.7). As shown in Table 3, the correlation between T_2 and T_1 was 0.73 (r^2 = 0.53) for all subjects and 0.75 (r^2 = 0.56) for smokers' homes. The largest disparity was found in a subject exposed to an observed value of 20 cigarettes at home, whose salivary cotinine dropped from 15.1 ng mL^{-1} (T_1) to 5.3 mg mL^{-1} (T_2). However, on the whole, it seems that the sampling system did not significantly impact their lifestyle.

Exposure to airborne nicotine

The highest mean (7.4 $\mu g\ m^{-3}$) and median (2.3 $\mu g\ m^{-3}$) time-weighted exposures to nicotine were found in non-working women living in homes with smokers. The maximum exposure (45.4 $\mu g\ m^{-3}$) was also found in this category. Levels were much lower in smoker homes where the subject was working (mean 1.6 $\mu g\ m^{-3}$, median 0, range O to 9.6 $\mu g\ m^{-3}$). No nicotine was detected in a significant number of these subjects, the limit of detection being 0.1 $\mu g\ m^{-3}$. However, as this is time-weighted, it is possible that exposure to higher concentrations than 0.1 $\mu g\ m^{-3}$ during part of the day could still result in the time weighted average being below the limit of detection.

The mean nicotine concentration for working subjects living in non-smoking homes, was 0.8 $\mu g\ m^{-3}$ (median 0.4, range 0-2.6 $\mu g\ m^{-3}$). Subjects neither working nor exposed to ETS at home had the lowest exposure (mean 0.5, median O and range 0-7.2 $\mu g\ m^{-3}$). This exposure presumably only results from either travel or leisure.

Across all subjects, the mean exposure to nicotine was 2.5 $\mu g\ m^{-3}$, with a median below 0.1 $\mu g\ m^{-3}$. The data seems to correspond to that found by McCarthy et al. (1987) where children from smoking families were found to be exposed to means of 2.5 $\mu g\ m^{-3}$ whilst those from non-smoking families were exposed to 0.3 $\mu g\ m^{-3}$ nicotine.

Our results suggest, as has been indicated by previous studies (Haley et al. 1989b), that the most influential source of exposure to ETS is in the domestic environment and that contributions at work, leisure or during travel are much smaller. Moreover, mean exposures are low. Some authors (Oldaker and Conrad 1987; Carson and Erikson 1988; Proctor et al. 1989) have attempted to put the levels of ETS constituents in perspective through cigarette equivalent calculations. This exercise takes the median exposure to airborne nicotine and typical breathing rates to give a daily exposure. This is then compared to the delivery of nicotine that would be obtained from smoking one cigarette. Such calculations are strictly an estimate of exposure, not dose, are only relevant to nicotine and not ETS as a whole, and take no account of the differences between breathing air and inhaling smoke. Taking a typical female breathing rate of 0.62 $m^{-3}\ h^{-1}$ (Arundel et al. 1987) and a mainstream nicotine delivery of 1.3 mg cig^{-1} for a typical U.K. cigarette, then the median daily exposure over all subjects would be less than the nicotine equivalent of 0.001 cigarette. That means that the non-smoking subject on the average would only be exposed to the equivalent nicotine of smoking a single cigarette after a period in excess of 2 y.

Salivary cotinine levels

The highest mean (2.2 ng mL^{-1}) and median (1.5 ng mL^{-1}) T_2 salivary cotinine levels were found in non-smoking subjects living in smoker households. Working subjects living with smokers had a T_2 mean of 1.7 ng mL^{-1} (median 1.3 ng mL^{-1}, whilst those living in non-smoker households had a T_2 mean of 1.3 ng mL^{-1} (median 1.0 ng mL^{-1}). Subjects that neither worked nor lived with a smoker had the lowest T_2 mean of 1.1 ng mL^{-1} (median 0.8 ng mL^{-1}) Hence, these trends follow the results found in the personal monitoring data for nicotine.

However, salivary cotinine levels were observed in all but one subject. In 30 of the 52 subjects, there was no detectable exposure to nicotine. This, at first inspection, seems to indicate that the salivary cotinine measure is more sensitive to nicotine exposure than personal monitoring. It should be expected though that detection of salivary cotinine would be associated with an observation of cigarettes being smoked in proximity to the subject. But in 15 cases, the subjects observed no exposure to ETS and yet salivary cotinine was detected. Moreover, the levels in these cases (mean 1.0 ng mL^{-1}; median 0.85 ng mL^{-1}; range 0.5-3.7 ng mL^{-1}), overlap with cases where ETS exposure was observed. This might be

Table 3. Correlations and regression analysis.

		Corr.	r^2	F	P
Salivary cotinine T_1 and salivary cotinine T_2	(All subjects)	0.73	0.53	55.3	0
Salivary cotinine T_1 and salivary cotinine T_2	(Smokers' households)	0.75	0.56	26.9	0
Salivary cotinine T_1 and salivary cotinine T_2	(Non-smokers' households)	0.59	0.34	14.4	0.001
Salivary cotinine T_1 and nicotine	(All subjects)	0.49	0.24	15.5	0
Salivary cotinine T_2 and nicotine	(All subjects)	0.71	0.51	52	0
Salivary cotinine T_1 and nicotine	(Smokers' households)	0.45	0.2	5.3	0.032
Salivary cotinine T_1 and nicotine	(Non-smokers' households)	0.32	0.1	3.1	0.09
Salivary cotinine T_2 and nicotine	(Smokers' households)	0.79	0.63	35	0
Salivary cotinine T_2 and nicotine	(Non-smokers' households)	0.21	0.04	1.3	0.27
Observed total number of cigarettes and nicotine	(All subjects)	0.5	0.25	16.4	0
Observed total number of cigarettes and nicotine	(Smokers' households)	0.74	0.55	25.3	0
Observed total number of cigarettes and nicotine	(Non-smokers' households)	0.29	0.09	2.5	0.125
Observed total number of cigarettes and salivary cotinine T_2	(All subjects)	0.63	0.39	32.5	0
Observed total number of cigarettes and salivary cotinine T_2	(Smokers' households)	0.70	0.49	20.4	0
Observed total number of cigarettes and salivary cotinine T_2	(Non-smokers' households)	0.62	0.38	16.7	0
Observed total number of cigarettes smoked at home and nicotine	(Smokers' households)	0.80	0.64	37.2	0
Observed total number of cigarettes smoked at home and salivary cotinine T_2	(Smokers' households)	0.69	0.48	19.3	0
Assessed exposure to ETS and nicotine (all subjects)	(All subjects)	0.42	0.17	10.7	0.002
Assessed exposure to ETS and salivary cotinine T_2	(All subjects)	0.50	0.25	16.6	0
Assessed cigarettes per day and nicotine	(Smokers' households)	0.57	0.32	9.8	0.005
Assessed cigarettes per day and salivary cotinine T_2	(Smokers' households)	0.53	0.28	8.3	0.009
Benzene and nicotine	(All subjects)	0.05	0.002	0.12	0.726
Benzene and nicotine	(Smokers' households)	0.304	0.09	2.13	0.159
Benzene and salivary cotinine T_2	(All subjects)	0.137	0.002	0.95	0.334
Benzene and salivary cotinine T_2	(Smokers' households)	-0.009	0.0	0	0.969

Corr = Pearson correlation (r)
r^2 = Square of the correlation
F = F ratio, the mean square factor/mean square error
P = Probability of F occurring by chance

explained by ETS exposure during previous days, but, if this were to be the case, then it would be expected that the level at T_2 would be less than that at T_1. In fact, for 10 of these 15 cases, T_2 was higher than T_1. This raises doubts about the validity of the salivary cotinine information at low levels and suggests that studies that have suggested large proportions of the population being exposed to ETS may be misleading (Repace and Lowry 1985; Wells 1988).

Comparing personal exposure to nicotine with salivary cotinine

Table 3 shows that for the full data set, the correlation between salivary cotinine at T_2 and nicotine was 0.71 (r^2 = 0.51, F = 52). When restricted to smoker households, this increases to a correlation of 0.79 (r^2 = 0.63, F = 35). In non-smoker households, the correlation of 0.21 (r^2 = 0.04, F = 1.3) is not significant. However, here many of the nicotine data points were below the detection limit.

Salivary cotinine at T_1 correlates with nicotine at 0.49 (r^2 = 0.24, F = 15.5) for all subjects, but this reduces to 0.45 (r^2 = 0.2, F = 5.3) in smoker households. Hence, it seems possible to correlate salivary cotinine levels taken after monitoring with personal nicotine exposures, but only in the higher exposure group of subjects living with smokers.

Some authors have used salivary cotinine data to interpret exposures in terms of cigarette equivalents (Jarvis et al. 1987). Using typical salivary cotinine levels in a 20 cigarettes/d smoker of 300 ng ml, it was suggested that levels found in non-smoking children were as high as the equivalent of one half of a cigarette/d. Carrying out the same calculation on our data, would suggest that the highest exposed group (living with smokers, not working), would be receiving the mean equivalent nicotine dose of 0.15 cigarettes/d.

However, if one again takes the mean exposure to nicotine over the 24-h period, using a female respiration rate of 0.62 m^{-3} h^{-1} and a typical mainstream nicotine delivery of 1.3 mg cig^{-1}, then this exposure is the nicotine equivalent of smoking 0.08 cigarettes /d. This disparity is further illustrated in the non-working subjects in non-smoking homes where calculations based on salivary cotinine would suggest cigarette equivalents of 0.08 cigarettes/d, whilst those based on nicotine exposure suggest 0.006 cigarettes/d. The difference, as Haley et al. (1989b) suggest, is likely due to the salivary cotinine calculation not taking into account the different metabolic clearance rates of cotinine in smokers and non-smokers.

Correlating objective and subjective evaluations of ETS exposure

It might be expected that the observed number of cigarettes smoked close to the subject would positively correlate with both measures of personal nicotine exposure and salivary cotinine levels at T_2. When taking all subjects, the correlation between total cigarettes and nicotine is 0.5 (r^2 = 0.25, F = 16.4), and with salivary cotinine T_2 is 0.63 (r^2 = 0.39, F = 32. 5); hence, there is a modest correlation. If the data set is restricted to the numbers of cigarettes smoked at home in smoking households, then the correlation with nicotine is much stronger at 0.8 (r^2 = 0.64, F = 37.2). With salivary cotinine T_2, this correlation is not so good, at 0.69 (r^2 = 0.48, F = 19.3).

Two further assessments of ETS exposure were acquired by questionnaire. The first was to ask, prior to monitoring, how many cigarettes were typically smoked per day by the smoker, a question often used in epidemiological studies. This assessment correlated relatively poorly with nicotine exposure at 0.57 (r^2 = 0.32, F = 16.6). With salivary cotinine T_2 the correlation was 0.51 (r^2 = 0.25, F = 17.5). This assessment of cnly a modest correlation between objective and subjective measures of ETS exposure is in agreement with recent work presented by Coultas et al. (1989).

All subjects were also asked to assess their exposure to ETS scaled from 1 (none) to 5 (extreme) during the sampling period. This again, did not correlate well with either nicotine or salivary cotinine T_2 levels.

Exposure to volatile organic compounds

The 24-h time-weighted average exposures to a range of VOCs are given in Table 2. The concentrations found are broadly similar to the winter/indoor data published in the U.S. Environmental Protection Agency's (EPA) Total Exposure Assessment Methodology (TEAM) studies (Pellizari et al. 1986; Wallace 1987). For example, the TEAM study found median personal exposure levels of benzene during daytime at 11 μg m^{-3} (Wallace 1987), whilst the median benzene level for all of our subjects was 13 μg m^{-3}. Our study also used a similar analytical methodology to that utilised in TEAM studies.

Overall, neither working nor smoking had a dramatic effect on personal exposures to VOCs. However, there are some trends. Taking differences between means for smoking/non-smoking and working/non-working to be equivalent if the difference was less than 10% of the mean of all for a particular compound, then there are increased levels of exposure for subjects working over subjects not working for 13 of the 21 VOCs analysed. This includes benzene (mean working of 38 μg m^{-3}, not working 16 μg m^{-3}), toluene (mean working of 267 μg m^{-3}, not working 131 μg m^{-3}), styrene (mean working of 6 μg m^{-3}, not working 3 μg m^{-3}) and 1,1,1-trichloroethane (mean working 248 μg m^{-3}, not working 7 μg m^{-3}). For five of the VOCs, means were higher for subjects not working, including nicotine (not working 3.2 μg m^{-3}, working 1.2 μg m^{-3}) and α-pinene (not working 16 μg m^{-3}, working 8 μg m^{-3}). For three further VOCs, exposures were equivalent. However, none of the differences found were statistically significant.

Comparing mean VOC data in a similar manner for subjects living in smoking households against non-smoking households, 6 VOCs were higher for the smoker household category. These included nicotine (smoking 4.3 μg m^{-3}, non-smoking 0.7 μg m^{-3}), limonene (smoking 18 μg m^{-3}, non-smoking 15 μg m^{-3}) and 1,1,1 trichloroethane (smoking 252 μg m^{-3}, non-smoking 13 μg m^{-3}). Subjects not living with smokers were exposed to higher means of 12 VOCs, including benzene (non-smoking 33 μg m^{-3}, smoking 19 μg m^{-3}), m/p xylene (non-smoking 40 μg m^{-3}, smoking 34 mg m^{-3}) and n-decane (non-smoking 44 μg m^{-3}, smoking 19 μg m^{-3}).

Means for each of the VOCs were separated by social classification [AB (high), C1, C2, DE (low)] of the subject. In general, exposures were evenly distributed by social class, though there was a trend of benzene and toluene exposures increasing with lower social class, and 1,1,1-trichloroethane and α-pinene increasing with higher social class.

Wallace (1989) has suggested that exposure to environmental tobacco smoke corresponds to significantly increased personal exposures to benzene, xylenes, ethylbenzene, and styrene. Several previous studies have suggested that this is unlikely (Bayer and Black 1987; Proctor et al. 1989). If it were to be the case, then it might be expected that there would be a strong correlation between personal exposures to nicotine and to these aromatic VOCs. As shown in Table 3, there is no significant correlation between either benzene and nicotine or between benzene and salivary cotinine (T_2) levels. The same holds true for xylenes, ethylbenzene, and styrene.

The highest observed exposure to benzene (510 μg m^{-3}) was some 40 times greater than the median exposure for all subjects. This was found in a subject that worked as a cashier in a garage forecourt. Benzene is a significant component of petrol fumes. This subject was also found to be exposed to nearly 18 times (1588 μg m^{-3}) the median exposure to toluene and higher than average exposure to ethylbenzene and m/p-xylene. Another subject, working as an accountant in a bedding material retail outlet, was exposed to the highest toluene level (2190 μg m^{-3}), the highest o-xylene level (50 μg m^{-3}), and much higher than average levels of 1,4-dichlorobenzene, n-decane, n-undecane, and styrene (39 μg m^{-3}).

One subject used an open wood fire for heating in the home. This seems to correspond to much higher than average exposure to octane (55 μg m^{-3}), decane (484 μg m^{-3}), and undecane (163 μg m^{-3}), though aromatic VOCs were not significantly higher than average. Neither the use of gas heating or whether or not the house was double-glazed had any significant effect on personal exposures to VOCs. However, gas cooking was associated with increased mean exposures to benzene, ethylbenzene, o-xylene, styrene, toluene, and 1,4-dichlorobenzene. All of the high levels of exposure to 1,1,1-trichloroethane occurred in subjects that both worked and were exposed to ETS at home. This solvent usually results from contact with industrial cleaning or degreasing operations (Droz et al. 1988), and one possible source is dry-cleaned clothes. However, subjects were questioned as to whether they visited a dry cleaner on the study day or whether the clothes they wore had been recently dry cleaned, but the response to both these questions was negative for all subjects. It is unclear what was the source or whether there were several sources, but it is unlikely that this exposure is related to ETS as there was only a modest correlation with nicotine or salivary cotinine (T_2). The subject experiencing the highest exposure to 1,1,1-trichloroethane worked as a receptionist, and a possible source is typing correction fluid.

CONCLUSIONS

Although this study has been based on a relatively small subject set, some clear trends are apparent. It seems that the main factor in exposure to environmental tobacco smoke is living with a smoker. Exposure at work, leisure, or travel seems to be minor. Overall, exposure to airborne nicotine was found to be low (mean 2.3 μg m^{-3}, median <0.1 μg m^{-3}).

Salivary cotinine levels tend to increase with exposure to airborne nicotine, but many subjects not exposed to ETS were found to have detectable salivary cotinine levels at values that overlapped with subjects that were exposed. This warrants further investigation. Also, cigarette equivalent calculations based on salivary cotinine levels did not correspond with similar calculations based on exposure to ETS.

The study evaluated various objective and subjective methods for assessing populations' exposure to ETS. It was found that questions regarding spouse smoking habits, as commonly used in epidemiological studies, did not correspond well with either levels of exposure to nicotine or salivary cotinine measurements, although trends did exist.

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THE INDOOR AIR QUALITY IN FINNISH HOMES WITH MOLD PROBLEMS

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A survey about mold problems in Finnish homes was made. Of the 135 reported cases 30 homes were chosen for bioaerosol measurements. Indoor and outdoor air fungal spores and bacteria were sampled in the spring and fall. Corresponding data, gathered from 18 reference homes sampled in the spring, were used as reference material. The range of the fungal spore levels was 10-2300 colony-forming units/m^3 (cfu/m^3) in moldy homes and 165-850 cfu/m^3 in the reference homes. The mean indoor/outdoor ratio of fungal spores in moldy homes was 4.2 vs. 0.6 in the reference homes. Mesophilic actinomycetes were found in moldy homes but not in the reference homes. No thermophilic actinomycetes were found in moldy or reference homes. In seven complaint sites the total bacteria levels were exceedingly high, 4500-12 200 cfu/m^3, which probably resulted from poor ventilation.

INTRODUCTION

Dampness and mold growth in buildings is often associated with health complaints of occupants. Adults living in damp dwellings have been reported to suffer from symptoms such as nausea, blocked nose, and breathlessness and children to have a higher frequency of respiratory symptoms, headaches, and fever than those living in dry dwellings (Platt et al. 1989). However, the nature of exposure in these damp dwellings is not clear.

Moisture may be condensed, leaking or penetrating inside or into the building. This may result in mold growth on construction materials and cause spore generation into indoor air. This type of exposure to spores may be one reason for the symptoms of the occupants. On the other hand, indoor air bacteria reflect mostly the presence and activities of humans (Pellikka et al. 1986) and raised levels of bacteria may result from insufficient ventilation.

High humidity, dampness, and associated microbial problems in buildings are not common in Finland where cold climate requires good heating and insulation. Energy conservation goals often lead to tight insulation and insufficient ventilation which have sometimes brought moisture condensation problems. Sporadic, but sometimes serious cases of mold growth in a building and also associated health problems have been complicated in medical, administrational, juridical, and technical sense. Therefore, a survey on the frequency and severity of mold problems in Finnish homes was made.

In our earlier studies, bioaerosol measurements have been carried out in normal homes without building-associated health problems or complaints (Reponen et al. 1989). We have also observed the indoor and outdoor variation of fungal spores and bacteria levels. From spring to fall, indoor and outdoor air fungal spore levels are of the same magnitude and outdoor air is an important source of indoor fungi (Pellikka et al. 1986). However, in the subarctic winter when the soil is frozen and covered by snow, the outdoor air levels are 1-2 orders of magnitude lower than in the spring and fall, while the seasonal differences in the indoor air levels are relatively small (Pellikka et al. 1986).

Using the accumulated data about the normal bioaerosol levels as a reference, the objective was to find out how the levels of airborne fungal spores, actinomycete spores or other bacteria are affected by microbial growth in the buildings.

MATERIAL AND METHODS

An inquiry in search for moldy homes or building-associated health problems was mailed in 1987 by the National Board of Health to the health authorities of all 450 municipalities of Finland. The cases reported in response were contacted by the research group by phone. Thirty moldy homes were chosen for a technical and indoor air quality survey. The technical survey included a questionnaire and interviews of both the occupants and the landlord. Indoor air data from 18 non-complaint apartments sampled earlier by the same technique were used as a reference (Reponen et al. 1989).

Samples of indoor air fungal spores and bacteria were collected in March-April and in October 1987 in several rooms of moldy homes. Outdoor samples were taken daily or when a series of indoor sampling was started and finished at any site. Bioaerosols were sampled with six-stage impactors (Andersen 10-800) on malt-extract-based Hagem agar for total fungi, tryptone-yeast-glucose (TYG) agar for total bacteria, and half-strength nutrient agar for thermophilic actinomycetes. The Petri plates were incubated at room temperature for 5-7 d, except for the nutrient agar plates which were incubated at 55°C.

The distributions of any aerosols counts approximate lognormal and, therefore, the logarithms of the counts are used in the statistics. The results are expressed as geometric means and geometric standard deviations. To correct for the effect of outdoor fungal spore levels, indoor/outdoor (I/O) ratios were used to compare reference and moldy homes. The significance of the difference between the I/O ratios were tested with the Mann-Whitney U-test.

RESULTS AND DISCUSSION

Results of the technical survey

The inquiry resulted in 135 cases of moldy homes, reported from 40 municipalities. In the technical survey an apparent reason for the moisture problem was found in most cases. Often the reason was an improperly weatherproofed outside wall which allowed rainfall to wet the insulation material. Equally often moisture was penetrating in through the floor because of missing or inadequate drainage. In some cases, water leaked through the ceiling or construction errors had been made in bathroom insulation.

Fungal spores

The range of the indoor fungal spore levels was 10-2300 cfu/m^3 (colony-forming units/m^3) in the moldy homes and 170-850 cfu/m^3 in the reference homes. The geometric means and geometric standard deviations of the fungal spore levels are presented in the Table 1. The lowest and the highest spore levels were observed in the homes with visible mold; however, the levels of fungal spores in moldy and reference homes were of the same order of magnitude.

The mean fungal spore level in the moldy home samples was lower than that of the reference home samples (Table 1), but the mean I/O ratio of the fungal spores in the moldy homes was 4.2, indicating dominant indoor sources, while it was only 0.6 in the reference homes, indicating normal filtration of outdoor air in ventilation. The moldy homes were sampled during days when the outdoor air levels were low compared to the days when the reference homes were sampled. This somewhat complicates the interpretation of our results.

Orders-of-magnitude higher levels of fungal spores have been observed in some individual homes in our previous field work and reported from occupational environments with fungal aerosol-associated illness (Blomquist et al. 1984). When exposed to high levels of fungi, people may or may not present symptoms. Fungi growing in buildings do not sporulate or release spores continuously but depend on air temperature and humidity (Jantunen et al. 1987; Pasanen et al. 1991). This is why the spore levels in rooms where fungal growth is clearly visible, may well be low at the time of sampling.

Table 1. The geometric means (GM), geometric standard deviations (GSD) and the mean indoor/outdoor (I/O) ratios of the fungal spore levels (cfu/m³) in the moldy and reference homes.

	n	GM	GSD	I/O
moldy homes, indoors	32	102	3.3	4.2
outdoors	15	84	3.1	
reference homes, indoors	18	308	1.6	0.6
outdoors	18	750	1.7	

$p<0.001$

Airborne bacteria

The range of the bacteria levels in the moldy home samples was 60-12 200 cfu/m^3 and in the reference home samples 170-2540 cfu/m^3. The geometric means and standard deviations of the bacteria levels are presented in Table 2. In seven moldy home samples the total bacteria levels were abnormally high, 4500-12 200 cfu/m^3. The main sources of indoor air bacteria are people, and usually high airborne bacteria levels indicate crowding or poor ventilation. Probably, a part of the mold problems and indoor air complaints in homes are explained by lack of ventilation which may be an outcome of misdirected energy conservation. Health inspection of complaint homes should, therefore, include determination of the ventilation rate.

Mesophilic actinomycetes were found in 70% of the sampled moldy homes, but in none of the reference homes (Table 2). Even though the actinomycete levels were low, 0-154 cfu/m^3, their presence seems to indicate a moisture problem which is also the premise for fungal growth. These actinomycetes release an intense odor of "soil" which, besides visible mold, may be one of the reasons for complaints. No thermophilic actinomycetes were found.

We conclude that in a subarctic climate

1) the airborne fungal spore levels are not necessarily higher in samples from moldy or damp homes than in those from reference homes and therefore low fungal spore levels do not indicate absence of mold growth;

2) more emphasis should be given on ventilation in health inspection of homes with a suspected mold problem; and

3) the role of mesophilic actinomycetes as an indicator of moisture problems and associated microbial growth should be further studied.

Almost all of the moldy homes found in the survey had been reported by occupants of rented homes or apartments; however, 64% of people in Finland live in their own homes or apartments. We assume that owners of moldy homes are unlikely to report about their problems to the health authorities and, so, we could only see one side of the iceberg.

Table 2. The geometric means (GM) and standard deviations (GSD) of the total bacteria levels (cfu/m³) and the actinomycete levels in the indoor air of moldy and reference homes.

	total bacteria			actinomycete
	n	GM	GSD	range
moldy homes	32	1011	3.1	0-154
reference homes	18	678	2.2	0

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PERFORMANCE OF DISPLACEMENT AIR DISTRIBUTION IN AN OFFICE ROOM

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Two mixing and several low velocity supply air devices for displacement ventilation have been studied in a full scale room model. The cooling loads varied from 0-50 W/m^2 and air change rates from 3-8 $m^3/h\ m^3$. Velocity and turbulence intensity were measured in several locations near the floor level. The mean values of turbulence intensity of displacement air flow were slightly lower than with mixing air flow. However, there was no significant difference between minimum values of turbulence intensity of mixing and displacement air flows. The difference was greatest in the maximum values of the turbulence intensity. The vertical temperature gradient in the middle of the room was dependent on the total temperature difference between exhaust and supply air temperature. The limiting factor for displacement ventilation in an office room seemed to be thermal comfort. If the cooling load exceeded 40 W/m^2, either the vertical temperature gradient or air velocity at the ankle level becomes too large.

INTRODUCTION

A new way to supply air with low velocity directly into the occupied zone, displacement ventilation, has become more popular in Nordic countries during the 1980s. It offers at least one reasonable benefit compared with mixing air distribution. When cooling is used, the supply air temperature is higher with displacement ventilation than with mixing ventilation. This offers better possibilities to utilize free cooling.

In some cases lower concentration of air pollutants has been measured with the displacement ventilation system in the occupied zone. However, the concentration distribution in rooms depends on the supply air flow rate.

One main problem with displacement ventilation is the high velocity in the front of the supply air device. In the zone close to the device, relatively high air velocity combined with low air temperature can cause significant discomfort. The total effect of low air temperature at the ankle level combined with high velocities on thermal comfort is not yet known, and final conclusions cannot yet be drawn.

A recent study (Fanger et al. 1988) has shown how the influence of air movement on the draught sensation can be expressed with two variables at a fixed temperature. The mean velocity can be described as a static part and the fluctuation of air flow as a dynamic part. The experiments have shown that people complain more about draught when the fluctuation of air flow is higher with fixed mean air velocity. The fluctuation is described with turbulence intensity which is defined in Equation 1.

$$Tu = \frac{\sigma}{\bar{v}} \cdot 100\% \tag{1}$$

where
Tu = turbulence intensity (%)
σ = standard deviation of air velocity (m/s)
$\bar{v}$ = mean velocity (m/s).

Turbulence intensity affects the sensation of draught and is an important factor when evaluating the air distribution systems. Equation 2 includes air temperature, mean velocity, and turbulence intensity. With air temperature of 21°C the predicted percentage of dissatisfied persons with the air movement around the neck or ankles can be estimated from the equation:

$$PD = (40.86 + 4.80\,\bar{v}\;Tu)\,(\bar{v} - 0.05)^{0.6223} \quad (2)$$

where
PD = predisted percentage of dissatisfied, %
$\bar{v}$ = mean air velocity, m/s
Tu = turbulence intensity, %.

The variation in thermal sensation between head and ankle regions is also an important comfort factor. It becomes critical with displacement ventilation systems where the cool air is supplied to the floor level. The criterion for the vertical gradient is established with a temperature difference between the levels of 1.1 and 0.1 m from the floor. It should not exceed 3 K (ISO/DIS 7730, 1984).

There is also another disadvantage with a high positive temperature gradient. When the air in the breathing zone becomes warmer than the average in the occupied zone, the sensation of dryness, stuffiness and sick building symptoms may increase. In a Swedish study the air was felt dryer when the air temperature was 23-24°C than when it was 21-22°C (Andersson et al. 1975), even though the relative humidity was the same in both cases. In a Finnish study (Jaakkola and Heinonen 1987), a linear correlation was found between the prevalence of the sick building symptoms and the air temperature in an office building.

EXPERIMENTAL CONDITIONS

The measurements were made in a full scale office model of 4.75 × 4.12 × 2.65 m (L · W · H), a floor area of 19.5 m^2, and a room volume of 51 m^3. Tests were accomplished with 10, 25 and 50 W/m^2 cooling loads. Air flows and temperatures were selected accordingly (Table 1). Cooling load was created with light fixtures at the ceiling and simulated office equipment on the desks at a height of 0.8 m.

Nine fixed measuring points (1-9) were located in the test room as shown in Fig. 1. In addition, measurements were taken at the heights of 0.07, 0.17, 0.27, and 0.37 m at the distance of 0.75 m from the outlet surface of the low velocity supply air device. The mean velocity and the instant values of the air temperature were measured at heights of 0.05, 0.15, 1.1, and 1.7 m. Vertical temperature distribution was measured continuously in the middle of the room (Fig. 1, Point 5). The instrumentation has been described earlier (Kovanen et al. 1987). The accuracy of the velocity measurement was $(0.03 + 0.03 \cdot \bar{v})$, when the air velocity was higher than 0.05 m/s. The time constant of the system was less than 1 s. The velocity was recorded at each point of at least 180 s.

Two mixing type outlets were used in the tests. The outlet for the mixing system was a wall register in the back wall (Fig. 1, Mix. A) and a 3 m long and 4.0 mm high opening with one or two slots, 0.1 m from the ceiling in the back wall (Fig. 1, Mix. B). The low-velocity supply air devices had three different designs of the outlet surface. The device A had a free area of 10%, device B 85%, and device C 50% of the total face area. The device A had a triangular section with heights of 0.9 or 1.2 m. Device B had a triangular or semicircular section with a height of 0.7 m. Device C had a semi- and quartercylinderical section with a heights of 0.5 and 0.7 m. Devices with semicylinderical sections were placed in the middle of the wall (Fig. 1, Displa. A) and devices with triangular

Table 1. Test conditions.

	(1)	(2)	(3)
Supply air flow rate, L/s	50	75	100
Nominal supply air flow rate, $m^3/h\ m^3$	3.6	5.4	7.2
Temperature difference between exhaust and supply air, K	3.0	5.0	8.0
Cooling load, W/m^2	10	25	50

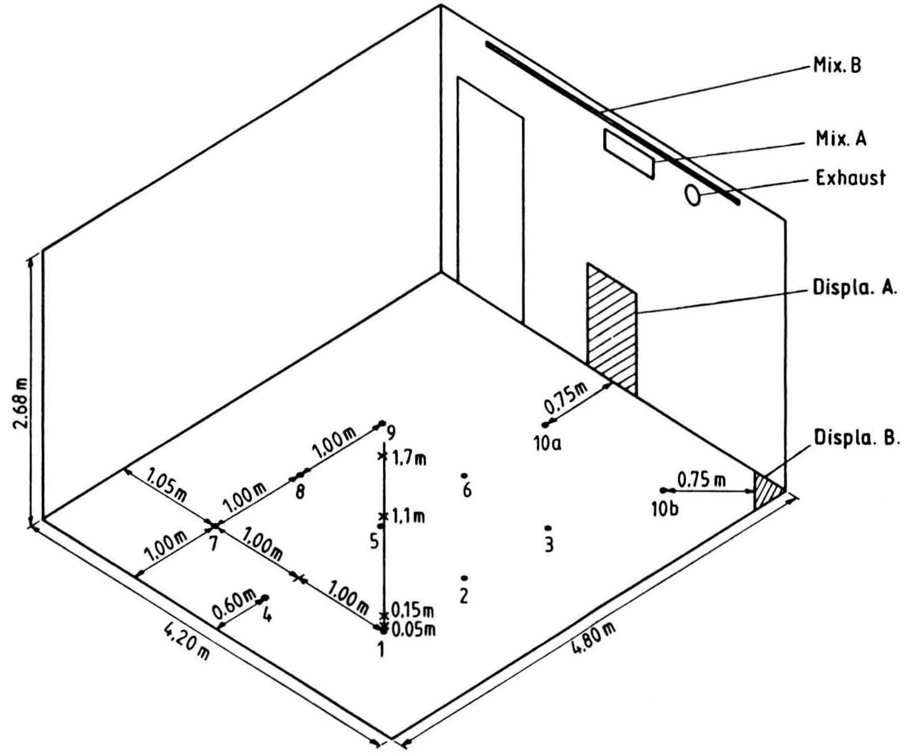

Fig. 1. The dimension of the test room and location of temperature and air velocity measurements.

or quarter cylinderical sections in the corner (Fig. 1, Displa. B).

RESULTS

Mean velocities

The mean value of all velocities, measured at nine locations at the level of 0.05 m above the floor, is shown as a function of the supply air flow rate in Fig. 2, for tested devices. The maximum measured mean velocity at a distance of 0.75 m from the face of the displacement ventilation device, located either in the corner of the room or in middle of the wall, is shown in Fig. 3.

Turbulence intensity

The minimum, maximum, and mean values of turbulence intensity were measured. The results are shown for the displacement and mixing air flow pattern at the level of 0.05 m in Tables 2 and 3. The turbulence intensity at a distance of 0.75 m from the displacement supply devices at the level of 0.07 m is shown in Table 4.

Vertical temperature distribution

There was a linear correlation between the local vertical temperature difference in the middle of the room and the cooling load. Figure 4 shows the vertical temperature difference (K) between the levels of 1.1 and 0.1 m above the floor, measured in the middle of the room when the air change rates were 3.6, 5.4, and 7.2 $m^3/h\ m^3$. The corresponding correlation coefficients between temperature difference and cooling load were 0.95, 0.86, and 0.78.

DISCUSSION

Mean velocity

The difference of the mean velocity at the height of 0.05 m was large, as can been seen in Fig. 2. The main reason for this lies in the variation of the supply air velocity and the design of the supply air device.

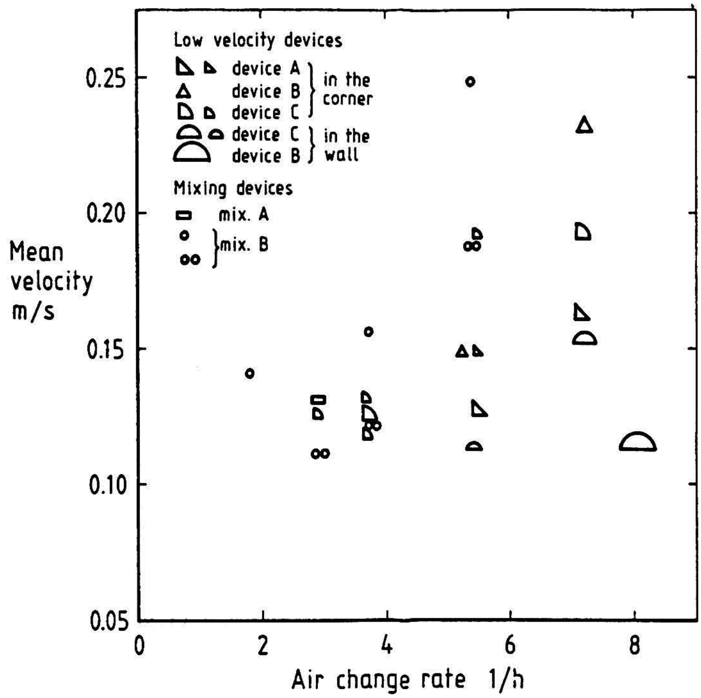

Fig. 2. The mean value of measured velocities at level 0.05 m, depending on the supply air flow rate, expressed as air change rate.

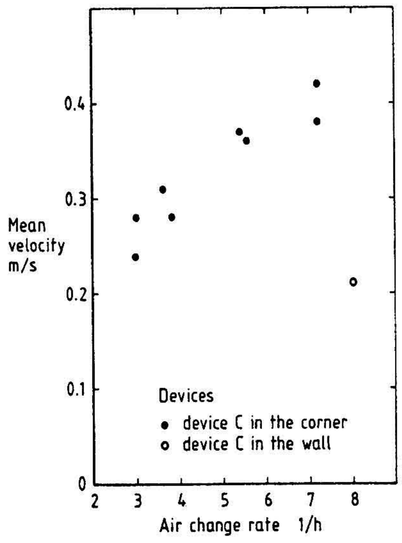

Fig. 3. The maximum mean velocity at a distance of 0.75 m from the low velocity device, depending on the supply air flow rate, expressed as air change rate.

The displacement ventilation devices with semicylinderical section gave the lowest velocity in the occupied zone. In general, the maximum value of the local mean velocity is above 0.2 m/s when only one displacement ventilation device, located in the corner of the room, is used and the supply air flow rate is over 2 $m^3/h\ m^3$. Two or more devices are required to meet the draught criteria if the flow rate exceeds this. The other alternative to meet the draught criteria is to use a device with semicylinderical section and place it in the wall, not in the corner.

In all experiments with displacement ventilation devices the highest velocities were measured close to the floor. The mean velocities measured 0.15 m above the floor were typically 15-30% lower than velocities 0.05 m above the floor. In all experiments with displacement ventilation devices the mean velocities in all locations at heights of 1.1 and 1.7 m were below 0.05 m/s.

Turbulence intensity

The differences in the turbulence intensity were surprisingly small between mixing and displacement ventilation devices, measured at the height of 0.05 m

Table 2. The minimum, maximum, and mean values of turbulence intensity for displacement air flow at level 0.05 m.

Range m/s	No of data points	Minimum	Mean %	Maximum
0.05 - 0.10	40	14.1	31.8	64.2
0.10 - 0.15	55	14.4	24.7	38.5
0.15 - 0.20	43	14.1	21.9	30.1
0.20 - 0.25	28	13.1	20.5	31.5
0.25 - 0.30	15	10.0	19.5	24.6
0.30 - 0.35	7	16.9	17.9	19.6
0.35 - 0.40	4	9.6	13.9	17.4

Table 3. The minimum, maximum, and mean values of turbulence intensity for mixing air flow at level 0.05 m.

Range m/s	No of data points	Minimum	Mean %	Maximum
0.05 - 0.10	13	25.5	38.0	75.5
0.10 - 0.15	34	16.7	33.4	55.8
0.15 - 0.20	24	12.9	28.6	39.8
0.20 - 0.25	16	13.2	27.8	38.7
0.25 - 0.30	2	22.1	24.3	26.4
0.30 - 0.35	9	13.3	20.0	29.1
0.35 - 0.40	2	14.6	15.7	16.9

Table 4. The minimum, maximum, and mean values of turbulence intensity for displacement air distribution system measured a distance of 0.75 m from device.

Range m/s	No of data points	Minimum	Mean %	Maximum
0.10 - 0.20	6	9.3	27.9	47.5
0.20 - 0.30	20	9.7	16.7	34.7
0.30 - 0.40	11	5.2	8.5	14.7
0.40 - 0.50	8	3.6	6.7	13.2

Table 5. The percentage of dissatisfied persons depending on the mean velocity and the measured mean value of the turbulence intensity for both displacement and mixing systems.

Mean velocity m/s	Percentage of Dissatisfied Displacement	Mixing	Difference (%)
0.10	8.7	9.2	0.7
0.15	14.0	15.5	1.5
0.20	19.0	21.0	2.0

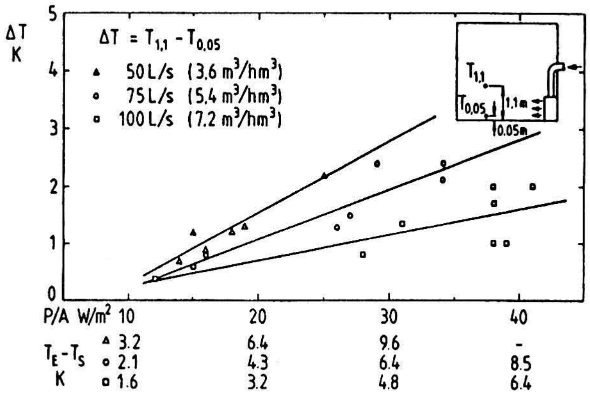

Fig. 4. Vertical temperature difference (θT) in the middle of the room between levels 1.1 and 0.05 m above the floor, depending on the cooling load (W/m²).

above the floor. The difference was highest between the maximum values of turbulence intensity (7-17%), while no difference between minimum values was detected when the mean velocity was below 0.25 m/s.

Equation 2 can be used to evaluate differences between the air distribution systems in respect to draught sensation. When the data from Tables 2 and 3 are used, the predicted percentage of dissatisfied persons is obtained for three values of mean air velocity (Table 5).

The results show only a small difference between the systems in the percentage of dissatisfied persons (~10%). It has to be pointed out that the same temperature and mean velocity was assumed in the calculations and there may be significant differences between the designs.

Vertical temperature difference

In the displacement ventilation systems, the temperature difference is dependent on the temperature difference between exhaust and supply air, as can be seen in Fig. 4. With a given supply air flow rate the temperature difference depends on the cooling load. If the temperature difference between exhaust and supply exceeds 10 K, the vertical temperature in the middle of the room becomes greater than 3 K/m which is the criterion for thermal comfort.

In the displacement ventilation system the temperature in the breathing zone cannot be decreased much because the temperature in the ankle level decreases simultaneously and increases the risk for the sensation of draught.

The vertical temperature gradient decreases when the supply air flow rate increases but, at the same time, the air velocity at the ankle level increases and may cause more draught problems. It looks like in an office room the limiting factor is actually the cooling load. If it exceeds 40 W/m² comfort problems may be anticipated either in respect to too high vertical temperature gradient or too high air velocity and low temperature at the ankle level.

CONCLUSIONS

Displacement ventilation has been an attractive alternative for the mixing flow pattern. It has been applied widely in industrial ventilation where the ceiling height is typically greater than in office buildings and where criteria for thermal comfort are not so stringent.

Based on the experiments with existing devices it looks like thermal comfort is a major limitation for the displacement ventilation system with higher cooling loads. If the load exceeds 40 W/m², either the temperature difference between head and ankle levels may cause discomfort or high velocity and low temperature at the ankle level may cause draught sensation. The careful selection of the supply device is very important.

Turbulence intensity is slightly lower with the displacement ventilation system than with a mixing flow pattern which is advantageous in respect of the draught sensation. However, the difference is small and does not justify any significant adjustments in the criteria for the mean velocity in the occupied zone.

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IMPACT OF CERTAIN INDOOR PARAMETERS ON CHILDREN: A QUESTIONNAIRE STUDY

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This population questionnaire study indicates that direct electric heating, visible home dust, perceived stuffy indoor air, and some room surface linings may have adverse health effects on children. House heating, room surface linings, home dustiness and indoor air stuffiness can affect the health of people by synergism or by antagonism. Dustiness and air stuffiness are subjective but good surrogate variables predicting the healthiness of homes. Results are based solely on the statistical treatment of questionnaire data from 1700 children.

INTRODUCTION

People live indoors most of their time on cold winter days. Children usually stay at home or daycare centers. This way children are not exposed to the work environments adults use to be. The many varying qualities of indoor environments act on the health and well-being of the occupants. It is not easy to identify or quantify which physical factors of indoor spaces have the most powerful effect on health.

Buildings and indoor environments have profoundly changed during the last 30-40 y in all industrialized countries. Today's thermal insulation consists of light weight fibrous materials (mineral wool, glass fibre, wood fiber) installed into walls. To work properly, this insulation is thought to need a tight water vapour barrier, except for wood fiber (Meyer 1983). New houses, be of concrete, brick, or wood are fairly airtight with minimal passive air infiltration. Unfortunately, often the ventilation does not work (Levin 1988).

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The indoor air quality depends upon a number of measurable factors. These include indoor and outdoor sources of dust, volatile smelling, and irritant organic compounds from building materials and furniture, frequency of cleaning, efficiency of ventilation, and humidity conditions (Berglund et al. 1982, 1988; Kuehner 1982; Kulmala et al. 1986). The weighs of each of these factors are different in every home. Probably a great deal of dust comes from decaying textiles, food left-overs, paper products, outdoor sources, and indoor mold growth. Besides the amount, the chemical composition and allergenicity of dust are important factors determining the health effects of house dust exposure. Measurements show that frequent cleaning produces a high concentration of fine particles (<1 μm) for many hours into the air (Kulmala el al. 1986).

According to Gubernskij (1983), the heating delivery system of a house influences the health of people. The old traditional heating delivery form was water-base central heating with low temperature surfaces of the heating elements. Today, approximately 85 % of all new single family houses in Finland are equipped with direct electric heating units on the walls. Of these units, 85 % are such that room air flows through the units. When switched on, the electrical heating wires inside the unit, typically, have a temperature of 250-450°C. If suspended room air particles settle on the hot resistance wires, they will burn.

Emissions from room linings may cause allergic reactions in occupants (Rutkowska 1981). Formaldehyde emitted from particle boards, textiles etc., produces irritation in respiratory ways and skin of sensitive occupants (Berglund et al. 1984). Other surface or furniture materials emit volatile organic compounds which can cause sensitization or irritation in some persons (Engstrom et al. 1988). It is wellknown that vacuuming and other cleaning practices resuspend fine particles. Understanding the kinetics and formation of indoor air aerosols (particles, dust) is useful when trying to explain the health effects from exposure to indoor dusts (Raunemaa et al. 1989; Kulmala et al. 1986).

MATERIALS, METHODS, AND STUDY DESIGN

The study was aimed to estimate (the perception of) potential adverse health effects of outdoor and indoor air pollutants on the populations of one polluted outdoor air city (Oulu, paper mill industry) and one clean outdoor air city (Vaasa). Vaasa is located about 200 km southwest of Oulu, both at the seashore of the Bothnian Gulf. The study was conducted during the coldest winter season, February-March 1985. The mean daily outdoor temperature was -20 to -30°C.

A simple random sample of the entire population of the two Finnish cities, Oulu and Vaasa, was made. Reliance was placed on the population files of the cities which had been updated one year earlier.

A postal questionnaire was sent to 16 500 adults and 4000 children. Every time a child of 1-7 y of age was found in the adult sampling, the child was added to the child sample population. The response rate of the adult questionnaire was 54% (0.2% lower in Vaasa) and the one for children 53%. Only a small proportion (approximately 0.5%) of responses was disregarded due to inadequate filling-out practices. The Post Office returned about 20% of letters non-attained. The study material consisted of 6900 adults and 1700 children so that every child's parent was included in the adult sample.

The self-administered questionnaire contained data of demographic and family features, occupational exposures, health state, experienced symptoms, and frequencies of respiratory infections on a one-year and one-week basis, respectively, and detailed information on the physical features of the house and indoor environment of the home.

Simple tabulation or variance analysis with covariate variables was applied. Output data of the variance analyses included cell means of the explained variables. These cell means were then used for calculation of unadjusted risk ratios (OR, odds ratio).

RESULTS

In children, fatigue symptons, headache, and concentration troubles are not easy to detect nor to define in exact terms. No attempt was made to present a definition of these symptoms to parents because no gain in the form of smaller variability could be expected. Mothers gave generally significantly higher symptom scores than fathers. This difference disappeared in more clear diseases like tonsillitis (throat infections) and middle ear infections.

According to Table 1, 2 and 3 low, weekly prevalence (proportions, %/100, i.e. number of children with symptoms divided by the number of children in the index group) of fatigue (CNS) symptoms was seen in old wood houses, no-dust homes, not-stuffy indoor air, homes with paper wallpapers or wood panel walls (non-reactive walls), or homes with water base heating. High prevalence of CNS symptoms was almost always connected with stuffy indoor air and visible house dust.

Table 4 shows a high prevalence of eye symptoms connected to reactive walls (paint, plastics) with or without dust and air stuffiness, and this connection is independent of the heating system. The absence of dust and air stuffiness alone are enough to produce eye symptoms. This finding is verified by the results in Table 5.

Non-reactive wall materials combined with a clean home, fresh indoor air, and water base heating seem to provide the perception of healthy conditions of the home at least to some extent. Fresh indoor air or cleanliness alone seem to be insufficient to reach the optimum indoor environment (all tables). Table 7 and 8 show the favorable effect of water base heating system on respiratory infections.

Table 6 shows some paradoxical results of the eye symptoms connected with the direct electric heating. Weekly eye symptom prevalences in all DEH-homes versus WBH-homes were almost equal, 0.12 and 0.13 respectively. When DEH is grouped for dust (no visible dust, "0"), dust and stuffiness (no dust; not-stuffy air, "0,0") or dust and wall material (no dust; reactive wall material, "0,1"), the odds rate of the eye stymptom appearance (OR) is significantly different from 1, i.e., 3.4, 5.5, and 7.2, respectively. Reactive wall means paint or plastic wall lining in the child's bedroom. Of the binary (0,1) covariate variables, some had statistically significant non-zero (positive) raw regression coefficients: responder (mother/father) and atopy. Daycare form (center/home) was not significantly different from zero.

Table 1. High one-week prevalences (%/100) of fatigue symptoms in children are found by crosstabulation in the following type of houses and indoor environments. New style wood house = one-story, single-family house, basic construction material wood with plastic vapor barrier. Wood/brick house = like wood house, basic construction materials being wood and brick. Plus-sign means that all the conditions should be satisfied simultaneously.

Home features	Prevalence
Wood&brick house+stuffy air+natural ventilation	(0.77, n= 30)
Wood&brick house+dusts+stuffy air	(0.74, n= 27)
New style wood house+WBH+dusts+stuffy air	(0.71, n= 24)
New style wood house+dusts+stuffy air+reactive walls	(0.65, n= 23)
DEH+dusts+stuffy air+non-reactive walls	(0.64, n= 11)
DEH+dusts+stuffy air	(0.53, n= 17)
WBH+dusts+stuffy air+reactive walls	(0.48, n=180)
Concrete house+dusts+stuffy air+non-reactive walls	(0.48, n= 65)
Dusts+stuffy air+reactive walls	(0.47, n=188)
Stuffy air	(0.42, n=360)

The variables for tables 1-8 are coded in the following way: daycare (0=home, 1=outside home), atopy (0=no atopic like skin symptoms during the last year, 1= appeared atopic skin manifestations), heating (1=direct electric heating (DEH), 0=water base heating (WBH)), dusts (0=home is not experienced dusty by the responding parent, 1=home dusty often or occasionally), stuffiness (0=parents or one of them do not wake up in the night for stuffy bedroom air during the heating season, 1= parents wake up at nights), wall (0=genuine paper wall-paper in the child's room (non-reactive wall), 1=all other wall linings: paints, plastics (reactive wall)).

Table 2. Low prevalences of fatigue symptoms in children was found in houses with the following characterizations (for explanations, see Table 1).

Home features	Prevalence
Old wood house+not stuffy air+non-reactive walls	(0.08, n= 37)
WBH+no dusts+not stuffy air+non-reactive walls	(0.11, n=131)
No dusts+not stuffy air+non-reactive walls	(0.13, n=154)
Old wood house+WBH	(0.17, n= 80)
No dusts	(0.18, n=525)
Wood&brick house+not stuffy air+reactive walls	(0.18, n=136)
Old wood houses	(0.19, n= 99)

Table 3. Means and odds ratios of central nervous system symptoms (fatigue) in children according to variance analysis. Adjusted means of the main effect variables are stratified according to the variable values: 0 or 1 . The grand mean value of symptoms is 0.28. The CEORM is the quotient (1,1)/(0,0) of the effect (disease or symptom frequency) of two explanators both being effective, i.e., (1,1) and the effect of the two explanators both being ineffective (absent), (0,0). In the table, DEH is controlled by stratification for dust as indicated by indention (for explanations, see Table 1).

Main effects	Adjusted means 0	Adjusted means 1	Adjusted OR (95% CI) (95% CI=confidence interval)
DEH	0.28	0.29	1.0
Dusts	0.21	0.32	1.8 (1.4-2.3)
Stuffiness	0.24	0.39	2.0 (1.5-2.6)
Wall	0.24	0.30	1.4 (1.1-1.8)

Stratified analyses with controlled (indention) variables Variables	OR (95% CI)
DEH	
Dusts=0	3.6 (1.7-7.6) (n=64)
Dusts=1	0.7 (0.4-1.3) (n=88)
	CEORM
DEH x Dusts	2.0 (1.6-2.7)
DEH x Stuffiness	1.8 (0.7-4.5)
Dusts x Stuffiness	4.0 (3.3-4.8)

Table 4. High weekly prevalence of eye symptoms can be expected in children in homes with the following features (for explanations, see Table 1).

Home features	Prevalence
DEH+no dusts+not stuffy air+reactive walls	(0.35, n= 34)
DEH+stuffy air+reactive walls	(0.31, n= 39)
Dusts+stuffy air+reactive walls	(0.24, n=188)
WBH+stuffy air+reactive walls	(0.23, n=228)
DEH+no dusts+not stuffy air	(0.23, n= 57)
Dusts+stuffy air	(0.22, n=283)
Stuffy air+reactive walls	(0.22, n=241)

Table 5. Low weekly prevalence of eye symptoms in children can be expected in homes with the following features (for explanations, see Table 1).

Home features	Prevalence
WBH+no dusts+not stuffy air	(0.05, n=391)
WBH+no dusts	(0.07, n=461)
No dusts+non-reactive walls	(0.07, n=178)
No dusts	(0.08, n=525)
No dusts+not stuffy air	(0.08, n=448)

Table 6. One-week eye symptoms of children according to variance analysis (for explanations, see Table 3 and 1).

Main effects	Adjusted means 0	Adjusted means 1	Adjusted OR (95% CI)
DEH	0.13	0.12	1.0
Dusts	0.08	0.15	2.0 (1.4-2.8)
Stuffiness	0.10	0.20	2.3 (1.6-3.2)
Wall	0.11	0.14	1.4 (0.9-1.8)

Stratified analyses with controlled variables (indention)

Variables	OR (95% CI)
DEH	
Dusts = 0	3.4 (1.7-7.0)
Dusts = 1	0.3 (0.1-0.8)
DEH	
Dusts=0 and stuff.=0	5.5 (2.5-12)
DEH	
Dusts=0 and wall=1	7.2 (3.5-15)
	CEORM
Dusts x Stuffiness	3.2 (2.1-2.6)
Stuffiness x Wall	2.9 (1.9-4.3)
Dusts x Wall	2.6 (1.4-4.9)

Table 7. Low cumulative incidence (12 months, mean values) of maxillary sinus, middle ear or throat infections is expected in homes with the following features (for explanations, see Table 1).

Home features	Prevalence
WBH+no dusts+non-reactive wall	(0.63, n=155)
WBH+no dusts+not stuffy air	(0.64, n=386)
WBH+no dusts	(0.65, n=451)

Table 8. High cumulative incidence (12 months, mean values) of maxillary sinus, middle ear or throat infections is expected in homes with the following features (for explanations, see Table 1).

Home features	Prevalence
DEH+dusts+reactive walls	(1.36, n= 47)
DEH+dusts+not stuffy air	(1.29, n= 66)

Dust and air stuffiness alone increase eye symptom prevalence significantly. Combined effects (CEORM) of dust and stuffiness, stuffiness and wall, and dust and wall seem to be synergistic. One week's prevalence differences and numeric risk indicators became flattened when comparing the respective one year's figures.

DISCUSSION

Although the response rate was low and may have caused bias, it hardly changes the results qualitatively. Age of parents, their smoking habits, presence of pets in household, and social class (education) did not explain significantly the symptoms nor were they confounders for the associations. Instead, age of children (e.g., cut-off 3 y), type of daycare, and gender of the responding parent explained significantly the symptoms but were not confounders in comparing heating systems, dustiness, air stuffiness or wall lining materials.

We can suppose that sources of home dust are similar and evenly distributed in homes with direct electric heating and water-base heating. Probably the number and age of children in families are the main factors determining the frequency of cleaning and sources and accumulation of dust.

This way, too frequent cleaning could explain the paradoxical results that direct electric heating produces eye symptoms when home is clean and air is fresh. Visible dust and stuffy air alone produced ill health. Plastic wallpapers and latex paints accumulate static electricity and thus collect charged dust particles.

Dustiness and stuffiness are, of course, highly subjective at individual level but are valid group measures because the intersubjective perception variability eventually disappears in groups. These perception variables bear a similarity with olfactorial evaluations of the environment (Fanger 1988).

A curious finding was that ear and throat infections were related to direct electric heating and appearance of dust, but eye and CNS symptoms favor DEH with no dusts. Dust alone was related to excess of throat and middle ear infections. Experimental test conditions are needed to search out the complicated interactions among various indoor factors affecting health. Statistical studies may help in modeling the perception of health effects of many simultaneous indoor variables.

This study concerns the heating systems common in Finland, Scandinavia, and parts of Canada. The proportion of hot surface temperature to direct electric heating is increasing in Finland, anyhow. In the U.S., a forced-air heating system is very common. Even this system may contain hot surfaces in heat transfer.

The basic point of this study was to indicate that hot surfaces of heating systems in contact with room air (fine particles) can impose a health risk on occupants. Experimental research is needed to determine the acceptable higher surface temperature limits of heating systems, probably in the range of 60-80°C. The excess of health risk connected to heating systems is expected to depend on the concentration and chemical and physical characteristics of the air-fine particles, humidity content of the air, and many other simultaneous exposures in homes.

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THE EFFECT OF VENTILATION ON EMISSION RATES OF WOOD FINISHING MATERIALS

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The rate of emission of organic compounds from building materials varies according to: type of material, material loading (area of material/volume of room), compound emitted, temperature, humidity, and ventilation rate. For some compounds and materials (e.g., formaldehyde from particleboard), the relationship between emission rate and these variables is well established. For most materials and compounds, however, such relationships are unavailable. Research, using small test chambers, is being conducted by the U.S. Environmental Protection Agency (EPA) to develop data on emission rates from a variety of building materials. This paper presents selected results from the EPA studies. Emphasis is placed on the effect of ventilation (air changes/h) and material loading on the emission rate for selected organics and total measured organics. Test data for three wood finishing materials (i.e., stain, polyurethane, and wax) are presented. The data are analyzed to show the effect of ventilation on the emission characteristics of each material.

INTRODUCTION

The rate of emission of organic compounds from building materials varies according to: type and age of material, material loading (area of material/volume of room), compound emitted, temperature, humidity, and ventilation rate (Tichenor and Mason 1988). Numerous studies have been conducted on emissions of formaldehyde from pressed wood products, and relationships between the emission rate and the controlling variables have been established (Matthews 1986; Matthews et al. 1987; Nelms et al. 1986). Studies have also been conducted on emissions of a variety of organic compounds from various building materials and consumer products (Girman et al. 1984; Knoppel and Schauenburg 1987; Mølhave 1982; Tichenor and Mason 1988). Such studies are generally conducted under constant environmental conditions, and while they provide emission rate data (e.g., $mg/m^2 \cdot h$), they do not generally examine the effect of the controlling variables on the emission rate.

When emissions from materials are evaporative, the effect of ventilation (air exchange rate) is well understood. As the air exchange rate increases, the indoor concentration decreases due to dilution and flushing. This reduced concentration increases the difference in vapor pressure between the emission source and the indoor environment. Since the vapor pressure difference is the driving force for evaporation, the emission rate increases. Thus, higher air exchange rates cause higher emission rates. Material loading has the opposite effect; as the loading is increased, the concentration increases and the vapor pressure difference decreases. This decreases the emission rate. Thus, for evaporative emissions, the emission rate is generally proportional to the ratio of the air exchange rate (N) and material loading (L). This relationship has been shown for formaldehyde emissions from particleboard (Matthews 1986; Matthews et al. 1987; Nelms et al. 1986).

In some cases, where the emission rate is not purely evaporative, diffusion of the emitting compound within the source may be important. If the diffusion of the compound to the surface of the source is slower than the evaporation rate, then the rate of emission will be reduced. If the diffusion rate is very slow, changing the air exchange rate will have minimal effect on the emission rate. One study suggests that non-formaldehyde emissions from particleboard are diffusion limited (Nelms et al. 1986).

Finally, the effect of sinks in the indoor environment can affect the emission rate. As compounds are emitted, they may adsorb to other materials. Such adsorption causes a decrease in concentration analogous to an increase in air exchange rate. The effect on emission rate is similar; that is, a sink effect can cause an increase in the emission rate. Reemissions from the sinks can also occur (Tichenor et al. 1990a).

The United States Environmental Protection Agency is conducting research on the processes affecting the rate of emission of organic compounds from building materials and consumer products (Tichenor 1987). Studies are being conducted on dry, constant emission (or slowly decaying) sources (e.g., particleboard, moth crystal cakes) and on wet, decreasing emission sources (e.g., caulks, adhesives, paints, waxes). Previous papers have discussed the results of this research (Nelms et al. 1986; Tichenor 1987; Tichenor and Mason 1988), including the development of a source emissions model which accounts for effects of vapor pressure and sinks on emission rates for the chamber experiments (Dunn and Tichenor 1988). This paper presents results of experiments to determine the effect of air exchange rate and material loading on emissions of organic compounds from three materials: wood stain, polyurethane wood finish, and liquid wood floor wax. The materials tested are commonly available and were purchased at a local retail store.

EXPERIMENTAL PROCEDURES

Laboratory facility

EPA's Indoor Air Source Characterization Laboratory consists of a clean air-conditioning and delivery system, an incubator containing two 166-L environmental test chambers, sampling manifolds, and sample collection adsorbers using Tenax and charcoal. A fan in each chamber ensures complete mixing. A permeation system for quality control is included. The environmental variables are monitored and controlled by a microcomputer. Organic analyses are conducted by thermal desorption, concentration via purge and trap, and gas chromatography (GC) using flame ionization detectors (FID). A separate microcomputer provides GC data analysis. All data are input to spreadsheets for further analysis.

Headspace analysis

Prior to evaluation in the environmental test chambers, materials are evaluated by headspace analysis. A sample of material is placed in a 1 L Teflon-lined container that is purged with nitrogen at 50 mL/min for 30 min. The exit flow is collected on Tenax and analyzed after thermal desorption. Gas chromatography/mass spectroscopy (GC/MS) analysis identifies the compounds contained in the material's emissions. Approximately ten of the compounds of highest concentration are selected for measurement in subsequent chamber tests. Table 1 shows the compounds selected for the stain, polyurethane, and wax, based on GC/MS analysis.

Chamber testing

Experimental designs were established for each material tested to evaluate the effect of various parameters: temperature, air exchange rate (N), and chamber loading (L). For the materials discussed herein, all testing was conducted at 50% relative humidity. The stain and polyurethane were tested at 23°C; the wax at 20°C. Table 2 provides the test matrices showing N, sample area (A), and L for the three materials. The number of test replicates is also shown.

Prior to each test, the chambers were purged with clean air for several hours before placing samples in the chambers. The sample substrates varied according to the material being tested. The wood stain was applied to hardwood (poplar) boards that had their edges sealed with sodium silicate to prevent adsorption to and reemissions from (i.e., sink effects) the bare wood. The sodium silicate was applied and allowed to dry well before the application of the stain.

Table 1. Compounds identified by headspace analysis.

Material	Compounds
Wood stain	2-butanone, benzene, hexane (isomer), trimethylhexane (two isomers), nonane, decane (two isomers), cyclodecane (isomer), trimethylbenzene, n-decane, undecane
Polyurethane	ethylbenzene, nonane, trimethylbenzene, n-decane, undecane, hexanal*
Wood floor wax	trimethylcyclohexane, methyloctane, methylethylcyclohexane (two isomers), nonane, dimethyloctane, p-ethyltoluene, trimethylbenzene, n-decane, undecane

*Hexanal was not identified in the original headspace analysis; it was discovered several hours after chamber testing began and was identified by subsequent GC/MS analysis after collection on XAD.

The polyurethane was applied to the stained boards. The floor wax was spread on aluminum plates. [Note that the floor wax was tested prior to the other two materials. The aluminum plate substrate was selected to make the testing consistent with other materials (i.e., caulk, flooring adhesive) tested in the chambers.] The samples were placed in the chamber within 10 min of applying the material to the substrate. The test start (time = 0) was established when the door to the chamber was closed. The first sample was collected within 30 min of the start. The samples were collected on Tenax/charcoal and analyzed by GC/FID. Throughout the test, an internal standard (usually hexane) was added from the permeation ovens for quality control. The organic species quantified depended on the results of the headspace analysis; total measured organics (as hexane) were also determined and recorded. The duration of each test depended on the type of material being tested; generally, tests were concluded when the same chamber concentration was observed for several measurements or when the analytical detection limits were reached.

Table 2. Chamber test conditions.

Material	N (h^{-1})	A (cm^2)	L (m^2/m^3)	N/L	No. of Reps.
Wood stain	0.35	2158	1.3	0.27	2
	0.35	166	0.1	3.50	1
	2.5	1162	0.7	3.57	2
	4.6	2158	1.3	3.54	2
Polyurethane	0.5	347	0.21	2.38	2
	1.0	694	0.42	2.38	2
	1.0	347	0.21	4.76	2
	2.0	347	0.21	9.52	2
Wood floor wax	0.25	200	0.12	2.1	1
	0.5	200	0.12	4.2	2
	0.5	100	0.06	8.3	1
	1.0	200	0.12	8.3	1
	2.0	400	0.24	8.3	1
	2.0	200	0.12	16.7	1

Chamber data

The results of the chamber testing are illustrated in Fig. 1, where the concentration of total organics and four individual compounds is presented for the wood stain tested at an air exchange rate (N) of 0.35 h^{-1} and a sample area (A) equal to 166 cm^2. Data are presented for the first day of a 7-d test. The concentration of total organics at the end of the test was less than 1 mg/m^3. The figure shows the concentration increasing rapidly for the first 1 or 2 h and then declining as the emission rate drops and the material is diluted and flushed from the chamber. This behavior is typical of wet, solvent-containing materials.

DATA ANALYSIS

Models have been developed to analyze the results of the chamber tests in order to provide emission rates (Equation 1). The simplest model (i.e., neglecting sink and vapor pressure effects) assumes: 1) the chambers are ideal continuous stirred tank reactors (CSTR), and 2) the change in emission rate can be approximated by a first order decay, as shown in Equation 1.

$$R = R_o e^{-kt} \tag{1}$$

where
- R = Emission rate, $mg/m^2 \cdot h$
- R_o = Initial emission rate, $mg/m^2 \cdot h$
- k = First order rate constant, h^{-1}
- t = Time, h
- e = Natural log base.

The mass balance for the chamber over a small time increment dt is:

Change in mass = mass emitted—mass leaving chamber

This can be expressed as:

$$VdC = AR_o e^{-kt} dt - QCdt \tag{2}$$

where
- V = Chamber volume, m^3
- C = Chamber concentration, mg/m^3
- A = Area of source, m^2
- Q = Flow through chamber, m^3/h.

Equation 2 can be rearranged:

$$dC/dt + (Q/V)C = (A/V)R_o e^{-kt}. \tag{3}$$

Equation 3 is a linear, non-homogeneous differential equation. Given that C = 0 when t = 0, the solution to Equation 3 is:

$$C = AR_o (e^{-kt} - e^{-Nt}) / V (N - k) \tag{4}$$

where
N = Air exchange rate, h^{-1}, and is equal to Q/V.

Using a non-linear regression curve fit routine, implemented on a microcomputer, values of R_o and k can be obtained by fitting the concentration vs. time data from the chambers to Equation 4. In order to conduct such analyses, initial estimates of R_o and k are required. A good initial estimate of k is:

$$k = Ne^{(k-N)\, t_{max}} \tag{5}$$

where
t_{max} is the time of the maximum concentration(C_{max}).

Equation 5 is obtained by substituting C (Equation 4) into Equation 3 and setting $dC/dt = 0$ at $t = t_{max}$. Once an estimate of k is achieved from Equation 5, R_o can be estimated from Equation 4. Fig. 2 illustrates the curve fitting process for a wood stain chamber test; the solid line is the "best fit" of Equation 4, and the data points are shown as diamonds. (Fig. 2 shows only the first 10 h of data, but the fit was made over the total test period.)

All of the test runs were analyzed using this procedure, and the results (R_o and k) for total organics are presented in Table 3. The table also contains values for R_o/k, which represents the total available emissions (or source strength) per unit area for the material being tested. Total emissions are estimated by integrating Equation 1 from time zero to infinity. Each row in Table 3 corresponds to the test conditions for the same row in Table 2.

DISCUSSION

The values of R_o and k allow comparisons of the emissions characteristics of the materials between test conditions. The N/L ratio is used to investigate the effect of ventilation on the emission characteristics. For a given L, any change in N/L is directly proportional to the air exchange rate (N). The wood stain results show a clear effect of N/L, where the three tests with similar N/L values (i.e., 3.50, 3.57, and 3.54) have consistent R_o and k values. The test with the low N/L has much lower values for R_o and k. This indicates that, for the low N/L test, vapor pressure suppression is

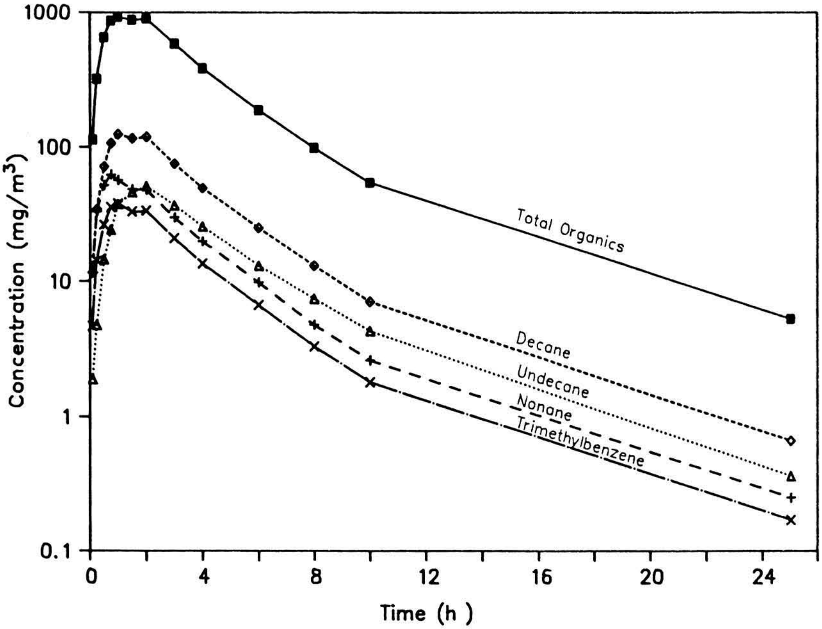

Fig. 1. Chamber data—wood stain.

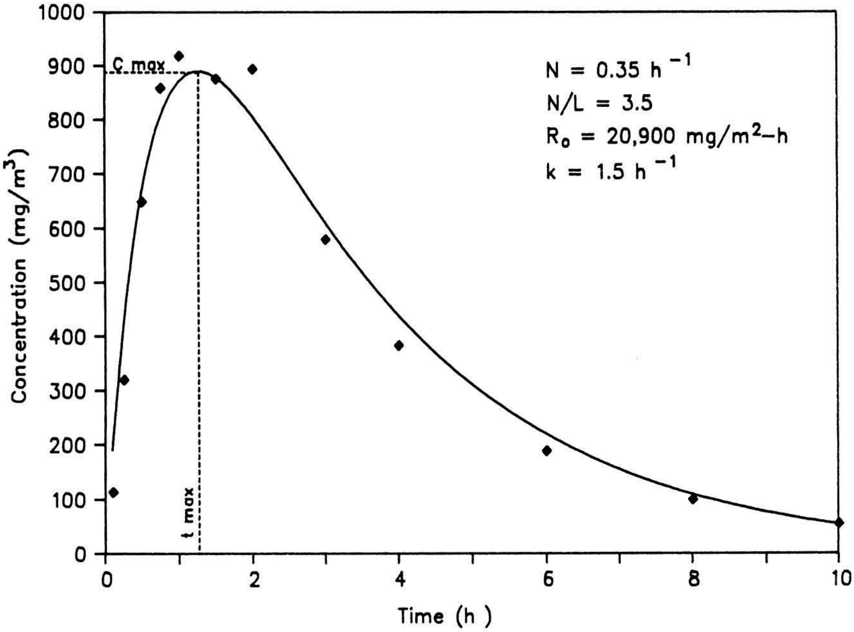

Fig. 2. Wood stain—total organics.

Table 3. Results of data analyses.

Material	N/L	R_o (mg/m^2-h)	k (h^{-1})	R_o/k (mg/m^2)
Wood stain	0.27	2200	0.24	9200
	3.50	20900	1.51	13800
	3.57	17400	1.24	14000
	3.54	27000	2.41	11200
Polyurethane	2.38	1680	0.25	6720
	2.38	2610	0.29	9000
	4.76	6500	0.61	10660
	9.52	5780	0.64	9480
Wood floor wax	2.1	38000	6.3	6030
	4.2	23000	5.3	4340
	8.3	19000	5.4	3520
	8.3	28000	10.2	2750
	8.3	32000	8.1	3950
	16.7	23000	6.3	3650

Table 4. Source strengths and mass applied.

Material	Source Strength (mg/m^2)	Mass Applied (mg/m^2)
Wood stain	11,800	24,000
Polyurethane	9,000	70,000
Wood floor wax	4,100	5,000

occurring which causes a reduction in the initial emission rate and a much slower decay. Note that the R_o/k values are consistent for all four tests, indicating that the total emissions (mg/m^2) were similar. The data for polyurethane also show vapor pressure suppression, since the R_o and k values for the tests conducted at N/L = 2.38 are lower than for the other two test conditions. Note that there is little difference between the R_o and k values for the tests with N/L = 4.76 and 9.52. This may indicate that, at higher N/L values, diffusion limitations may be occurring. The results of the wood floor wax testing show little relationship between the N/L values and the R_o and k values. Under all test conditions, the emission rate was extremely fast. The average $k = 6.7\ h^{-1}$, which indicates that 95% of the emissions occurred within the first 30 min. Thus, in a practical sense, the emissions from the wood floor wax can be considered to occur in a single burst with essentially no emissions occurring after the first few minutes of application.

The results can also be used to compare the emission characteristics of the three materials. In terms of emission rates, the wood floor wax has the highest initial rate (R_o) and the fastest decay (k); the wood stain also has a high initial emission rate, but a much slower decay; the polyurethane finish has the lowest initial emission rate and the slowest decay.

The source strengths (or total available emissions) from the materials can be compared, using the R_o/k ratio. Table 4 shows the source strengths, based on the average R_o/k ratio for all tests, for each of the three materials. The table also provides the total mass of material applied to the substrate used in the test chambers. These data show that wood stain has the highest source strength, polyurethane is second, and wood floor wax is lowest. Note that these source strengths do not correspond to the amount of material actually applied.

CONCLUSIONS

Small test chambers are used to evaluate the emission rate characteristics of building materials, including wood surface treatments. Models are used to fit the chamber data and determine initial emission rates (R_0), emission rate decay (k), and source strength (R_0/k). The effect of air exchange rate (N), as represented by N/L, on R_0 and k is shown for three materials. Based on this analysis, increased air ex-change rates would increase the emission rates for the wood stain and polyurethane; the floor wax emission rate does not appear to be affected by the air exchange rate. The source strength of each material is also presented, with wood stain being the strongest source, followed by polyurethane and floor wax.

This paper discusses source emissions models and how they can be used to evaluate the effect of environmental variables on emission rates. The reader is encouraged to consult other papers for discussions on how source emissions models are used to evaluate the effect of sources on indoor air quality (Tichenor et al. 1990b) and for the selection of indoor materials and products (Tucker 1990).

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BIOCLIMATIC ANALYSIS OF TRADITIONAL TURKISH HOUSES

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Olgyay proposed the Bioclimatic Chart as an index of thermal comfort in 1963. It indicates the effects of air temperature, humidity, radiation and wind velocity on thermal comfort, separately, for people wearing normal bussiness clothes and at sedentary activity. This form of the index makes it suitable to identify the climate of a region. Arens, Zeren, Gonzalez, Berglund and McNalls proposed in 1981 the revised form of the chart and called it the New Bioclimatic Chart. By using the New Bioclimatic Chart, the author analysed the climate of Turkey and found seven different climatic regions. The climate and the Turkish traditional houses in each of these regions were described. Some building parameters, related to the climate, were analysed statistically. The Turkish traditional houses in these climatic regions show a clear distinction in settlement pattern, building form, plan, space organization, building elements and materials. The intelligent solutions employed by the masters of traditional houses have many clues for the modern buildings of today.

INTRODUCTION

Traditional buildings all over the world have many qualities which can provide hints for the design of modern buildings. They had been repeated many times with similar building materials in each region. In the absence of modern techniques, the builders of these houses specialized in controlling the indoor climate by the use of suitable settlement pattern, building form, space organization, building elements, and materials.

Rapoport had studied the traditional house form in the world, in relation to socio-cultural factors, climate, construction and materials (Rapoport 1969). Turkish traditional houses have the traces of many civilizations originating in Anatolia and the skills of numerous builders. They had been studied from the point of view of historical development by Kuban (1965) and by Arel (1982), spatial organization by Aksoy (1963) and by Küçükerman (1985), plan typology by Eldem (1968), materials and construction by Eriç (1979). The aim of this study is to classify the climate of Turkey according to the bioclimatic analysis and to show the differences and similarities of the traditional houses in these climatic regions.

There are a number of thermal comfort indices in literature. The New Bioclimatic Chart, as a thermal comfort index, is suitable to define the climate of a region for architectural purposes. It is a graphical index and indicates the effects of air temperature, humidity, air velocity, solar radiation separately on thermal comfort of an average person at sedentary activity and in normal bussiness clothes (Arens et al. 1981). The comfort zone on the chart indicates the conditions at which average people feel thermally comfortable. The environmental conditions at which people require moisture, wind, solar radiation, cooling and heating for thermal comfort can be seen on the chart. The left and right side zones above the comfort zone of the chart are the moisture and wind needed conditions, respectively. The zone below the comfort zone indicates the solar radiation and heating needed conditions. The New Bioclimatic Chart is the revised form of the original Bioclimatic Chart of Ölgyay and it was derived by the use of recent research on thermal comfort (Ölgyay 1963).

THE METHODS AND THE STUDY

The monthly values of the Mean Highest Air Temperature versus 14 h Mean Relative Humidity, and the Mean Lowest Air Temperature versus 7 h Mean Relative Humidity were plotted on the New Bioclimatic Chart for each town of Turkey by the author. The Mean Highest Air Temperature is the mean of the maximum daily temperatures in each of the 12 months and averaged over the observation period. Likewise, the Mean Lowest Air Temperature is the mean of the minimum daily temperatures in each of the 12 months and averaged over the observation period. The 07.00 and 14.00 h Mean Relative Humidities are the means of the measurements at the stated hours everyday in each month. The air temperatures in °C and the relative humidities as percentages are being measured by the Turkish Meteorological Organization according to the World Meteorological Organisation standards (DMIGM 1985). The meteorological data of 80 stations were used in this study. The observation periods of these stations ranges from 25-55 y.

The meteorological data-plotted New Bioclimatic Charts were then compared with each other and grouped according to the distribution of the plots around the comfort zone. It was possible to divide the charts into seven groups and they were named: 1) cool, 2) temperate—dry, 3) temperate, 4) temperate-humid, 5) hot—humid, 6) hot—dry, 7) composite climates. The map in Fig. 1 shows the climatic regions of Turkey and Fig. 2 gives the meteorological data-plotted New Bioclimatic Charts of typical towns from each region.

The traditional houses in these climatic regions were surveyed at site. The plans, sections, and elevations were drawn by the students of Karadeniz Technical University, Department of Architecture under the supervision of the author. The published architectural drawings of other authors were also used in the evaluation. The climatic elements which are not di-

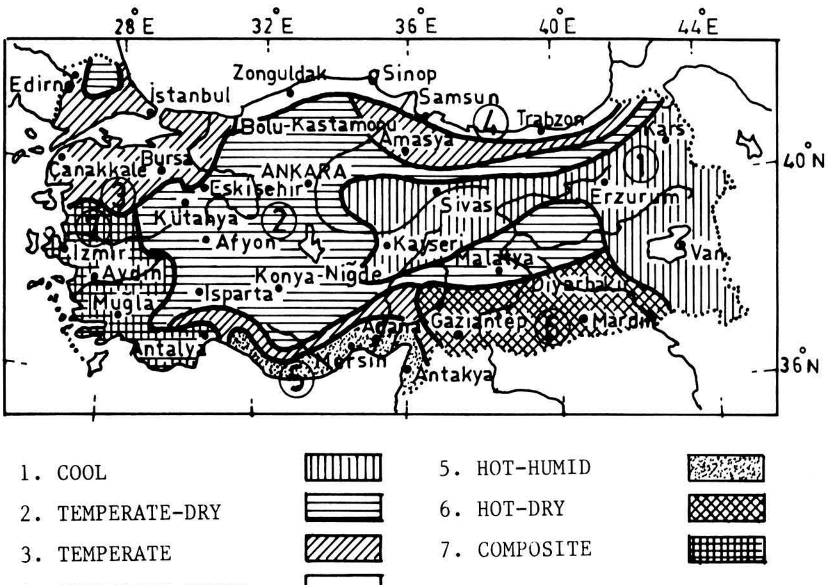


Fig. 1. The climatic map of Turkey according to the New Bioclimatic Analysis.

rectly related to thermal comfort like rain, snow, sky conditions etc. were studied (Özdeniz 1984). The climate and the Turkish traditional houses in these climatic regions are described below. The plans and the elevations of one sample house from each region are given. This house is similar in appearance, construction and material to the most often repeated traditional houses of the region.

1. The cool climate

The summer period is short with low relative humidity. The precipitation is also low, except for the snow in winter. The compact or row-settlement patterns have been adopted for the traditional dwellings, in order to reduce the heat loss due to wind. The houses generally have two floors. The ground floor is used in winter. The external walls of this floor are made of stone which are 0.90 to 1.5 m thick. The windows are very small and few. The "tandırevi" which serves both as the kitchen and the living room is in the central or the sheltered part of the ground floor. Thus, the heat produced keeps most of the house warm. It has a small ceiling window. The first floor is used in summer and the window area is larger than that of the ground floor. All the corridors and also the halls are divided by doors and partitions, in order to reduce the heat loss (Fig. 3).

2. The temperate-dry climate

This type of climate is observed at locations near the cool region. The relative humidity is low in summer. A traditional building form has evolved which has a courtyard type plan with different spaces for summer and winter use. The use of separate rooms for different seasons reduces the heating expenses. The courtyard provides coolness and humidity in hot dry summer days.

The walls are either made of stone or adobe brick and are 0.65 to 0.90 m thick. They provide good thermal insulation. Both, the flat earth-covered and the gabled tile-covered roofs are used in the traditional houses of this climate (Figs. 4a, b).

3. The temperate climate

In summer, medium temperature and humidity is observed. It is not very cold in winter. In this climatic region, it is possible to build the dwellings in any form. However, wooden constructions with low heat storage capacity and gabled roofs are widely used in the traditional houses of the region.

4. The temperate-humid climate

This is a temperate climate with plenty of rain and high relative humidity throughout the year.The detached settlement pattern has been adopted in order to provide good ventilation of the houses.

The windows are abundant and cross ventilation is provided. The plans of the houses have recesses and extrusions in order to diffuse summer heat to the exterior easily. The walls of the ground floor are made of stone because of ground moisture. On the upper floors wood is used extensively to avoid summer heat storage. Most of the houses have all-stone walls on façades housing the chimney or on the northwest façade which is exposed to driving rain. Buildings with all-stone exterior walls were also built in town centers. However, these walls are very thin (0.30-0.40 m) in relation to the stone houses of other regions (Figs. 5a, b).

5. The hot-humid climate

The hot-humid region of Turkey has a temperate-humid climate with a hot-humid summer period. It is called hot-humid to differentiate it from the other. The winter months are rainy. Although there is no snow in winter, the air temperature is lower than the thermal comfort limits.

The traditional houses of the hot-humid region of Turkey are usually detached. They are elevated on piers and walls in order to catch the cool breezes. Since the hot-humid period does not continue throughout the year, the spaces for summer and winter use are separate. The constructions and the materials of these spaces are different. The winter rooms were made of stone walls and covered with flat, earth-covered roofs. The summer rooms are made of plastered, double-layer wooden walls with ventilated cavities and sheltered with tile-covered gabled roofs (Fig. 6).

6. The hot-dry climate

The hot-dry region of Turkey has a temperate climate with hot-dry summer periods. The Mean Highest Air Temperature reaches 40°C in summer. There is a wide diurnal air temperature range.

The Turkish traditional houses of the hot-dry region have a form which resists the heat gain in summer. The buildings cast shadows on each other. The courtyard plan type is widely used. It keeps the coolness and humidity of the night and gives refreshment throughout the summer days.

In this region, the courtyard is always planned on the northern side of the main building. The traditional houses generally have only the ground floor and the basement. However, if a large courtyard is wanted,

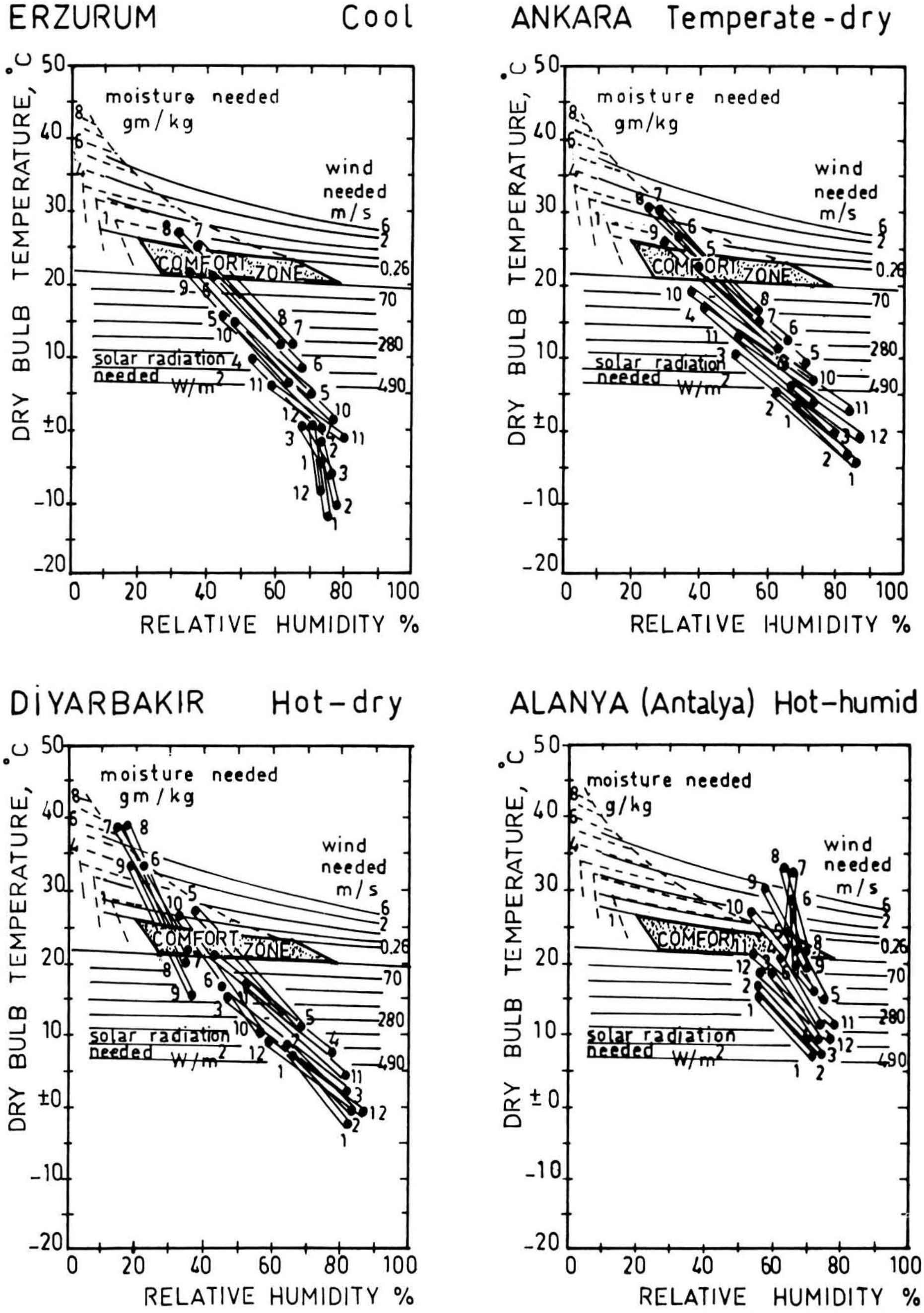
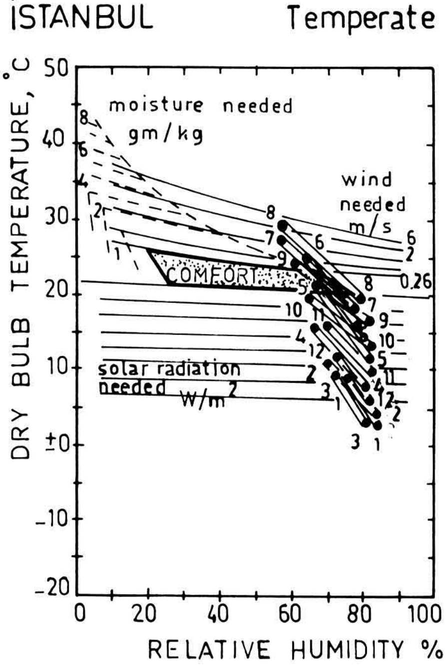
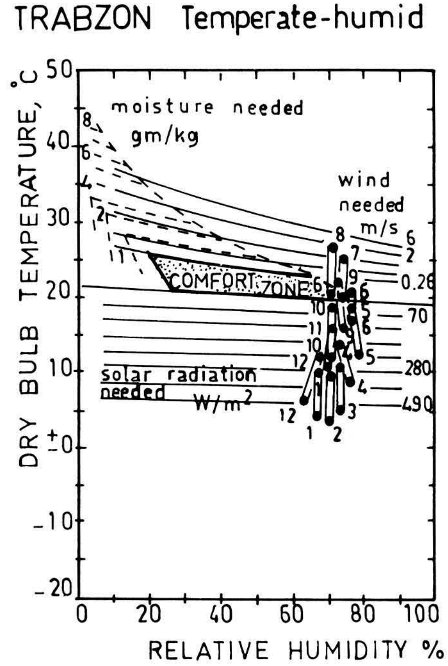


Fig. 2. The meteorological data-plotted New Bioclimatic Charts of the typical towns from each region.





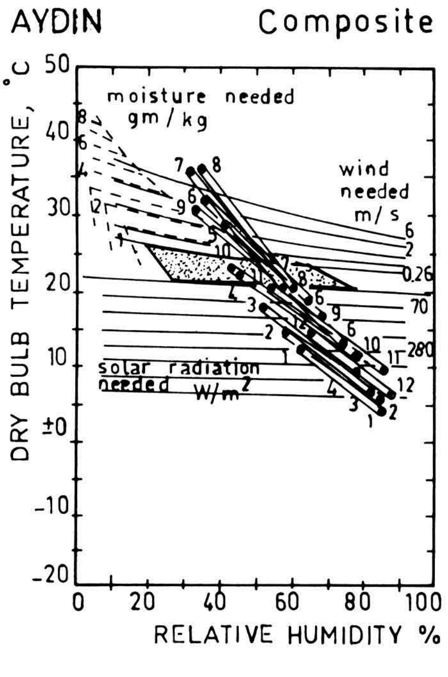


Fig. 2. Continued.

the first floor is also built, in order not to reduce the shade and the cool comfort of the courtyard. All the spaces of the house are located around the courtyard. The summer rooms are larger and have higher ceilings than the winter rooms. In placing the rooms around the courtyard, the movement of the sun is observed. The solar rays are allowed to enter the winter rooms but not the summer rooms.

A space locally called "eyvan" is widely used. It is a hall open to one side and covered with a vault. The open side faces the courtyard. The summer rooms may have windows opening to the eyvan.

The water flowing over the pool at the courtyard runs through the joints of the stone ground plates. The evaporation of this water provides refreshment in the dry climate. There are also artificial waterfalls at the eyvans and the basement rooms used for living in summer.

The stone walls with a thickness of 0.50-0.60 m and the flat earth- covered roofs with a thickness of 0.30-0.50 m provide good thermal insulation and suitable thermal lag. Since the lowest night time air temperature in summer may be well above the thermal comfort limits, outdoor sleeping places are also provided (Fig. 7).

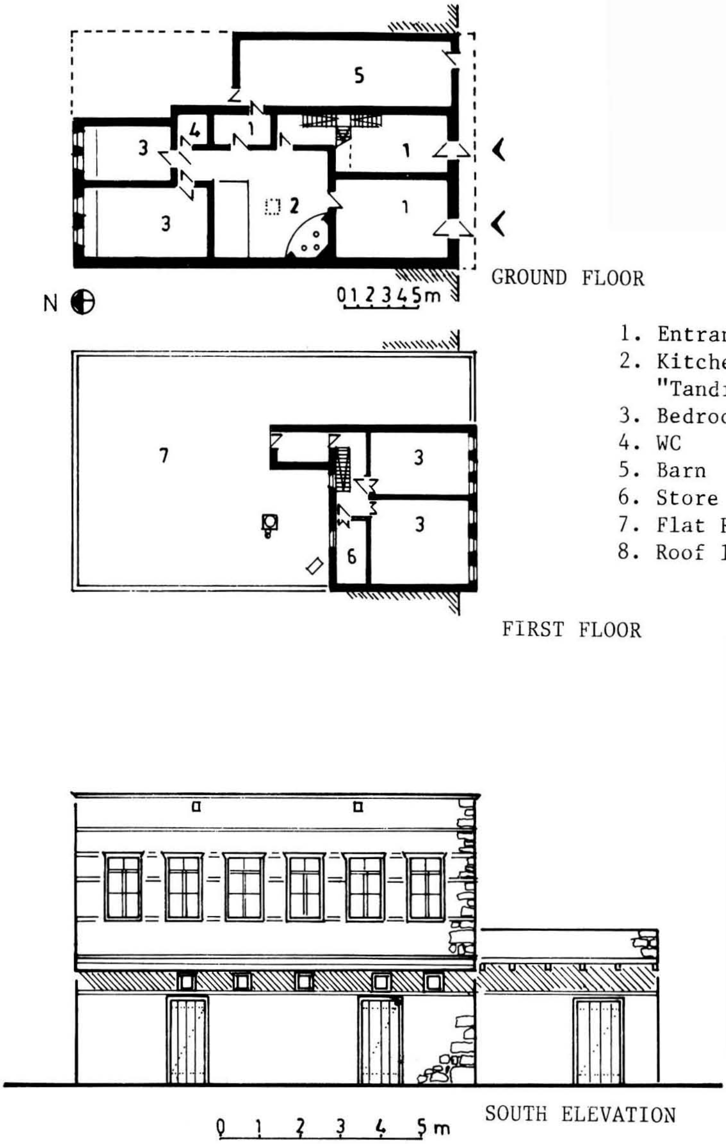


Fig. 3. A traditional house from Erzurum. The cool climate.

7. The composite climate

The summer months are hot-dry and the winter months are temperate with lots of rain. The traditional houses of the composite climate have a form which unite the requirements of two different climates. The buildings have compact forms, thick walls with long thermal lag, and small windows to reduce summer heat gain. The walls are whitewashed to reflect the sunshine. The buildings cast shadows on each other. Both the flat and the gabled roofs were used in the region, depending on the severity of rain (Fig.8a, b).

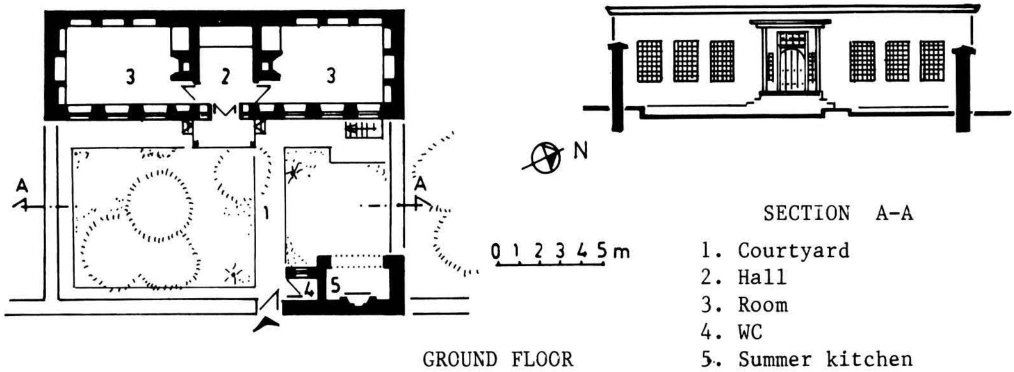


Fig. 4a. A traditional house from Konya. The temperate/dry climate (Berk 1952).

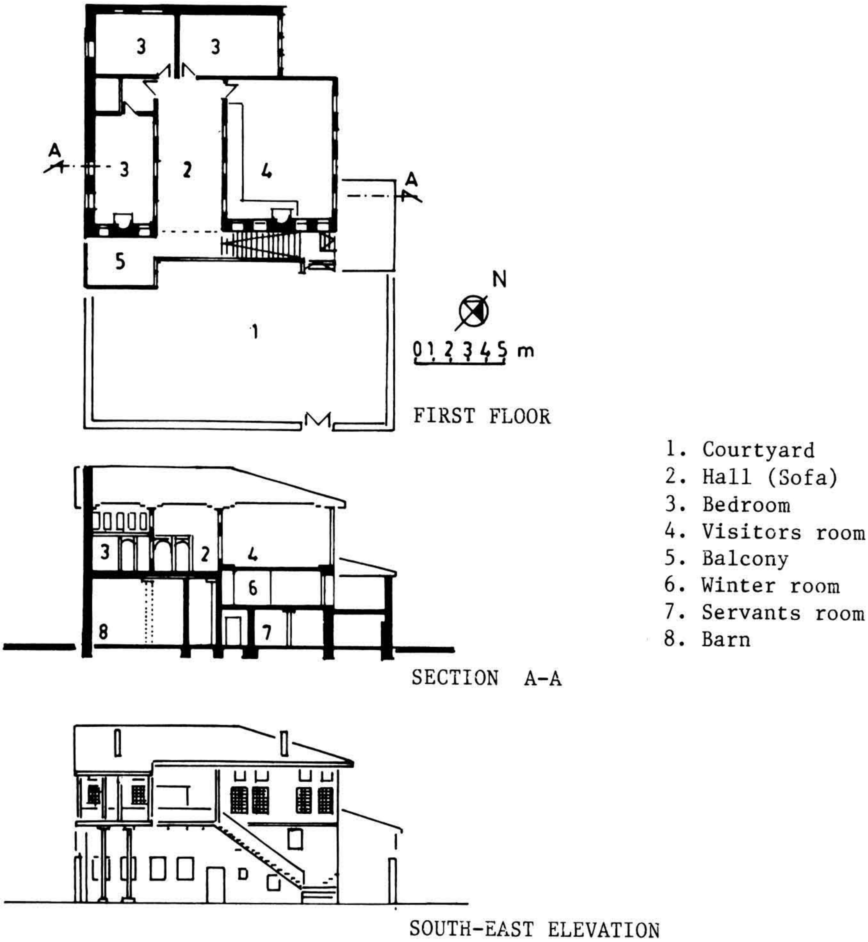
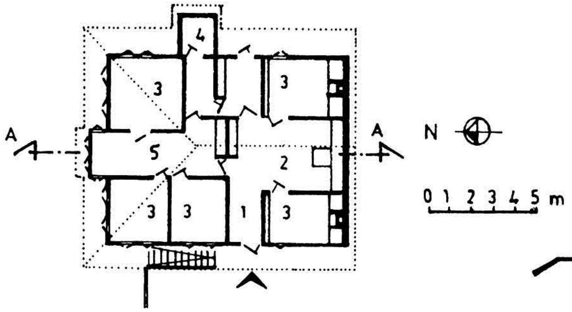
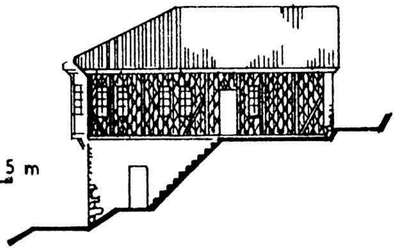


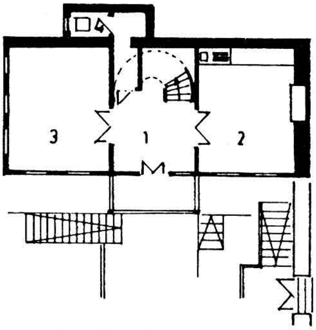
Fig. 4b. A traditional house from Ankara. The temperate/dry climate (Kömürcüoğlu 1950).

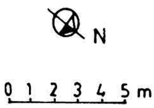


GROUND FLOOR



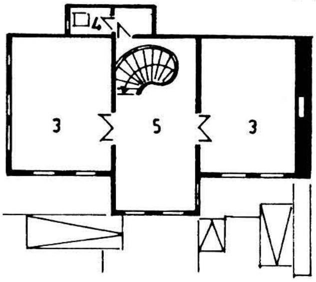
WEST ELEVATION





GROUND FLOOR

1. Entrance
2. Kitchen
3. Room
4. WC
5. Hall
6. Barn



FIRST FLOOR

NORTH-EAST ELEVATION

SOUTH-EAST ELEVATION

Fig. 5. Two traditional houses from Trabzon. The temperate/humid climate.

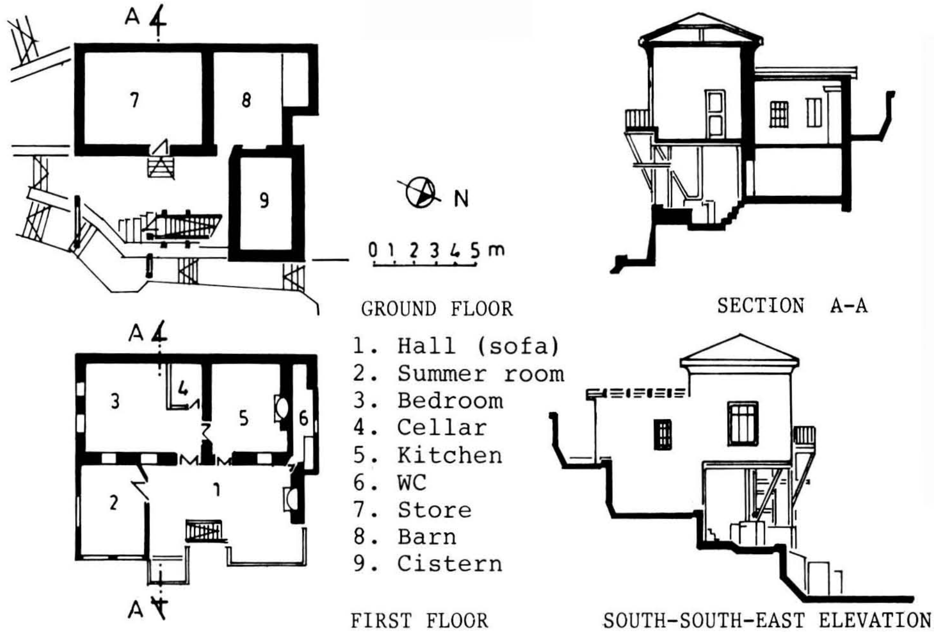


Fig. 6. A traditional house from Alanya. The hot/humid climate (Şener 1984).

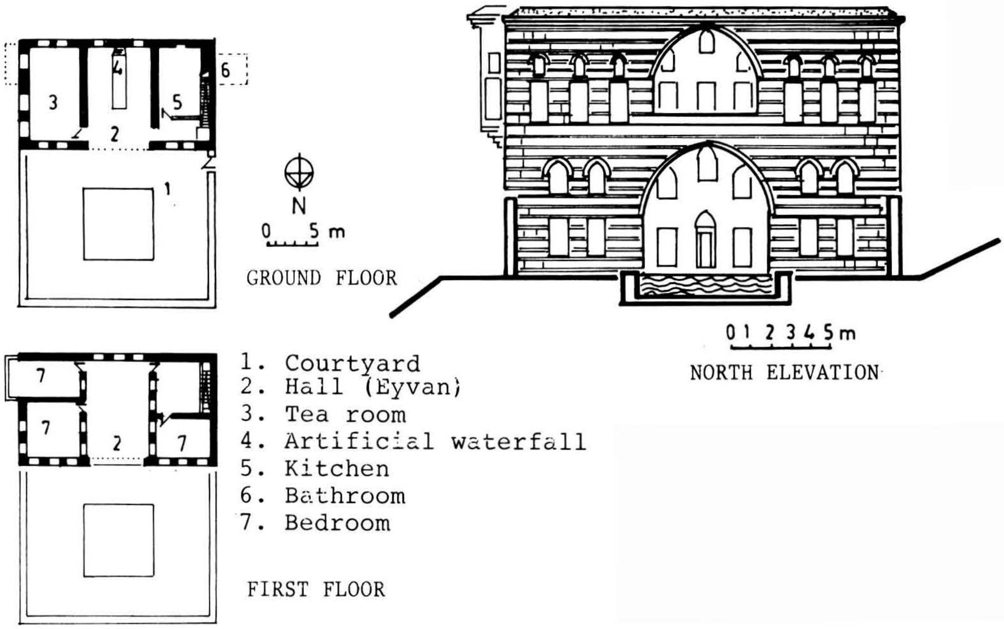


Fig. 7. A traditional house from Diyarbakir. The hot/dry climate (Erginbaş 1954).

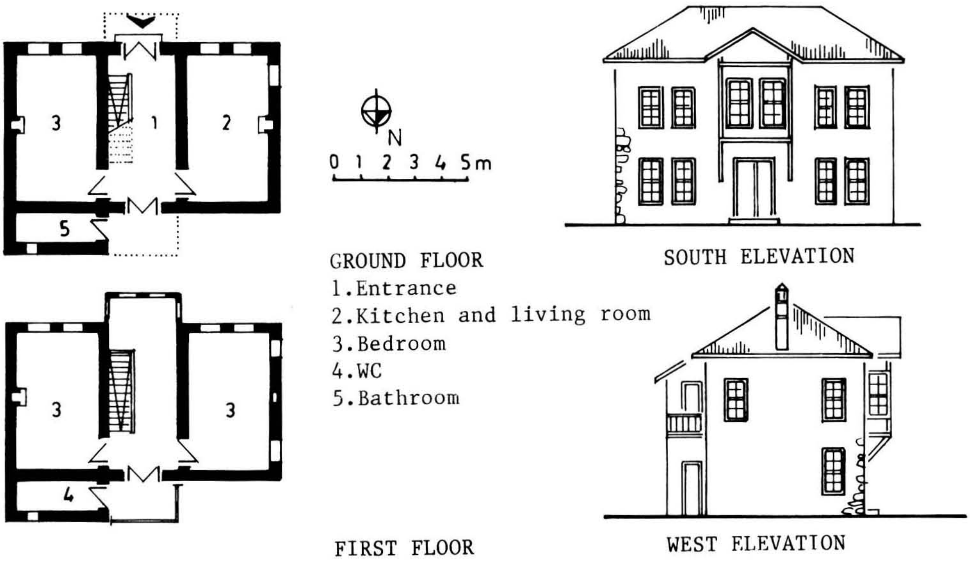


Fig. 8a. A traditional house from Side, Antalya. The composite climate.

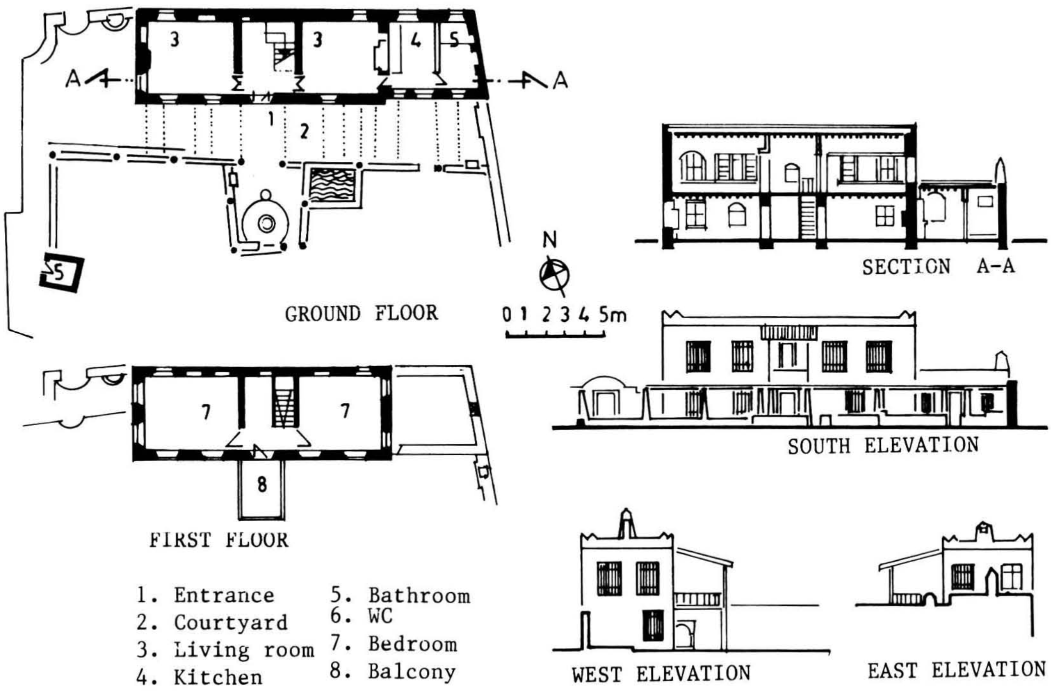


Fig. 8b. A traditional house from Bodrum, Muğla. The composite climate (Bektaş 1983).

Some of the measurable building parameters related to the climate were studied statistically. These building parameters are

A/V	: The ratio of the building exterior surface (A) to the volume (V) of the building.
A_{window}/A_{floor}	: The ratio of the window area to the floor area.
$A_{window}/A_{façade}$	: The ratio of the window area to the façade area.
R	: The thermal resistance of the wall, m^2K/W.
$U_{window+wall}$	: The area weighted average U-value of the building facade, W/m^2K .

The mean values of these building parameters for each region were found from the architectural drawings. Since the sample size did not cover the whole population, it was necessary to find the confidence interval for the mean values computed. It was decided to choose a 95% confidence interval. This means, there will be a 5% probabilty that the true mean values of the building parameters in each climatic region will not fall within this interval. Thus, the standard deviation of the building parameters, and the standard error of the mean building parameters were computed. Since the distribution is normal but the number of houses evaluated for each region was less than 30, the t-test was applied to find the 95% confidence interval of the mean values, according to the following equation:

$$\bar{x} \pm t_c\ (s/\sqrt{n})$$

where

$\bar{x}$	is the mean value of a building parameter for each climatic region
t_c	is the percentage point of t-distribution (chosen from the statistical tables so that 1/2(100-95)% of the t-distribution with (n-1) degrees of freedom lies above it),
s	is the standard deviation of each traditional house's building parameter,and
n	is the number of houses evaluated in each region.

The details of the procedure is given in statistical text books and also in Chatfield (1975). The results are listed in Table 1.

DISCUSSION

The Turkish traditional houses are the result of experience with the physical environment. In places where cold, hot, humidity, wind, or rain are causing excessive discomfort, different settlement patterns and building forms had been used.

The most important aim in designing the Turkish traditional house is to control the indoor climate by reducing the climatic stresses. By selecting suitable sites for settlement, the builders of the traditional

Table 1. The values of some of the climatic building parameters of traditional Turkish houses.

CLIMATE		COOL	TEMPERATE DRY	TEMPERATE	TEMPERATE HUMID	HOT-HUMID	HOT-DRY	COMPOSITE
SAMPLE SIZE		20	28	13	29	10	8	14
PARAMETERS:	Mean	0.33±0.02	0.50±0.06	0.60±0.08	0.90±0.06	0.95±0.05	0.36±0.02	0.61±0.08
	s.d.	0.042	0.15	0.13	0.15	0.07	0.024	0.14
R	Min.	0.45	0.27	0.24	0.24	0.30	0.98	0.29
m^2K/W	Max	1.05	0.51	0.52	0.52	0.55	1.23	0.31
$U_{window+wall}$ W/m^2K	Mean	1.17±0.09	2.49±0.19	2.40±0.15	2.32±0.12	2.07±0.12	1.21±0.08	1.70±0.10
	s.d.	0.19	0.49	0.25	0.31	0.16	0.1	0.17
A_{window}/A_{wall}	Mean	0.03±0.002	0.19±0.017	0.23±0.02	0.28±0.02	0.35±0.02	0.10±0.01	0.11±0.01
	s.d.	0.004	0.04	0.03	0.05	0.028	0.028	0.017
A_{window}/A_{facade}	Mean	0.03±0.002	0.12±0.006	0.14±0.006	0.14±0.006	0.25±0.02	0.09±0.006	0.07±0.005
	s.d.	0.004	0.015	0.01	0.015	0.028	0.007	0.009

houses tried to reduce the climatic stresses rather than redesigning the building envelope. The climatic elements have different effects on differently oriented exterior walls. Thus, the spaces have been planned according to the orientation. In some regions, separate rooms were used for summer and winter. The selection of a different window-to-façade area ratio and different constructions according to the orientation are also the results of the efforts of reducing stresses.

Ölgyay (1963) had computed in the 1950s that the south facing slopes of the northern hemisphere receive the most balanced sunshine throughout the year. It is known that many ancient settlers of Anatolia preferred the southern slopes of hills and mountains (Turan 1983).

The traditional builders respected the environment of the other houses. The inclination of the roofs was selected to prevent the rainwater, flowing off the roofs, from running towards the walls of the neighbouring houses.

The Turkish traditional houses depend largely on crafts. The construction knowledge was passed from the master to the apprentice. Since all the components were handmade, the details which control the physical environment had not been forgotten. The eaves with wind expellers, windowsills, demountable windows, window lattices, constructional details, indoor pools and the artificial waterfalls unite art with the function of controlling indoor climate. Most of the decorative objects used in these houses have a hidden function behind it.

The recent increase in land and building material cost may make the separation of rooms for winter and summer use uneconomical. However, in modern buildings, it is possible to design the building elements and the details so as to reduce the environmental stresses. It is also possible to use constructions and building parameters, like the exterior surface-to-volume and the window-to-façade area ratios, suitable for the climate.

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BASEMENT STRUCTURE AND BARRIERS BETWEEN THE FLOORS AS MAIN BUILDING CHARACTERISTICS AFFECTING THE INDOOR RADON LEVEL OF DWELLINGS IN THE SWISS ALPINE AREAS

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Our investigations with passive track etch dosemeters, involving 50 pairs of adjacent buildings, indicate that radon concentrations in the cellar, on the ground floor and the first floor are increased by 1146 (±423), 176 (±58) and 113 (±39) Bqm^{-3}, respectively. These tests were carried out in single-family homes with a basement in direct contact with the subsoil compared to the levels obtained in houses sealed against the soil with a concrete slab. The extent to which radon concentrations in the cellar account for the radon levels in the living quarters, depends on specific structural characteristics of the building. Barriers between cellar and ground floor clearly decrease the amount of radon entering the living areas.

INTRODUCTION

Switzerland is a small country, in the centre of western Europe. About 24 000 km^2 of its surface (57%) is situated in the Alps, 31% in the Molasse Basin and 12% in the Jura. The high variability of the soil structure gives rise to indoor radon concentrations ranging over more than two orders of magnitude, depending on the geology and radium content of the subsoil (Burkart 1984; Crameri et al. 1989). In the southeastern parts of Switzerland, one of the most affected regions, the arithmetic mean radon concentration for the living quarters exceeds 300 Bqm^{-3} and leads to an annual effective dose equivalent in the range of 9 mSvy^{-1} to the population living in this area (Crameri et al. 1988). Also in the rest of the Swiss alpine zone, indoor radon levels turn out to be relatively high (Crameri et al. 1989). The high altitude of the region above sea level results in a cold climate with long heating periods (Burkart 1983). Thus, the efforts to save energy are particularly intensive in this region and may contribute to the increase of the indoor radon concentrations up to dangereous levels (Burkart 1983; 1984). Radon enters buildings from several major sources, principally building materials, tap water, and soil or rocks that underlie or surround the building foundations. Tap water, with a contribution in the range of 2% to the indoor radon levels, was found to be negligible in terms of source strength (Buchli and Burkart 1985). Building materials do not contribute in a significant way to the indoor radon concentration in Switzerland (Schuler et al. 1989). Recent experimental studies show that the soil is the predominant source for the radon levels measured in the cellar of single family homes in the Swiss alpine region (Crameri et al. 1988). Thus, vertical radon transport from the cellar to the living quarters is assumed to be the principal mechanism responsible for the high radon concentrations in the living quarters of small buildings situated in this area (Crameri et al. 1986). Characteristics of the buildings, such as the structure of the basement and the building configuration, may influence radon concentrations significantly (Pensko 1986). To assess the contribution from these parameters to the indoor radon levels, the much larger fluctuations due to geological parameters have to be eliminated. The analysis of pairs of dwellings, matched for the major parameters influencing the indoor radon concentration (geology of the subsoil, building materials, and tap water supplies), but differing in a specific characteristic to be examined, provide an unbiased method to quantify the contribution of single parameters to the indoor radon levels.

MATERIALS AND METHODS

Measurements of radon gas with passive track etch dosemeters of the Karlsruhe-type are described elsewhere (Urban and Piesch 1981). The type of dosemeters used, strongly suppresses the radon-220 contribution (Fleischer et al. 1975). Details of the calibration are reported by Burkart et al. (1984). In each home, three passive radon dosemeters were placed for the determination of the source strength in the cellar, in the living room (generally the ground floor), and a bedroom (mostly on the first floor). The measuring period was 120 d. After exposure, the detectors were electro-chemically etched and track counting was performed automatically by a Quantimet image analyser.

SAMPLING LOCATION

Pairs of adjacent single-family homes, matched for most characteristics but differing in the structure of the basement or in the communication between the floors, were formed in different areas of the Swiss alpine region and analysed for the indoor radon distribution. Only pairs being inhabited during the full measuring period were considered.

RESULTS

The role of the basement structure

Radon entry into basements depends on the radon source strength and on many, in some cases poorly understood, parameters influencing the transport of radon-rich soil gas indoors (Nero and Nazaroff 1984). However, the most important factors affecting the radon concentration in the cellar are the tightness of the foundation under the house, the ventilation rate, and the permeability of the soil (Nero and Nazaroff 1984). One of the characteristics of Swiss homes situated in the alpine region is to have, quite often, bare earth floors in the storage areas. Thus, the radon concentration in the cellar of homes having a basement in direct contact with the soil can be expected to be on the average higher than the concentration in the cellar of homes having a basement sealed against the soil with a concrete slab. To assess the influence of a bare-earth basement on the indoor radon concentration, 50 pairs of adjacent homes differing in the foundation structure were pooled and the difference for each pair calculated (Fig. 1).

Despite the large fluctuations between the different pairs, Table 1 indicates a significant increase of the indoor radon concentration in homes having a basement in direct contact with the soil. This kind of analysis clearly shows that the radon concentration in the cellar influences the radon concentration in the living quarters in a significant way. Thus, radon infiltration from the basement to higher floors due to vertical air movements is responsible for the main part of radon detected in the living quarters of the single-family homes investigated. The increase by a factor of about 2.0 (2.14 for the ground floor and

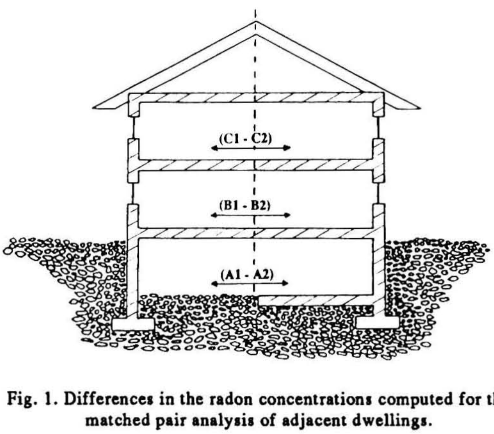

Fig. 1. Differences in the radon concentrations computed for the matched pair analysis of adjacent dwellings.

Table 1. Matched pair analysis of 50 pairs of adjacent dwellings differing in their basement structure.

Basement structure	Radon gas concentration Bqm^{-3} (S.D. of the mean)		
	cellar (A)	ground floor(B)	first floor (C)
bare earth (1)	1715 (398)	330 (57)	241 (36)
concrete slab (2)	569 (136)	154 (22)	128 (17)
	Difference (S.D.)	P	Ratio (1 : 2)
cellar (A1 -A2)	1146(423)	<<0.005	3.01
ground floor (B1 - B1)	176(58)	<0.0025	2.14
first floor (C1 - C2)	113(39)	<0.005	1.88

1.88 for the first floor) of the radon levels in homes with a bare-earth basement is comparable to the factor of 1.5 obtained by Burkart (1986) from airtightening of homes.

The role of the barriers between the floors

The marked tendency to use part of the cellar for family activities in Switzerland decreases the relative airtightness of the boundary between basement and living area. Facilitated infiltration of radon-rich air from the basement to higher floors can influence the radon concentration in the living quarters significantly. Thus, houses where internal staircases do not possess doors, which could obstruct the air exchange between different floors, are expected to yield higher average radon concentrations in the living quarters than houses where the staircase is provided with a closed door between cellar and ground floor. An effort to quantify the influence of barriers between the floors was undertaken analysing 50 matched pairs of homes differing in the communication between cellar and ground floor. The analysis of the data was performed as explained in Fig. 1 and the results are reported in Table 2.

As noted above, the radon concentration in the cellar can influence the radon levels throughout the

Table 2. Matched pair analysis of 50 pairs of adjacent dwelling differing in the communication between cellar and ground floor.

Communication cellar/ground floor	Radon gas concentration Bqm^{-3} (S. D. of the mean)		
	cellar (A)	ground floor (B)	first floor (C)
open (1)	937 (162)	335 (57)	238 (37)
closed (2)	1347 (404)	149 (19)	131 (16)
	Difference (S.D.)	P	Ratio (1 : 2)
cellar (A1 - A2)	-410 (414)	>0.15	0.70
ground floor (B1 - B2)	186 (78)	<0.0125	2.24
first floor C1 -C2)	107(37)	<0.005	1.82

whole building. Thus, the concentrations in the cellar have to be considered in order to assess the influence of the communication between cellar and ground floor to the radon levels in the living area. The analysis of the recorded data reported in Table 2 shows that there is no statistically significant difference between the radon levels in the cellar of houses with a closed and open communication. Not surprisingly, the average radon concentrations in the cellars of houses with a closed door between cellar and ground floor are somewhat higher than the concentrations in the cellars of houses lacking obstructions between the floors. Based on a simple model, we can consider the ground floor of a dwelling with an open and the ground floor of a dwelling with a closed communication between cellar and ground floor as a matched pair where the difference of the radon gas concentration can be attributed to the lack of barriers for vertical air movements between the floors. The results of this matched pair analysis (Table 2) clearly confirm, that an open communication between cellar and ground floor contributes to statistically significant increased indoor radon levels. The same calculation method applied to the first floor also yields statistically significant differences in the radon concentration of the matched pairs.

DISCUSSION

The main sources influencing the average indoor radon concentration in the Swiss alpine area are the geology of the subsoil (Crameri et al. 1989), water supplies (Buchli and Burkart 1985), and building materials (Pensko and Burkart 1986; Schuler et al. 1989). The two latter were shown to be of lesser importance. The radium contents of the building materials so far investigated, are in the range of the values obtained for other European building materials (Schuler et al. 1989; UNSCEAR 1982). The contribution from tap water consumption was estimated to be in the range of 2 % (Buchli and Burkart 1985) .

The dominant source of radon turns out to be the soil surrounding the buildings (Crameri et al. 1988). Thus, the tightness of the foundation under the house can be expected to be an important factor for the resulting radon concentration in the cellar. A characteristic of single-family homes in the Swiss alpine area is, quite often, to have bare earth floors in the storage areas. In an effort to quantify the influence of a basement in direct contact with the soil on the indoor radon level, pairs of adjacent homes differing in the foundation structure were formed and analysed for the indoor radon distribution. A statistically significant increase of about 145 Bqm^{-3} for the living quarters of homes with a bare-earth floor in the cellar was detected (ground floor and first floor weighted each 50%). Using ICRP 50 (1987) conversion factors and an equilibrium factor of 0.45, the additional annual dose contracted in the living quarters is estimated to average 4 mSv H_{eff}. As earlier reported (Crameri et al. 1986), vertical air movements are considered to be responsible for the high indoor radon levels encountered in the living area of homes located in the Swiss alpine area. The results reported in Table 2 show that the lack of doors between cellar and ground floor causes a marked increase by a factor of about 2 (147 Bqm^{-3}) on the indoor radon level of the living area. It can be deduced from our results that certain building designs commonly used in the Swiss alpine area, have the potential for high radon entry rates. Control of radon entering from the soil requires attention to the basement structure and to the communication between cellar and higher floors. These findings suggest that specific control measures, such as the sealing of surfaces in direct contact with the soil and efficient barriers obstructing vertical air movements between the different floors, would be very efficient in reducing the indoor radon levels of homes located in the Swiss alpine area.

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THE CONTRIBUTION OF PLANTS FOR CO_2 REMOVAL FROM INDOOR AIR

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This paper deals with the ability of certain succulent plants in absorbing CO_2 in different types of rooms inhabited by household members. Plants, generally, are known to remove CO_2 in daytime in the presence of sunlight but certain succulent plants, which have a crassulacean acid metabolism (CAM), have a specialized mechanism of stomatal opening and closing which help in the reduction of CO_2 during night. A study, using *Bryophyllum* and *Agave*, has been carried out in rooms used mostly for resting and sleeping. The number of persons, along with many other parameters, plays a prominent role in the maintenance of CO_2 levels in indoor conditions. These plants, grown in pots, were placed in the bedrooms. They lowered CO_2 levels to a considerable extent, thus establishing the ability of succulents and CAM plants in lowering CO_2 in indoor environments.

INTRODUCTION

The role of vegetation in the management of pollution has been known for some time (Gilbert 1968; Rao 1979; Rich 1970). There has been an interest in keeping indoor plants, but the real significance of plants as sources and sinks for pollutants has received little attention. (Benson et al. 1972). Due to the absence of photosynthetic activity in the night, CO_2 concentrations are known to rise at night. But certain succulent plants, with a crassulacean acid metabolism, have a special mechanism for absorbing CO_2 during the night. There is little information available on the ability of succulent plants in lowering CO_2 in indoor environments. Hence, the present investigation on the ability of two succulent plants, viz., *Bryophyllum* and *Agave*, to absorb CO_2 from different types of indoor environments, has been undertaken.

MATERIAL AND METHODS

Home studies (pot transplant experiments): The transplant studies were made to assess the CO_2-absorbing potential of certain succulent plants. Measurements of CO_2 were done in different indoor habitations, such as domestic kitchens and in certain rooms in industrial establishments. The CO_2 concentrations of indoor air were measured by the NaOH-absorption method (Wilson 1982), according to the following reactions:

$$CO_2 + 2NaOH \text{ ----------> } Na_2CO_3 + H_2O$$

$$Na_2CO_3 + BaCl_2 \text{ -------> } BaCO_3 + 2NaCl$$

The residual NaOH in the filtrate was titrated with 0.2 N HCl. The difference between the amount of NaOH converted to Na_2CO_3 gives the amount of CO_2

Table 1. Conditions of the different indoor rooms.

Type of Indoor environment	Size: Length (cm)	Size: Breadth (cm)	Number of: Windows	Doors	Ventilaters	Persons
Kitchen room	660	420	1	1	2	6 in day &
Ventilation	120	60				4 in night
Industry room	300	300	1	1	1	8 in day &
Ventilation	90	30				2 in night
Hospital room	840	450	-	1	4	10 in day &
Ventilation	60	60				2 in night

produced. The values are expressed in µL/L. The measurement of CO_2 was made indoors, separately during day and night, for 4 h, without closing the ventilators. An average of four readings were taken. The indoor rooms used in this experiment were categorized as (1) empty rooms, (2) rooms + persons, and (3) rooms + persons + succulent plants in pots. The details of the different indoor environments were given in Table 1. The two types of succulent plants employed in the study, were *Bryophyllum* and *Agave*. The character of the plants used were given in Table 2.

Chamber experiments: The experiments were conducted in cuboid chambers, constructed with transluscent, corrugated plastic sheets with aluminium frames. The potted plants (*Bryophyllum* and *Agave*) were placed in the bedrooms and the amount of CO_2 was measured (Wilson 1982) during the day for 4 h and expressed as µL/L. Similarly, CO_2 was estimated

Table 2. Details of the succulent plants employed.

Characters	Bryophyllum	Agave
Height of the plant (cm)	30	25
Number of leaves	16	70
Total leaf area (cm)	864	384
Number of Plants per pot	1	1
Number of pots	6	6

for 4 h during the night. An empty plastic chamber without plants was maintained as a control.

RESULTS AND DISCUSSION

The conditions of the different indoor rooms, indicating their size, number of windows, doors, ventilations, and number of persons who were occupying the room, are presented in Table 1. Information regarding height of the plant, number of leaves, leaf area, number of plants per pot, and number of pots of *Bryophyllum* and *Agave* is given in Table 2.

The results of CO_2 levels in a room in an industrial establishment and a domestic kitchen are presented in Table 3 and Table 4, respectively. It was observed that at night in a typical Indian domestic kitchen CO_2 levels were high compared to a room in an industrial establishment. The presence of the succulent plants named above in a domestic kitchen decreased CO_2 levels from 374.16-301.4 µL/L during the day, and from 334.95-290.07 µL/L during the night, revealing statistically significant differences.

Table 5 shows the concentration of CO_2 in the experimental chambers. In control conditions, in the absence of plants, the CO_2 levels were lower during the day than during the night. *Agave* plants removed more CO_2 during the night than *Bryophyllum* plants. These plants lowered CO_2 levels efficiently during nights. Similar results were also observed in field conditions.

Tables 3, 4, 5 also present the analysis of variance, showing the statistical test of ratio of two mean sums of squares (F test). This F test has been carried out to determine whether there is any significant variation due to the changes in room conditions (A), the variations due to day and night (B), and the interaction between A and B (Snedecor and Cochran 1967). Also, the critical difference (C D) has been calculated to determine whether there is a significant difference, not only between two means, but also between individual variants (Snedecor and Cochran 1967).

In a room in an industrial establishment, the CO_2 concentrations were higher in the night than in the day due to the general respiratory process of plants and the outdoor exchange rates. The CO_2 level was higher in rooms with persons due to the fact that the presence of human beings influences the rate of CO_2 exchange levels (Nielson 1987). By introducing these succulent plants in the indoor habitats, it was practicable to reduce the levels of CO_2 during night, as

Table 3. Concentration of CO_2 (µL/L) in industry with different conditions.

Condition of the Environment	CO_2 Concentration Day	Night
Empty room	101.7	177.6
Room + Persons	108.9	118.8
Room + Person + Plants	106.1	116.0

Statistical Analysis	Standard error(SE)	Critical difference
A. Variation due to room cond.	0.134	0.282
B. Variation due to day & night	0.164	0.345
AB	1.516	6.520
Sample size (18)		

A - Variation due to room condition
B - Variation due to day and night
AB - Interaction between A and B.
For - Standard error (SE)
Critical difference (CD)
(for statistical analysis see Snedecor and Cochran 1967).

Table 4. Concentrations of CO_2 (μL/L) in typical Indian domestic kitchens with different conditions.

Condition of the Environment	CO_2 Concentration Day	Night
Empty room	345.9	296.6
Room + Person	374.1	334.9
Room + Persons + Plants	301.4	290.1

Analysis of Variance (F test)

Source	df	S S	M S S	F
A Treatment	1,18	9.04	9.04	30.66**
B Treatment	2,18	19.48	9.74	33.03**
AB Treatment	2,18	2.1	1.05	3.58*

A - Variation due to room condition
B - Variation due to day and night
AB- Interaction between A and B.
** Significant at 1% level of significance
*Significant at 5% level of significance
d f = degrees of freedom
F = Ratio of two mean sum of squares
M S S = Mean sum of squares
S S = Sums of squares
(See Snedecor & Cochran 1967 for detailed statistical analysis of the data).

Table 5. Concentrations of CO_2 (μL/L) in experimental chambers.

Condition	Day	Night
Empty chambers	74.1	94.3
Chamber+Bryophyllum plants	107.2	83.1
	(+44.6)	(-11.9)
Chamber + Agave Plants	119.3	79.8
	(+60.9)	(-15.4)

(The figures in parentheses indicate the per cent variations, + = Increase, - = Decrease)

Analysis of Variance (F test)

Source	df	S S	M S S	F	C D
A Treatment	1,12	1.64	1.64	0.66	0.779
B Treatment	2,12	4.67	2.33	4.06	0.954
AB Treatment	2,12	13.97	6.98	12.15	6.561

A - Variation due to room condition
B - Variation due to day and night
AB -Interaction between A and B.
** Significant at 1% level of significance
*Significant at 5% level of significance
d f = degrees of freedom
F = Ratio of two mean sum of squares
M S S = Mean sum of squares
S S = Sums of squares

shown in Tables 3,4 and 5. The absorption of gases, particularly CO_2 (Raza and Shylaja 1989), was possible because of the nocturnal opening of the stomata of these plants.

In a typical Indian domestic kitchen, the CO_2 level is higher during the day because of the heating systems and of burning fuels (Colome et al. 1987). Indian women use fire wood fuel which emits total suspended particles, CO_2, and other gases (Ramakrishna 1987; Smith 1987; Smith et al. 1983). The levels of CO_2 are higher in kitchens, followed by rooms in industrial establishments. The size of the room, the number of persons occupying it, and the ventilating conditions also play a signficant role in the dispersal of CO_2 through diffusion and transportation (Turiel 1985).

Thus, in the present investigation, we could lower successfully the excess CO_2 that had accumulated in the sampling rooms. In control chamber experiments, CO_2 concentrations were higher during the day and lower during the night. Because of the succulent plants, *Bryophyllum* and *Agave*, used in this study, more CO_2 could be absorbed during the night.

CONCLUSIONS

Indian domestic kitchens are the sensitive places for higher CO_2 levels because of the burning of fuel. *Bryophyllum* and *Agave* can be used in lowering the CO_2 level in indoor environments during the night, thereby improving the quality of indoor air.

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THE EFFECT OF MATERIAL AGEING AND SEASON ON FORMALDEHYDE LEVELS IN DIFFERENT VENTILATION SYSTEMS

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The effect of season and material ageing on airborne formaldehyde concentration was followed in three new small apartment houses provided with different ventilation systems. Formaldehyde levels were determined periodically. Indoor temperature, humidity and ventilation rate were monitored continuously, and the dependence of formaldehyde concentration on these parameters was analyzed. Formaldehyde concentrations were highest when the houses were new and empty. Within 2 y, formaldehyde levels decreased to half of the initial values. The rate of decrease was fastest when the ventilation rate was highest. The highest levels in new houses were associated with high negative pressure in indoor air. Considerable seasonal variation in the minimum in winter was observed. The seasonal variation was considered to be due to variation of temperature, humidity and ventilation rate.

INTRODUCTION

Formaldehyde is a common indoor air pollutant that is emitted from a variety of consumer and construction products and materials. Formaldehyde may cause irritation of upper respiratory tract and eyes already at the level of 0.06 mg/m^3, as presented by Turiel (1985). Formaldehyde is also an important allergen and a suspected carcinogen. Therefore, the huge number of formaldehyde exposure studies conducted in various indoor environments is no surprise. In earlier studies, the release of formaldehyde has been found to fluctuate markedly due to several factors, such as temperature and relative humidity (Berge et al. 1980), ventilation (Matthews 1986), age of source (Andersen et al. 1975), and season (Tanner and Meng 1984). These studies have been laboratory experiments and, therefore, their practical significance in normal living spaces is unclear. In the studies that have been done in inhabited homes (Hanrahan et al. 1985; Meyer and Hermanns 1985; Norsted et al. 1985; Ritchie and Lehnen 1985; Stock and Mendez 1985; Sexton et al. 1989), the houses have been different in their construction, size, age, and ventilation. Therefore, the confounding environmental parameters are not well controlled in these studies.

In this study, the effect of material ageing and season on formaldehyde concentration was studied in three otherwise identical apartment houses but equipped with different ventilation systems. The systems were:

1. natural ventilation
2. mechanical exhaust ventilation
3. mechanical supply and exhaust ventilation.

The study was started before the tenants moved in and was then continued in occupied homes under normal living conditions for two years.

MATERIALS AND METHODS

The study houses are constructed from concrete elements. Among construction materials, particle board was the major source of formaldehyde. It was used on walls and in wardrobes and cupboards (about 0.7 m^2/m^3 in each apartment). Each study house had six apartments. Each apartment was provided with a separately controlled ventilation system. The families were allowed to freely adjust ventilation, temperature, and humidity level in their homes. The tenants of the two-room or three-room apartments were mainly young families. The average family had 2.6 members.

The first measurements were carried out in fall 1985 when the apartments were without furniture and tenants. The measurements were repeated three times in occupied homes: in winter (February 1986) and in two falls (September 1986 and 1987).

The formaldehyde concentration was determined with the chromotrophic acid method (NIOSH 1974). Two to four two-hour samples were taken in each apartment during each of the four measurement periods.

The ventilation rate, relative humidity, and temperature were monitored by an automatic measurement and data collection system reported by Savolainen et al. (1989). Other constituents of indoor air, for example, bioaerosols, particulate matter, and radon were also examined during these periods and were reported separately by Reponen et al. (1989) and Kokotti et al. (1989).

The measurements were carried out at daytime under normal household activity in the living room or in the bedroom of the apartment at the height of 1.5 m. The sampling was repeated at the same hour of the day in the same room during each study period.

During the first period, when there were no tenants in the apartments, formaldehyde concentration was measured both during minimum and maximum ventilation. The average of these measurements was used for the study. Before the measurement, ventilation was kept at the minimum efficiency at least for 20 h, but at the maximum ventilation only for 1-3 h, which was too short a time to reach the equilibrium concentration. Therefore, the equilibrium concentration during the maximum ventilation was estimated by using the general mass balance equation (see Ryan et al. 1988):

$$C_t = C_o\exp(-Nt) + m / Q[1-\exp(-Nt)] \qquad (1)$$

where

C_t = concentration at time t
C_o = concentration at time t = 0
N = air exchange rate (1/h)
t = time (h)
m = production rate of pollutant (mg/h)
Q = amount of air exchange (m^3/h).

The equilibrium concentration of pollutant is the amount found after infinite time or m/Q. Thus, the equilibrium concentration (C_{eq}) can be calculated by the following equation:

$$C_{eq} = \frac{C_t - C_o\exp(-Nt)}{1-\exp(-Nt)} \qquad (2)$$

The emission rate of formaldehyde, E (mg/m^2h), in equilibrium situation can be approximately calculated from the production rate and the area of particleboard, A (m^2):

$$E = \frac{m}{A} = \frac{C_{eq}Q}{A} \qquad (3)$$

Temperature and relative humidity are known to affect greatly the emission of formaldehyde from indoor sources. Because both factors varied both from home to home and between measurement periods, the formaldehyde values were adjusted according to the equation developed by Berge et al. (1980) which is based on an Arrhenius temperature dependence and linear relationship with relative humidity of the air. Following is the equation which is the most widely used expression of formaldehyde levels as a function of temperature and relative humidity (Godish and Rouch 1985):

$$C_o = \frac{C}{1 + A(H - H_o)\exp[-R(1/T - 1/T_o)]} \qquad (4)$$

where

C_o = adjusted concentration (mg/m^3)
C = measured concentration (mg/m^3)
R = coefficient of temperature (9799)
T = measured temperature (°K)
T_o = standardized temperature (°K)
A = coefficient of humidity (0.0175)
H = measured relative humidity (%)
H_o = standardized relative humidity (%).

As the standardized temperature value and relative humidity value, we used the averages of the whole data, which were 22°C and 50%, respectively. By comparing the original and adjusted formaldehyde values in the three ventilation systems, time variation caused by environmental factors can be analyzed.

Statistical analyses were performed by SPSS programs. Differences in various parameters between the various ventilation systems were studied by the Kruskal-Wallis one-way analysis of variance. The effect of season and material ageing was studied by comparing the different measurement periods by the Wilcoxon Signed-Ranks test.

RESULTS AND DISCUSSION

Formaldehyde concentrations in the three houses varied between 0.02 and 0.21 mg/m^3. The temperature ranged from 20.6-25.7°C and the relative humidity from 16.8-79.6%. The ventilation rates were clearly different for the three systems (Table 1), the range being 0.2-0.4 1/h in natural ventilation, 0.1-1.0 1/h in mechanical exhaust, and 0.1-1.3 1/h in mechanical supply and exhaust ventilation system.

Both the measured and the adjusted formaldehyde concentrations were at maximum in the beginning of

Table 1. Differences between the three ventilation systems by Kruskal-Wallis test.

Studied parameter	Fall 1985	Winter 1986	Fall 1986	Fall 1987
Formaldehyde concentration mg/m^3				
measured values	o	N.S.	*	N.S.
temperature and humidity adjusted	N.S.	N.S.	o	N.S.
Formaldehyde emission mg/m^{2}h	*	*	N.S.	N.S.
Indoor temperature °C	N.S.	N.S.	N.S.	N.S.
Indoor relative humidity %	N.S.	N.S.	*	N.S.
Ventilation rate 1/h	*	*	*	N.S.

N.S. non-significant

o $p < 0.1$

* $p < 0.05$

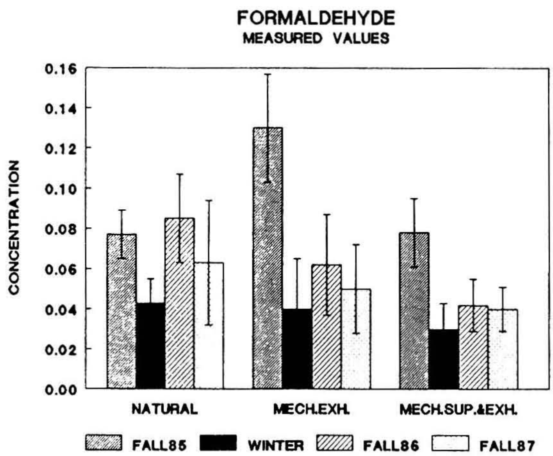

Fig. 1. The measured formaldehyde concentrations (mg/m^3) in houses with different ventilation systems during the four sampling periods. Each column presents the average of four homes during the fall 1985 and six homes during the other periods.

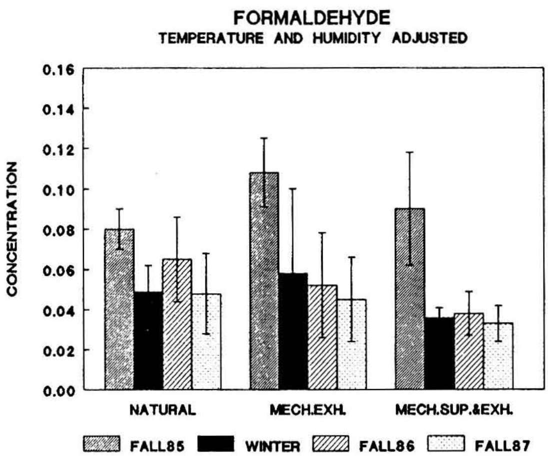

Fig. 2. Temperature and humidity adjusted formaldehyde concentrations (mg/m^3) in houses with different ventilation systems during the four sampling periods. Each column presents the average of four homes during the fall 1985 and six homes during the other periods.

the monitoring period (Fig. 1 and 2) and the highest levels were found in the house with a mechanical exhaust ventilation system. As Kokotti et al. (1989) have reported earlier, radon levels were also highest in this house due to highest negative pressure indoors. It seems that, in this respect, formaldehyde behaves like radon when the emitting materials are new: the higher the negative pressure indoors, the higher the emission rate.

The effect of material ageing

Because physical environmental conditions have a great influence on formaldehyde release, the effect of the ageing of particleboard was studied by comparing the adjusted formaldehyde values in the falls of 1985, 1986, and 1987 (Table 2). The adjusted formaldehyde values decreased constantly through the study period, on the average to half from the initial level (Fig. 2). Similar findings were made by Andersen et al. (1975) who followed the emission from new particleboard in a climate chamber for 13 months. In some other studies, it has also been observed that older houses have lower formaldehyde levels than new houses (Hanrahan et al. 1985; Norsted et al. 1985; Stock and Mendez 1985). On the other hand, Sexton et al. (1989) have found that in the houses that have been manufactured after 1980, formaldehyde concentrations are higher in older houses. In these studies, however, the comparisons were done in houses which not only were of different age, but also varied in their construction, quality, and area of particleboard.

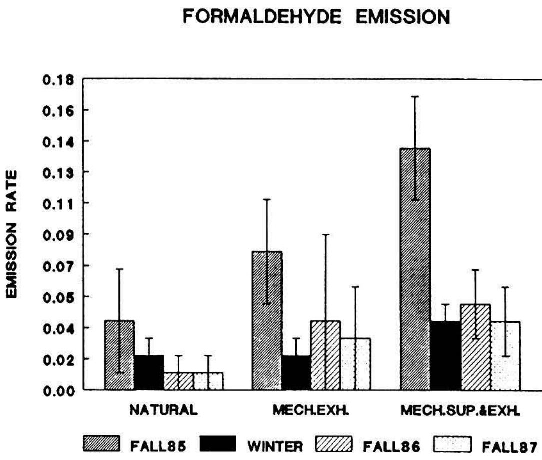

Fig. 3. The emission rates of formaldehyde (mg/m²h) in houses with different ventilation systems during the four sampling periods. The values are calculated from adjusted formaldehyde levels.

The decline of the adjusted formaldehyde level was found to depend on the ventilation rate which was fastest in the house with a mechanical supply and

Table 2. Differences between the falls 1985, 1986 and 1987 by Wilcoxon test.

Studied parameter	Falls 85 vs. 86	Falls 86 vs. 87	Falls 85 vs. 87
Formaldehyde concentration mg/m^3			
measured values	o	o	**
temperature and humidity adjusted	**	o	**
Formaldehyde emission mg/m^{2}h	o	o	**
Indoor temperature °C	*	N.S.	*
Indoor relative humidity %	**	N.S.	**
Ventilation rate 1/h	N.S.	N.S.	N.S.

N.S. non-significant

o $p < 0.1$

* $p < 0.05$

** $p < 0.01$

Table 3. Differences between the winter 1986 and the falls 1985, 1986 and 1987 by Wilcoxon test.

Studied parameter	Winter 86 vs. Fall 85	Winter 86 vs. Fall 86	Winter86 vs. Fall 87
Formaldehyde concentration mg/m^3			
measured values	**	**	o
temperature and humidity adjusted	**	N.S.	N.S.
Formaldehyde emission mg/m^{2}h	**	N.S.	N.S.
Indoor temperature °C	N.S.	***	**
Indoor relative humidity %	o	***	***
Ventilation rate 1/h	N.S.	N.S.	N.S.

N.S. non-significant
o $p < 0.1$
* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

exhaust ventilation system. In this house, the adjusted formaldehyde levels decreased already in the fall of 1986 to the levels which the other ventilation systems reached in the fall of 1987 (Fig. 2). This can be explained by the differences in emission rates of free formaldehyde from particleboard: the highest emission was calculated for the house with a mechanical supply and exhaust ventilation system (Fig. 3, Table 1). As reported by Gammage and Gupta (1984), formaldehyde is emitted from particleboard by two different mechanisms: by evaporation of free formaldehyde and by hydrolysis of the polymeric structure of UF resins. The first mechanism is typical for new materials. The latter mechanism is effective for longer periods and causes lower levels of formaldehyde than the emission of free formaldehyde. In earlier studies (Matthews 1986), it has been found that at the same time as the formaldehyde concentration decreases with an increased air exchange rate, the emission rate of formaldehyde increases. Thus, the concentration of free formaldehyde in the particleboard and other formaldehyde sources decreases faster with a higher ventilation rate.

The adjusted values of formaldehyde levels reached almost an equal level in the three houses after 2 y of occupancy. This indicates that most of the free formaldehyde in materials had already been released.

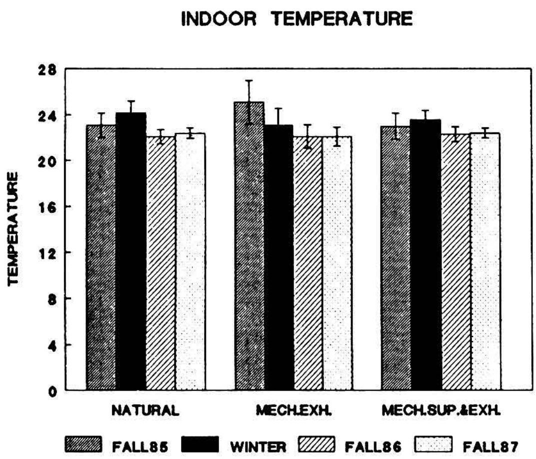

Fig. 4. Indoor temperature (°C) in houses with different ventilation systems during the four sampling periods. Each column presents the average of four homes during the fall 1985 and six homes during the other periods.

The effect of season

The measured formaldehyde levels were at minimum in winter (Fig. 1, Table 3). This supports the findings of Tanner and Meng (1984) and Meyer and Hermanns (1985). They suggested that the variation of solar radiation/photolysis-related sources and

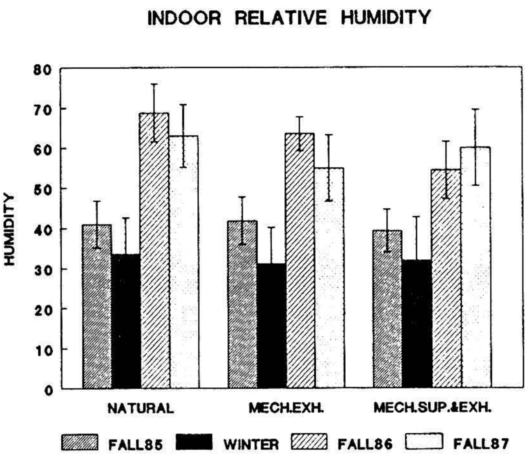

Fig. 5. Indoor relative humidity (%) in houses with different ventilation systems during the four sampling periods. Each column presents the average of four homes during the fall 1985 and six homes during the other periods.

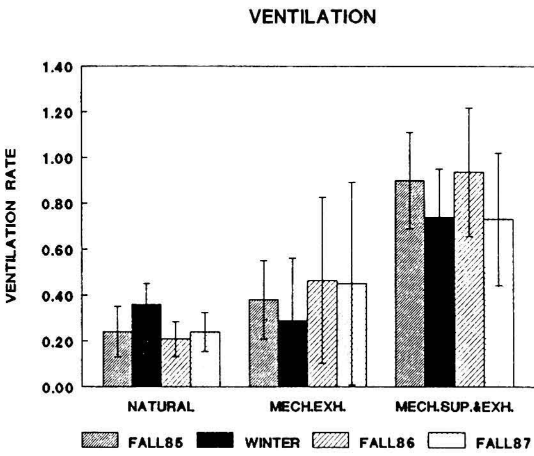

Fig. 6. Ventilation rate (1/h) in houses with different ventilation systems during the four sampling periods. Each column presents the average of four homes during the fall 1985 and six homes during the other periods except in the house with natural ventilation, where ventilation was measured in three homes only.

wet-deposition-related sinks caused the seasonal variation. On the other hand, Sexton et al. (1989) observed that formaldehyde levels were slightly higher during the winter. They explained this by the higher ventilation rate during the summer.

In this study, there also was a seasonal variation in the indoor temperature and humidity levels (Fig. 4 and 5, Table 3). When the formaldehyde levels were adjusted for temperature and humidity, the seasonal variation almost disappeared (Fig. 2, Table 3). Seasonal variation seems, therefore, to be attributable to the variation in indoor temperature and relative humidity.

On the other hand, the seasonal variation of formaldehyde emission partly originates in the variation of the ventilation rate because the ventilation rate affects the humidity of the air. As reported by Savolainen et al. (1989), ventilation has been shown to reduce indoor humidity in winter when the absolute humidity outdoors is low. So, the seasonal variation of formaldehyde emission is caused actually by the interaction of the humidity and the ventilation rate.

When the effect of humidity, and thereby also a part of the effect of ventilation, was adjusted for the the formaldehyde levels, the seasonal variation was seen only in the house with the natural ventilation system (Fig. 2). The difference in the seasonal variation by the three ventilation systems can be explained by the difference in the ventilation rate (Fig. 6, Table 1). With natural ventilation, the lowest adjusted formaldehyde levels were observed in winter when the ventilation rate was highest because of the largest temperature difference between inside and outside air. On the other hand, the ventilation rates of both mechanical systems were, at the time, generally adjusted to a minimum and, consequently, the adjusted formaldehyde levels were high.

CONCLUSIONS

Formaldehyde levels were observed to decrease with time in normal living conditions. In new houses, when the concentration of free formaldehyde in materials was highest, the decrease of airborne formaldehyde was faster, the higher the ventilation rate was. On the other hand, high negative pressure in the house was found to increase the formaldehyde emission. The effect of the ventilation rate and negative pressure decreased with time. This is probably due to change in formaldehyde emission characteristics. The effect of ventilation is more pronounced during the first emission phase caused by free formaldehyde in materials. This decreases with time. During the second hydrolytic phase of formaldehyde release, the direct effect of ventilation is smaller. In addition, the increasing ventilation rate decreases the humidity in indoor air during winter and, thus, also reduces formaldehyde emission. The seasonal variation of formaldehyde was caused by the variation in the temperature, humidity, and ventilation rate.

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EMISSION OF ORGANIC SUBSTANCES FROM INDOOR SURFACE MATERIALS

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A wide variety of surface materials in buildings can release organic compounds. Examples include building materials, furnishings, maintenance materials, clothing, and paper products. These sources contribute substantially to the hundreds of organic compounds that have been measured in indoor air. Their emissions have been directly connected to complaints of odors or hyperreactivity and are presumed to contribute to the problems in many "sick buildings" where the cause of complaints is uncertain. Significant progress has been made in the past decade in developing procedures for measuring emissions from such materials, in controlled experiments where factors affecting emission rates can be determined and quantified. Emissions data are still limited but are being accumulated gradually by research groups in Europe and North America. It is clear from the recent data gathered in research and modeling studies that one of the most effective ways to limit indoor concentrations of organic compounds is to limit the content of volatile compounds in materials that are used in buildings. Limiting the original residual content of such compounds in the materials, or conditioning such materials prior to use in buildings, or (perhaps) conditioning such materials in place before occupancy of a new or renovated building, are most likely to prevent excessive indoor concentrations. If emissions testing and product certification procedures are available and there is sufficient market demand for low-emitting materials caused by indoor air quality concerns, significant reductions of indoor concentrations of vapor-phase organic compounds could be achieved within the next decade.

INTRODUCTION

Many indoor air pollutants come from evaporation or sublimation from surfaces of indoor materials. These "material" sources of indoor air pollutants include any substances that form the building itself or its contents. Other source types are "combustion" sources, such as vented or unvented space heating devices; "activity" sources that involve human activities, such as maintaining, cooking, using aerosol spray products, and using machines; and "outside" sources, such as infiltrated air and contaminated soil gas.

Whereas indoor pollutants from surface materials can be inorganic and particulate in nature, vapor-phase organic chemicals generally predominate in terms of mass concentration and chemical variety. Typical long-term average indoor concentrations of organic vapors range from tens to thousands of micrograms per cubic meter; peak exposures of tens to hundreds of milligrams per cubic meter for a few hours or a few days are not uncommon. Tens to hundreds of different compounds are typically measurable. While surface materials are not the only sources of these compounds, they can be significant contributors.

EMISSIONS FROM SURFACE MATERIALS

The types of materials in typical residential and office buildings cover a wide variety of building materials and contents. They range from materials with virtually no emissions (which may in fact act as absorbers, or "sinks" for pollutants) to large surface area, high emission rate materials that can contaminate indoor air and irritate occupants for long periods.

In addition to emission rate, a measure often referred to as "source strength," materials can also be characterized by the duration of their emissions. Some materials have an essentially "constant emission rate." Examples include moth crystals that at room temperature emit paradichlorobenzene at a nearly constant rate until the crystals are gone and certain types of aged particleboard that have emission rate half-times of a year or more. Other materials have a "slow-decay emission rate." These materials have emission rate half-times of weeks or months. Examples include certain types of floor and wall coverings and furniture. A third category is "rapid-decay emission rate" materials. These have emission rate half-times of minutes, hours, or days. Many "wet" materials such as paints, polishes, and adhesives have such characteristics for a relatively short period after they have been applied.

Controlled studies of the rates and compositions of emissions from representative materials help us understand the potential impact of these sources on indoor air quality and the options for controlling their impacts. Such research studies were begun in Europe over ten years ago and, somewhat more recently, in North American laboratories.

The most common approach for such studies has been to put samples of materials in chambers through which controlled amounts of clean air are passed. Concentrations of emitted pollutants in the air exiting from the chambers are measured. In the most detailed studies, emissions are measured as a function of time (age of material), temperature, air flow rate, area of sample per unit volume of chamber, and relative humidity.

In North America, guidelines on procedures for testing organic compound emissions from indoor sources have been developed by the ASTM, a voluntary standards organization. These guidelines recommend procedures to use in research studies conducted in small chambers, large chambers, and actual buildings. Procedural guidance covers equipment specifications, experimental design, sampling and analysis, data analysis, and quality assurance (ASTM 1990). Similar guidelines are under development in Europe by the Commission of the European Communities (CEC 1990).

More routine testing procedures, for either product certification by manufacturers or product screening by purchasers, are less developed. The current intention within the indoor air research community is to first get consensus on research procedures and then develop simplified versions for routine product tests.

Although difficult to conduct and moderately expensive, such chamber studies are less expensive and more controllable than studies in actual buildings. If chamber data are modeled to simulate emissions from materials under a wide range of environmental conditions, and further modeled to predict indoor concentrations and exposures, chamber studies and modeling become valuable tools for design and selection of indoor materials.

FACTORS INFLUENCING EMISSIONS

The major factors that are now thought to influence emission of vapor-phase organic compounds from surface materials are:

1) Total content of vaporizable constituents in the materials,

2) distribution of these constituents between the surface and the interior of the material,

3) age of the material,

4) surface area of the material per volume of the space it is in ("loading"), and

5) environmental factors such as temperature, air exchange rate, and relative humidity.

Local air velocity near the surface of the material and material surface details undoubtedly have an effect for some materials, but controlled studies of this effect have not been reported in the indoor air quality literature.

For a given material, research studies of emission rates should account for time (age), temperature, and air exchange rate. Early research studies of formaldehyde emissions from pressed-wood products showed that relative humidity was also an important factor. However, research studies of other pollutants have shown that their emission rates from various materials are not particularly sensitive to relative humidity, at least for the normal range found indoors. Therefore, only materials that are known to emit highly polar compounds need to be tested at different relative humidities.

SOURCE (EMISSION) MODELS

Mathematical models are under development that relate emission rates for various types of materials to the major factors influencing emissions. The earliest efforts to do this were for formaldehyde emission from pressed-wood products. One model (Matthews 1986) shows that the emission rate of formaldehyde from these products is primarily a function of temperature, relative humidity, and concentration of formaldehyde in the air (which is, in turn, a function of loading).

Source modeling has been extended by others who are concerned about a greater variety of pollutants and materials. One type of model based on small-chamber testing of materials accounts for the effects of air exchange, loading, and time, but does not account for temperature or humidity effects. For constant emission rate materials, this type of model is simply:

$$EF = C(Q/A) \quad \text{or} \quad EF = C\,(N/L) \tag{1}$$

where

EF = emissions factor for any compound or group of compounds, mg/h per m^2 of surface material
C = concentration in outlet air from chamber, mg/m^3
Q = air flow through chamber, m^3/h
A = area of material in chamber, m^2
N = air exchange rate through chamber, h^{-1}
L = Loading of surface material in chamber, m^2/m^3

For most purposes, slow-decay emission rate materials are modeled in the same way, except through a serious of constant emission factors stepped down at appropriate points in time.

Rapid-decay emission rate materials require models that consider time. One current model (Tichenor 1988) assumes that the test chamber is an ideal continuous stirred tank reactor and that the emission rate decay is first-order. Its basic form is:

$$EF = EF_0 e^{-kt} \tag{2}$$

where

EF = emission factor, mg/m^2-h
EF_o = initial emission factor, mg/m^2-h
e = base of natural logarithms
k = first-order rate constant, h^{-1}
t = time, h

Both the initial emission factor and the rate constant are influenced by air exchange rate and material loading in the chamber. Values for EF_0 and k are obtained by nonlinear regression curve-fitting of the concentration versus time data from chamber experiments.

More comprehensive models that account for all additional significant factors influencing emissions—which can include temperature, the "sink" effects of absorbing indoor materials, and in certain cases relative humidity—have been developed for research purposes (Dunn 1988) but are not likely to be applied to practical situations in the near future. The experimental work required to support their development and subsequent use is too expensive. A more practical approach will be to determine the two (at most, three) factors that have the greatest influence on emissions for a particular type of material, and then develop a specific model that accounts for those two or three factors. Such source models will be quite sufficient for their two main uses: as inputs to indoor air quality predictive modeling, and as guidance on the most effective way to "condition" (i.e., accelerate the emissions from, and decrease the residual volatiles in) materials at the point of manufacture or use.

USING EMISSIONS DATA

There are two general uses of emissions data: evaluating risks for research or regulatory policy decisions and designing or selecting materials to ensure good indoor air quality. Public health officials can use emissions data to evaluate the exposure or health risks of sources. These risk evaluations lead to research priorities or to decisions on whether public guidance on source use or regulation of a material is needed.

Building designers, builders, and managers can make similar use of emissions data, although their decisions are of different types. They can use such data in the selection of materials to use and in the operation of building ventilation systems (especially when buildings are new or newly renovated and apt to have large amounts of new surface materials with volatile organic residuals).

Manufacturers of materials can use emissions data to design inherently low-emitting materials, ensure quality control during production, and develop guidelines for end users on conditioning their materials (to remove residual volatiles).

The traditional use of emissions data is in indoor air quality (IAQ) models that predict indoor concentration of the emitted pollutants. IAQ predictive models can be as simple as well-mixed equilibrium box models that equate indoor concentrations directly to source emission rate, building volume affected by the emissions, and air exchange between the affected volume and other spaces, including outdoors.

Personal computer-based models are now becoming available (Axley 1987; Sparks 1988) that can handle time varying sources and ventilation conditions. These are especially useful for evaluating IAQ control options.

Such calculations can be especially useful if there is an indoor concentration, or concentration range, that is considered undesirable to exceed. Public health officials and researchers can use such calculations for source comparisons, and manufacturers can use them to judge whether their products are likely to be acceptable from an IAQ standpoint.

A simplified example of emissions data use is illustrated in Table 1 and Fig. 1. Typical emission factors for vapor-phase organic compounds from a variety of surface materials—and, for general comparison, some combustion sources and aerosol spray products—are listed in Table 1. They were selected as illustrative, rather typical values from IAQ research studies. A typical application factor for residential use was then applied to obtain emission rates in mg/h.

Figure 1 shows these emission rates, on a logarithmic scale, in a simple bar chart. The chart also has two horizontal lines, at emission rates of 1000 mg/h and 100 mg/h (note the logarithmic scale). These lines correspond roughly to emission rates that in a typical house of 300 m^3 and 0.5 air changes/h would respectively lead to house-wide concentrations well above and well below 1000 $\mu g/m^3$. The 1000 $\mu g/m^3$ concentration is simply a per-source maximum contribution that might be advisable, based on the work of Mølhave (1985) which suggests that even concentrations of less than 5000 $\mu g/m^3$ of total vapor-phase organics may be irritating to some people. This is a concept proposed earlier (Tucker 1986) as interim guidance to building designers, owners, and product manufacturers until more definitive health response data from exposure to low-level organics become available. More recent guidance (Tucker 1990), which gives more consideration to multiple sources, suggests a per-source maximum contribution of 500 $\mu g/m^3$.

As an example, the particular floor adhesive and floor wax in Fig. 1 have average emission rates well above the upper bound of apparent concern during the first 10 h after they are applied. The aerosol disinfectant and hair sprays, for the use conditions assumed, are also above the upper line. Some products fall in the "grey zone" between 100 and 1000 mg/h, and most of the products shown fall below the lower level of apparent concern. In principle, plots such as Fig. 1, constructed around various health endpoints, can identify major sources of any pollutants of concern and can guide manufacturers on the indoor air suitability of their products.

An extension of such plots, taking into consideration the duration of emissions (when experimental data are available on emission rates over time), can be used to evaluate the possible benefits of condition-

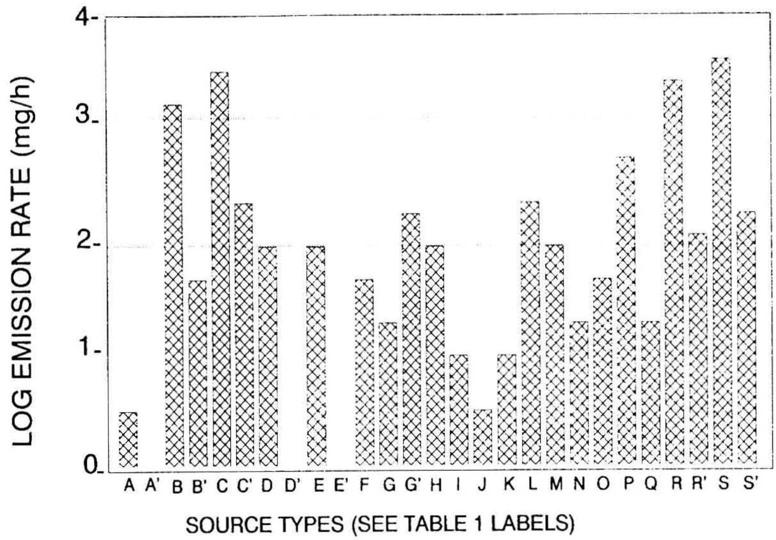

Fig. 1. Examples of emission rates in residences. (Total vapor-phase organic compounds.)

Table 1. Examples of emission rates for sources of vapor-phase organics in residences. (Total vapor-phase organic compounds, except as noted.)

Label	Source*	Condition	Emission factor**	Assumed amount	Emission rate (mg/h)
	Material Sources				
A	Silicone caulk	<10 hours	13 mg/h-m^2	0.2 m^2	3
A'	Silicone caulk	10-100 hours	<2 mg/h-m^2	0.2 m^2	<0.4
B	Floor adhesive	<10 hours	220 mg/h-m^2	10 m^2	2200
B'	Floor adhesive	10-100 hours	<5 mg/h-m^2	10 m^2	<50
C	Floor wax	<10 hours	80 mg/h-m^2	50 m^2	4000
C'	Floor wax	10-100 hours	<5 mg/h-m^2	50 m^2	<250
D	Wood stain	<10 hours	10 mg/h-m^2	10 m^2	100
D'	Wood stain	10-100 hours	<0.1 mg/h-m^2	10 m^2	<1
E	Polyurethane wood finish	<10 hours	9 mg/h-m^2	10 m^2	90
E'	Polyurethane wood finish	10-100 hours	<0.1 mg/h-m^2	10 m^2	<1
F	Floor varnish or lacquer		1 mg/h-m^2	50 m^2	50
G	Particleboard	2 years old	0.2 mg/h-m^2	100 m^2	20
G'	Particleboard (HCHO)	new	2 mg/h-m^2	100 m^2	200
H	Plywood paneling (HCHO)	new	1 mg/h-m^2	100 m^2	100
I	Chipboard		0.13 mg/h-m^2	100 m^2	10
J	Gypsum board		0.026 mg/h-m^2	100 m^2	3
K	Wallpaper		0.1 mg/h-m^2	100 m^2	10
L	Moth cake (Para)	23 °C	14,000 mg/h-m^2	0.02 m^2	280
	Combustion Sources				
M	Unvented gas burner		85-144 mg/h	1 burner	100
N	Unvented gas space heater (HCHO)	radiant	0.001 mg/kJ	20,000 kJ/h	20
O	Unvented kerosene space heater	convective/ radiant	0.007 mg/kJ	6100 kJ/h	45
P	Unvented kerosene heater	radiant/ radiant	0.064 mg/kJ	9400 kJ/h	600
Q	Cigarette smoking	one smoker	10 mg/cig.	2 cig./h	20
	Activity Sources				
R	Hair spray	6-sec. use	3 mg/use	1 use/h	3000
R'	Hair spray	6-sec. use	3 mg/use	1 use/day	120
S	Disinfectant spray	6-sec. use	5 mg/use	1 use/h	5000
S'	Disinfectant spray	6-sec. use	5 mg/use	1 use/day	210

Notes

* Emissions data shown are typical only for the specific brands, models, or units that have been tested; the data do not represent all products of the source type listed. Product-to-product variability can be very high.

** Typical values selected by author based on data in a database on the sources of indoor air pollutant emissions (White 1988).

Label = source type label on Figure 1
Para = paradichlorobenzene
HCHO = formaldehyde

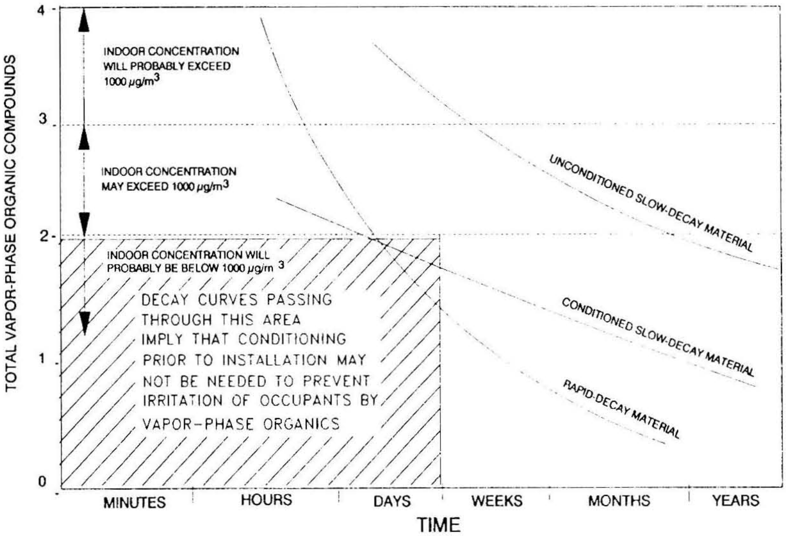

Fig. 2. Illustration of emission rate decay and material conditioning.
(Conceptual example based on residential situations and occupant irritation by vapor-phase organic compounds.)

ing materials. Such conditioning, also referred to as "airing out" and "baking out," can be done at the point of manufacture; after purchase but before installation in a building; after installation but before occupancy; or (least desirably) after a new or renovated building has been occupied and found to have unacceptable indoor air quality. Again in principle, because these concepts have not been tested extensively in practice, emissions data can be used to make decisions on when and where to condition surface materials with high emission rates.

Figure 2 illustrates an approach to making decisions on conditioning. It has the same scale and acceptability levels of emission rates as Fig. 1. Again, the values are based on typical residential space and ventilation conditions. This figure, however, has a general time scale that allows presentation of emission decay rates in terms that are meaningful to de-cisions on conditioning. The "rapid-decay material" curve is typical of substances like the floor adhesive and floor wax in Table 1 and Fig. 1. The decay is sufficiently rapid so that conditioning of the material (or reformulating a coating material like an adhesive or wax) prior to installation or use may not be necessary. Although the emissions are initially very high, it is only a matter of hours or days before indoor concentrations are likely to be in an acceptable range. Some type of conditioning of the building after application but before occupancy might be prudent, however, because some of the emissions may have been absorbed by other surfaces in the building. These surfaces, referred to as "sinks," may become substantial sources of re-emitted compounds.

The "unconditioned slow-decay material" also has a high initial emission rate. If the acceptability limits on emission rates are applicable, this material is likely to lead to complaints, perhaps for months or longer. It is therefore a candidate for conditioning prior to installation. Chamber tests can show which factors will accelerate emissions and deplete the residual volatile compounds most effectively. The most important factors might be temperature, air exchange, or time for airing out, or some treatment of the material such as cleaning. The goal would be to lower the emission characteristics to something like the "conditioned slow-decay material" curve. The latter curve, like the rapid-decay example, passes through a part of the figure that presumably ensures few or no complaints from occupants.

There are of course other approaches to evaluating the impact of emissions. One is to use IAQ models to predict indoor concentrations of pollutants and then incorporate time-activity patterns of people, to calculate exposures (e.g., in micrograms inhaled per day). This is especially relevant for individual pollutants for which dose-response data are available because health risk estimates can then be calculated (Stolwijk 1987). Another approach is to use panels of people to judge the perception and acceptability of emissions (Fanger 1988). This can be useful for identifying problematic materials and estimating ventilation requirements to avoid occupant dissatisfaction with odors and irritant emissions without making chemical measurements.

We are now at a point where researchers, building designers and architects, building managers, and manufacturers of materials can begin working together toward a goal of low-emitting materials. One place to start that joint effort is the adaptation of research procedures for emissions testing to more routine procedures for use by industrial manufacturers of materials (White 1988). Emissions testing by manufacturers can lead to both low-emitting materials and guidelines to consumers on conditioning of materials prior to use.

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STRATEGIES FOR THE DEVELOPMENT OF INDOOR AIR QUALITY STANDARDS

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In recent years, radon, formaldehyde, numerous solvents, asbestos, and nitrogen oxides have been repeatedly studied, both as they occur indoors and for their potential health effects. System studies encompassing pollutants in the context of their occurrence in an environment containing many other pollutants are, however, few and are primarily associated with the sick building syndrome (SBS). In general, indoor air pollutants can be categorized in two distinct groups. The first group consists of pollutants that are known to cause chronic effects such as cancer and chronic respiratory diseases. They can be assessed on the basis of their known or assumed dose response function. The second, and possibly more important group, consists of those pollutants that cause acute effects such as allergic reactions, irritation of the eyes and respiratory system discomfort, and similar effects. Their assessment requires the availability of a dose response function. Such a function will almost certainly have a threshold which is, however, not constant, and varies with the sensitivity and perception of individuals.This paper discusses these two groups, evaluates the assumed dose response functions, identifies those areas requiring a decision based on risk assessment, and provides a framework for regulations of indoor air pollutants.

INTRODUCTION

Traditionally, the emphasis on air pollution has dealt with atmospheric air or more precisely outdoor air. It has been presumed that if emissions from stationary sources such as power plants, chemical production facilities, and other manufacturing processes were reduced, the air pollution would be mitigated. Laws going back to the 19th century limited the activities of stationery sources. During the 1950s and 1960s, the first significant laws on mobile sources were enacted. These laws, as significant as they were, followed the same assumption as those dealing with stationery sources. The underlying philosophy was the concept of undesirability, involuntary exposure, and the acceptability of voluntary exposure. Limitations on emission of air pollution from production facilities reduced the exposure to pollutants to those who were not directly involved in the generation and release of air pollutants. Limitations on emission from mobile sources followed a similar approach. Accordingly, the automobile manufacturers were forced to reduce tail pipe emissions. However, the drivers of the automobile had comparatively significant limitations. To this date, the concept of voluntary and involuntary exposure has dominated the U.S. regulatory system.

Indoor air has been only recently recognized as an environmental problem. The primary reason for such a late recognition is that exposure to indoor air pollutants is essentially entirely voluntary. An example of the problem is radon that has been known to be a carcinogen for several decades. The occurrence of radon in indoor air has been known (Stanley and Moghissi 1974) and the need for its control has been expressed as early as 1975 (Moghissi and Carter 1976).

The first recognizable air pollution law was enacted in 1955 and was redefined in 1970. There have been numerous amendments to it since that time. The laws dealing with water, pesticides, toxic substances, radioactive materials, and several other environmental media and pollutants have been enacted during the decades of the fifties to the seventies. In contrast, indoor air was and, to a great extent, continues to be unregulated. From the standpoint of public health, this neglect is unfortunate. People spend significantly more time indoors than outdoors, and thus, the public health implications of the polluted air indoors are more relevant than the outside air. In the most recent past, great strides have been made in the identification and classification of indoor air pollutants. The results of these studies have shown an extremely complex problem. The complexity of the indoor air has led to the belief that no effective standards can be developed for indoor air, and thus, it cannot be subjected to any regulation. This school of thought suggests that the current ambient air quality standards can be applied to the indoor air. Furthermore, for hazardous air pollutants, an acceptable risk can be agreed upon, and this risk may then be converted to a concentration which, in turn, could be used as a standard.

This paper attempts to evaluate potential options for the development of standards for indoor air. In the context of this paper, standards may be regarded as guides, local ordinances, enforceable regulations, or other appropriate limits. Furthermore, this paper relies upon the U.S. system in other countries and, internationally, that may be more suitable for evaluation. However, the familiarity of the author with the U.S. system favors its usage.

REGULATIONS OF AIR POLLUTANTS

In the U.S., there are three groups of regulated air pollutants. Five air pollutants have been regulated and the National Ambient Air Quality Standards (NAAQS) have been developed for them. For the sake of simplicity, they will be referred to as NAAQS pollutants. A second group of air pollutants are Hazardous Air Pollutants (HAPs). These are regulated at the source of emission through the National Emission Standards for Hazardous Air Pollutants (NESHAPs). Finally, the Occupational Safety and Health Administration (OSHA) has standards for specific pollutants for the work place. These standards are expressed as Permissible Exposure Limits (PEL) and Short Term Exposure Limits (STEL). At occupational level, PEL and STEL have replaced Threshold Limit Values (TLV) developed through the consensus process of the American Conference of Governmental Industrial Hygienists (ACGIH 1980). Because these pollutants have been already assessed, it appears that they would be useful as a starting point.

NAAQS pollutants

The U.S. Environmental Protection Agency (EPA) was given the responsibility for setting up limits for various air pollutants. The EPA has developed standards for carbon monoxide, sulfur dioxide, nitrogen oxides, ozone, and particulate matter (USEPA 1987a). These standards are periodically reviewed and revised, and the revision is based on documents called Air Quality Criteria. A discussion on how these air pollutants are developed is beyond the scope of this paper. However, the determinant factor in NAAQS is health effects.

Numerous discussions have been held at the EPA on how to treat the sensitive populations. For example, it is known that those afflicted with asthma are more sensitive to ozone than those who are not. The question repeatedly raised is that if one covers asthmatics, one would also have to cover those who may have allergic reaction to specific pollutants. There are many other even more sensitive populations, and thus, one ends up with zero as a standard for most pollutants. In general, the EPA has attempted to avoid answering these questions by using the rule of reason.

The combined effects of the five NAAQS pollutants are treated by the EPA using the Uniform Air Quality Index (USEPA 1979; Ott 1978), based on the Pollution Standard Index (PSI). Stated simply, the concentration of each pollutant is divided by its limit and a percent is computed. The so-called computed percents are added up. Therefore, if all pollutants have reached their respective limit, the PSI would be 500 (5 times 100%). The EPA has by regulation assigned value judgements to the PSI.
These are:

0 - 50	= good
51 - 100	= moderate
101 - 199	= unhealthful
200 - 299	= very unhealthful
300 and above	= hazardous

For example, an evaluation of curves used by the EPA shows that PSI is intended as a health indicator. The ozone curve used for the computation of PSI shows a linear relationship 235 $\mu g/m^3$ (EPA's standard for ozone) to zero concentration. Although never stated, EPA used a dose response function, assuming a linear, non-threshold relationship between the concentration and an adverse health effect.

Hazardous air pollutants

The U.S. law identifies air pollutants that are presumed to be associated with adverse health effects essentially at any concentration as hazardous air pollutants. Accordingly, they are regulated at the source. In effect, the concept of As Low As Reasonably Achievable (ALARA), known in the radiation protection field, is used in setting NESHAPs (USEPA 1987b). For example, carcinogens are regulated as HAPs. The HAP concept is potentially as valid for outdoor air as it would be for indoor air. However, the application of the NESHAP concept to indoor air would probably pose certain problems. The only standard for a HAP pollutant promulgated for indoor air is radon (USEPA 1983).

Occupational standards

The occupation exposure to various chemicals and agents is regulated by the Occupational Health and Safety Administration (OSHA 1987). OSHA has developed PEL for 40 h/week exposure of individuals above 18 years of age. The PEL could be used as a guide for development of indoor air standards using appropriate modifications and safety factors. Unfortunately, safety factors are not easily derived. An indication of potential safety factors can be seen from comparing the OSHA values for NAAQS pollutants. The safety factor for SO_2 is 35 (13 000 vs. 365 $\mu g/m^3$), 55 for CO (55 vs. 10 mg/m^3) and one for ozone. Obviously, there is no simple safety factor.

Other standards

During the implementation of the law dealing with the abandoned hazardous waste disposal sites, the EPA needed standards to be used for cleanup of these sites. In general, the EPA has used Maximum Containment Levels (MCL), the enforceable drinking water limits for application in setting cleanup standards. Obviously, MCLs can be used for indoor air by adjusting the route of exposure and making appropriate modifications. Furthermore, the EPA has recognized that the number of agents for which MCLs were available is limited and thus a basic methodology is needed to provide for MCL substitutes. These substitutes are called Health Advisories (HA). Although HAs have only been developed for drinking water pollutants, the methodology applies to intake via inhalation as well. Briefly, a reference dose (RfD) is computed by using the animal no observed effect level (NOAEL) or lowest observed effect level (LOAEL). The RfD is computed based on

$$RfD = \frac{\text{NOAEL or NOAEL in mg/kgd}}{\text{Uncertainty Factor}}$$

The uncertainty factors are 10 for human NOAEL data, 100 for human LOAEL or animal NOAEL data, and 1000 for animal LOAEL data. The RfD is converted to HA by assuming a 70 kg person and a certain inhalation rate (Ohanian and Cotruvo 1986). The EPA's approach to derive RfD and HA is subject to considerable criticism. However, this criticism is generic and would impact the entire regulatory process rather than that of indoor air.

APPLICATION OF CURRENT STANDARDS TO INDOOR AIR

From the foregoing, it appears that the concentration limits can be developed for essentially every pollutant. The development of standards for indoor air would require a categorization of pollutants into two distinct categories: those causing chronic effects, and pollutants whose effects are presumed to be associated with a threshold. For the sake of simplicity, the first group is henceforth referred to an non-threshold and the second group as threshold pollutants. The specific requirements for the standard development would be as follows:

1. Characterization of most components of indoor air;
2. Categorization of so-identified pollutants into threshold and non-threshold pollutants;
3. Agreement on an acceptable risk for non-threshold pollutants;
4. Conversion of the risk limit to concentrations;
5. Development of concentration limits for threshold pollutants;
6. Treatment of microbiological pollutants, irritants, odorants and other "unconventional" pollutants;
7. Combination of the entire information into a cohesive system.

Characterization of indoor air pollutants

There have been numerous studies dealing with the identification of indoor air pollutants. The results of three symposia devoted to indoor air (Spengler et al.

1982; Berglund et al. 1986; Berglund et al. 1989) contain numerous studies identifying indoor air pollutants and providing sufficient information to assess their prevalence. Although there continues to be a need for improving the knowledge base, indoor air pollutants are reasonably characterized to make the development of standards, based on the system identified above, possible.

Categorization of indoor air pollutants

The objective of this process is to assign indoor air pollutants to the two categories, threshold and non-threshold pollutants. This categorization is significantly more complicated than it may appear. The identification of carcinogens is reasonably straightforward. There are a limited number of human carcinogens; and if one adds the entire groups of animal and suspected carcinogens, the number remains comparatively small. Once the non-threshold pollutants are identified, they are placed in one category and the others are considered as threshold pollutants. There are, however, other non-threshold agents appearing in indoor air. Many chemicals may cause chronic effects, if humans are exposed to them long enough. Therefore, identifying chemicals that may cause effects such as chronic respiratory diseases may be somewhat difficult.

Standards for non-threshold pollutants

The development of an acceptable risk is an integral part of most environmental regulations. However, this is probably one of the most challenged areas of environmental protection and is often subjected to court actions. For example, the regulations of HAPs were successfully challenged in the U.S. courts and the EPA is in the process of reevaluating the entire group of NESHAPs (USEPA 1989). Despite these problems, a risk limit can be agreed upon and, once this agreement has been reached, the development of a concentration equivalent of that limit would require a risk assessment for that pollutant. In the U.S. it has become common to report the "upper limit of risk" consisting of the upper 95th percentile of statistical errors. Given the scarcity of data, the errors are often large and thus the upper limit of risk may contain conservatism exceeding several orders of magnitude. Despite the inadequacy of the data, cancer risk assessment has reached a certain degree of maturity and has been incorporated into the U.S. system of regulations (USEPA 1986).

Standards for threshold pollutants

Because of the presence of a threshold below which no adverse effect is anticipated, the development of standards for threshold pollutants is significantly less contested than those for non-threshold pollutants. Despite problems shown in using occupational standards, the toxicological evaluations preceding the standards development can be used for the development of HAS. Furthermore, the list of chemicals that have been evaluated, and for which an RfD is calculated or is readily available, is growing rapidly. Therefore, the computation of concentration limits for threshold pollutants is reasonably achievable.

Treatment of unconventional pollutants

The requirements of indoor air are significantly different from those of the outside air. Due to the peculiarities of indoor air, an acceptable indoor air must not only be healthy, but also pleasant. Furthermore, the problem of the growth of molds and other microorganisms must be addressed. One must also consider odorants and irritants. The development of dose response functions for a single odorant appearing alone is relatively simple. The problem is a decision on what constitutes pollution and what is a pleasant smell. Whereas most individuals will agree that hydrogen sulfide is a pollutant because of its odor, there is no agreement on the effect of other odorous materials. What may be someone's perfume is someone else's pollutant. Furthermore, an assessment of the effect of multiple odorants is extremely difficult if not impossible. The situation is somewhat less controversial but no less easy with irritants. Whereas the agreement on what is an irritant is reasonably easy to achieve, the development of a dose response function is probably difficult. An approach such as RfD is not necessarily useful for irritants because of inherent problems associated with the mechanism of irritation. According to the EPA's approach, an RfD is computed by taking a LOAEL for humans and using a safety factor of 100. In the case of irritants, the establishment of a LOAEL in humans would be fundamentally possible. Using the LOAEL and a safety factor of 100, the computed HA would lead to concentrations far less than ambient concentrations of most irritants.

An area of considerable concern is that of microorganisms. Although risk assessments have been conducted for microorganisms (Haas 1983), and they lend themselves to indoor air; the problem remains essentially unattended.

Mixture of pollutants

Whereas the development of information discussed in the preceding steps is principally possible, the development of standards for the indoor air containing a number of pollutants is associated with significant problems. Because of the acceptance of additivity of carcinogenic effects and most other non-threshold pollutants, it is not difficult to develop standards for this category of pollutants. However, the standards for pollutants for chronic effects other than cancer will not be readily achievable, regardless of the chosen approach.

Standards development for threshold effects will be undoubtedly laborious and will be associated with formidable problems. The first inclination would be to use an approach such as PSI as used by the EPA for ambient air. A simplified formula for such an approach would be:

$$IPI = \frac{1}{n}\left(\frac{C_1}{L_1} + \frac{C_2}{L_2}\cdots\cdots\frac{C_n}{L_n}\right)$$

where IPI is the Indoor Pollution Index, C the Concentration of pollutants, L the concentration Limit for pollutants, and n the number of pollutants included in the computation. The EPA ranges could be modified and used for decision making. These would be:

0 - 0.1	=	good
0.1 - 0.2	=	moderate
0.2 - 0.4	=	unhealthy
0.4 and above	=	hazardous

The advantage of IPI is its reliance on an already existing system. The PSI is a part of the U.S. regulations and it is used nationwide on a daily basis. The public is familiar with the system and it would take a simple arithmetic conversion to explain to the public the difference between PSI and IPI. Furthermore, because PSI has undergone regulatory scrutiny, it appears that IPI would have fewer problems in being adopted as compared to a new system.

These major advantages should not overlook significant problems with PSI and IPI. As stated previously, the underlying biological foundation of PSI is as follows:

1. The dose response curve of pollutants follows a linear non-threshold function;
2. The effect of unrelated threshold pollutants is additive.

Both assumptions are clearly incorrect. There is no evidence that the biological effects of threshold pollutants follow a linear non-threshold function. The available evidence points to the opposite conclusion. The threshold pollutants do not follow a linear function below a certain exposure and are associated with the threshold. Although the location of the threshold may not be easily determined, there is no disagreement on the existence of a threshold. Furthermore, the additivity of effects must be questioned. These problems are further compounded by the presence of microbiological pollutants, irritants and odorants in the indoor air.

As with carcinogens, an upper limit can be developed for microbiological pollutants. This limit would be based on a risk assessment and would, in effect, attempt to balance the benefit of introducing chemicals causing the destruction of microbiological agents with the potentially adverse effects of that chemical agent to humans. These chemicals would be introduced only after other methods, such as increasing air circulation, are shown to be ineffective.

Evaluation of the effects of multiple irritants and odorants poses unique problems. The studies conducted by several investigators (Berglund and Lindvall 1986; Mølhave et al. 1986; Engen 1986) indicate that irritation is a complex problem and that the effect of a single irritant cannot necessarily be used to evaluate the irritation effects in a mixture. The effects of irritants may be additive or synergistic. A similar situation exists for odorants.

ALTERNATIVE STANDARDS

The strategy outlined above is extremely laborious. Furthermore, it leaves a number of unresolved issues and its scientific validity is less than adequate. There may be other approaches that are less laborious and may be at least as effective as the additive approach. The foundation for the scientific basis for some of these alternative approaches is laid by the Swedish group (Berglund and Lindvall 1986; Berglund et al. 1976; Berglund et al. 1982). A potential alternative may consist of the following approach:

1. Standards development for non-threshold pollutants based on additivity of individual components;
2. Treatment of microbiological pollutants as a class;
3. Assurance that no pollutant exceeds a certain limit, such as HA;
4. Treatment of threshold pollutants, irritants and odorants as a combined group.

The first three criteria are similar to the strategy outlined above. However, in contrast to the additivity approach, only major threshold pollutants must be identified and concentration limits must be developed only for these major constituents. An advantage of this alternative approach is the treatment of most pollutants as a system. Much of the discussion on Sick Buildings Syndrome is based on the premise that indoor air is a system rather than the combination of individual pollutants. According to this system, the human response may be significantly different to a pollutant that may appear singly as compared to its appearance in a mixture of pollutants, at a given temperature, humidity and other comfort parameters. According to this system, there are indicators of indoor air pollution that can be used to assess the prevalence of certain categories of pollutants.

RECOMMENDED APPROACH

Clearly, the regulation of every pollutant that may appear indoors is not possible. Therefore, one must choose those that require particular attention and group others together in a fashion that reduces potential health risks and is enforceable. One can logically identify three indicators: carbon dioxide, particulate matter, and total carbon. Carbon dioxide is an excellent indicator of human activity. It is the product of human breathing and combustion, two dominant sources of indoor air pollution. Particulate matter is another excellent indicator of human activity. Cooking, heating with wood, smoking, and several other human activities introduce particulate matter into the air. Furthermore, many allergens and microbiological pollutants are in particulate form. Total carbon is another indicator of pollution. The overwhelming majority of indoor air pollutants contain carbon and thus total carbon, in association with total carbon dioxide, is an indicator of indoor air pollution. Pollutants such as radon can be regulated independently. These three indicators must be related to potential effects of indoor pollutants, including irritation and odor. Much of the needed information is already available from studies dealing with composition of indoor air pollutants and their sources. The areas requiring further studies are those related to how the occupants of a dwelling perceive the effect of various pollutant mixtures occurring in the indoor air. These could be assessed in a system similar to odor evaluation by panels who would rate the quality of air. This psychological and somewhat subjective rating can be then included in an appropriate system using indicators as the primary parameters. The research that would be required to relate these and other potential indicators to an acceptable indoor air would be significantly less laborious than the conventional approach to air pollution abatement. It has also the advantage of no pretense as is implicit in PSI or any other additive system.

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INDOOR AIR QUALITY REQUIREMENTS FOR HEALTHY OFFICE BUILDINGS: RECOMMENDATIONS BASED ON AN EPIDEMIOLOGIC STUDY

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Indoor air quality requirements for healthy (healthful) office buildings in Nordic climate are presented based on the results of an epidemiological study. The study was performed in the Pasila Office Center, a modern eight-story building with 2150 office workers, located in Helsinki. The results of the study concerning the indoor air quality and health are summarized, and recommendations and their limitations are discussed. The following indoor air quality requirements are made for healthy (healthful) office buildings: (1) The recommended room temperature is 21 ± 2°C, (2) individual control of the room temperature is desirable, (3) relative humidity should exceed 20% in all conditions, (4) the minimum airflow rate for good ventilation is 10 L/s · persons, (5) windows should be openable to give extra individual control of the environment, and (6) involuntary exposure to environmental tobacco smoke should be avoided.

INTRODUCTION

The design and construction of healthy office buildings has become a major challenge for building designers and constructors due to the increased number of symptoms and environmental complaints expressed by office workers. The problem of indoor air pollution in office buildings has increased in two ways: new sources of potentially hazardous indoor air pollutants, such as building materials and office equipment, have been introduced continuously and the reduced ventilation rates after the energy crisis have increased the accumulation of pollutants in indoor air.

Often the cause of the symptoms and complaints has not been found in spite of thorough measurements of indoor air, although the occupants have often blamed the poor indoor air quality and the

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ventilation system for their problems. The phenomenon as well as the outcome has been called the sick building syndrome (SBS), tight building syndrome, building illness, building-related illness, and stuffy offices (Akimenko et al. 1986; Finnegan et al. 1984). Finnegan et al. (1984) defined empirically the six components of the SBS: nasal, eye, and mucous-membrane symptoms, lethargy, skin symptoms, and headache. The definition and the concepts of the phenomenon are confusing which make the comparison of results from different studies difficult. However, an increasing amount of research has been directed to find the determinants of the SBS.

Both in laboratory studies (Rasmussen 1971) and in field conditions (Andersson et al. 1975), it has been shown that the rise of temperature in constant relative humidity increases the sensation of dryness. In a Danish office building study, Valbjörn and Kousgard (1984) reported temperature above 23°C to increase the occurrence of mucous membrane symptoms but not headache. In a Canadian cross-sectional office building study, periods of high temperature and low relative humidity with imperfect ventilation were suggested to be contributory factors to typical SBS symptoms, although the effects of the temperature were vaguely documented (McDonald et al. 1986). The results of laboratory studies (Andersen et al. 1973; Rasmussen 1971) as well as of two epidemiologic office building studies (Andersson et al. 1975; Franzen 1969) on the human ability to sense the relative humidity are contradictory, although it is generally accepted that the increase of temperature increases the sensation of dryness in the range of indoor conditions. In two recent British studies the use of air conditioning with humidification has been associated with the SBS. In the first study of 46 office buildings by Hedge et al. (1987), a systematic relationship between the prevalence of different work-related symptoms and the engineering characteristics of the building ventilation system was demonstrated. Symptoms were most frequent in the air-conditioned offices, especially with water-based systems. In another similar study by Harrison et al. (1987), workers of mechanically ventilated office buildings with and also without humidification and recirculation had more SBS symptoms than workers in naturally ventilated buildings.

The minimum ventilation rates were universally lowered after the energy crisis to cut down on energy costs. In Finland the recommended minimum ventilation rate is 4 L/s · person in nonsmoking rooms. Low ventilation rates have been associated with the sick building syndrome or the synonym tight building syndrome which expresses the expected cause of the problem (Taylor et al. 1984; Turiel et al. 1983).

Exposure to environmental tobacco smoke (ETS) is a well-known cause of annoyance. According to laboratory studies (Cain et al. 1983), increase in ventilation rate is not a feasible solution to decrease adverse effects of smoking. In order to achieve 75% acceptance, the ventilation rate in smoking occupancy (17.5 L/s) would need to equal over four times the rate in non-smoking occupancy (4.0 L/s). However, in another study (Taylor et al. 1984), ETS was not found to relate with the SBS.

The symptoms of the SBS have been reported to associate with personal characteristics, such as gender with more women reporting symptoms than men (Finnegan et al. 1984; Jaakkola 1986; Burge et al. 1987; Skov et al. 1987) and presence of allergic disease (Jaakkola 1986), psychosocial factors such as job satisfaction, work stress, and social atmosphere at work (Jaakkola 1986; Skov et al. 1989) and type of work, such as photocopying (Skov et al. 1989) and VDU (video display unit) work (Hedge et al. 1989).

We performed an experimental and epidemiologic study in the Pasila Office Center, a modern eight-story building with 2150 workers, located in the center of Helsinki. The purpose of this paper is to summarize the results of the epidemiological part concerning the indoor air quality and health and to discuss the possible recommendations and their limitations. The details of the results have been reported elsewhere (Jaakkola 1986; Jaakkola et al. 1987, Jaakkola et al. 1989; Lindholm et al. 1987; Jaakkola et al. in press; Reinikainen et al. 1988).

MATERIALS AND METHODS

Pasila Office Center Study

Building. The Pasila Office Center was completed in 1981. The building was designed immediately after the energy crisis with good energy economy. Floors 3 to 8 consist of 1247 small offices, while the two bottom floors include heterogenous spaces for service and commercial activities. There are three floors below the ground level and these house clerical, printing, and service workers. The building is mechanically ventilated, mainly without recirculation and humidification. The windows are openable. The building is a concrete structure and has exterior walls of brick. The ventilation rates were known to be high.

Background. The office workers had exhibited symptoms typical of the sick building syndrome described in other studies, and the symptoms were often associated with poor air quality. The local medical center provided the initiative for the study. The aim of the study was to clarify the association of symptoms and complaints with mechanical ventilation and other indoor air factors. The experimental part was designed to test a hypothesis, that reducing the rate of mechanical ventilation would alleviate the symptoms (Jaakkola 1986; Jaakkola et al. 1987). In the epidemiologic part, the association of symptoms and environmental complaints with different indoor air factors was studied.

Study design. Baseline data of air handling and heating systems were collected, and measurements of airflow, temperature, and relative humidity in the office rooms were taken in February of 1985. After the baseline data collection, the ventilation was shut off in one part of the building, reduced in two parts, and one part was left unaltered as a reference. A self-administered questionnaire was sent to each worker once in February and twice after the change in ventilation, in March and April. These inquired about symptoms, diseases, environmental complaints, attitudes toward working conditions, and health behaviour.

Indoor air measurements. Temperature, airflow, and relative humidity were measured in a random sample of 410 rooms. Temperature and relative humidity was measured with VAISALA HMI-31 capacitive sensors, whose accuracy is ± 0.3°C for temperature and ± 2% for relative humidity. Airflow in the exhaust air registers was measured with a calibrated Wallac anemometer, whose accuracy is better than 15%. The mean of measured airflows in a given ventilation zone was used to estimate the airflows in other rooms of the zone. The validity of the estimates was tested by kappa statistics for categorical variables (Fleiss 1981). The estimates showed good concordance with the measured airflows with a kappa value of 0.54 (95% confidence interval 0.42-0.66). The relative humidity did not vary between nonhumidified rooms at any given point of time, and was very low in February (RH 10-20%). In humidified rooms the RH was in the range of 45-55%. Due to the unbalanced heating system the variation in temperature was large (21-26°C). The concentrations of chemical and biological factors, particles, ions, and radon were also measured in a small number of rooms with typical furniture and textiles. Air samples were taken into the TENAX adsorbent with a high volume air pump. The samples were analysed by gas chromatography. Formaldehyde was measured with a standardized chromotropic acid method (SFS 3862). Carbon dioxide concentration was measured with the BINOS infrared analyser and was recorded 24 h/d. The particulate samples were collected by the two-fraction method between 8 a.m. and 4 p.m. using a Nuclepore filter. A gravimetric measurement of the mass concentrations was carried out. The concentrations of indoor air pollutants were far below the values known to cause adverse health effects and were not considered to be important.

Study populations

The response rates in the first, second, and third inquiries were 81, 70, and 71, respectively. There were 1719 persons in the whole study group, 732 men (42.6%) and 987 women (57.4%). The average ages were in men 38 y (SD 12 y) and in women 42 y (SD 11 y).

Suitable subpopulations were chosen to study the effects of room temperature, relative humidity, ventilation rate, and exposure to environmental tobacco smoke (ETS) on symptoms. A cross-sectional comparison of symptoms in different levels of respective indoor air factors was made in otherwise comparable conditions. The effect of individual (sex, atopic tendency) and psychosocial factors, which were shown to associate with the symptoms in the main study (Jaakkola 1986), were taken into account in the analyses.

Room temperature. A cross section of the baseline data collected in February was used to study the effect of room temperature. Room temperature was recorded in 410 rooms in 3 to 8 floors and one person of each room was chosen randomly for the analyses (n = 333). The ventilation rate and relative humidity was measured in each room. None of these rooms were humidified. Relative humidity was homogeneously low (10-20%).

Relative humidity. Humidification was used only in some areas in the floors below the ground level. The effect of humidification was studied in three cross sections in February, March, and April (n = 257). A total of 122 persons working in humidified rooms and 135 persons in similar nonhumidified rooms were chosen. The room temperatures were estimated in later measurements.

Ventilation rate. The effects of the ventilation rate were studied in the cross section after the reduction of mechanical ventilation using subjects from the control area and two areas with reduced ventilation. One person from each room was chosen randomly (n = 581). Subjects in the area without any mechanical ventilation were left out. None of the rooms were humidified.

Methods

The main outcome, a summation score (range 0-6) was calculated to describe the total amount of symptoms including the six components of SBS suggested by Finnegan et al. (1984): nasal, eye, and mucous membrane symptoms, lethargy, skin symptoms, and headache. The subjects were asked about the occurrence of symptoms during the previous 7 d and were also asked to define if the symptoms were experienced mostly at home, mostly at work, or equally at home and work. The occurrence of a symptom mostly at work or equally at home and work would add one point in the respective component of the summation score. The symptoms occurring mostly at home were not included in the summation. Inclusion of symptoms occurring equally at work and at home was justified on the basis that part of the effect of office environment could be subacute and thus taking place also at home. In the cross-sectional analyses, factors in association with the SBS score were systematically screened in bivariate analyses, and a multiple linear regression model was constructed to define the determinants of SBS. Sex, atopic tendency, and attitude towards the psychosocial atmosphere at work were found to be determinants of the SBS and were taken into account as potential confounders.

Finally, the mean SBS scores in different levels of studied indoor air factors, adjusted by the potential confounders, were calculated in the analysis of covariance.

RESULTS

Indoor Air

The relative humidity during the study in February was low (10-20%) which reflects the cold winter season. The ventilation rates were in the average large (mean 26 L/s · person) but varied considerably (SD 10 L/s · person, range 7-70 L/s · person). The mean room temperature was high and the variation large (mean 23.3°C, SD 0.9°C, range 21-26°C). The concentrations of measured indoor air pollutants were far below the values known to cause adverse health effects. The mean carbon dioxide concentration was 420 cm^3/m^3 and did not exceed 950 cm^3/m^3. The concentration of formaldehyde was 47 $\mu g/m^3$ in a room with typical furniture, textiles, and ventilation rate. The maximum concentrations of organic gases were: ethanol 98 $\mu g/m^3$ (mean 73 $\mu g/m^3$), hexane 10 $\mu g/m^3$ (9 $\mu g/m^3$), acetone 33 $\mu g/m^3$ (32 $\mu g/m^3$), and toluene 165 $\mu g/m^3$ (107 $\mu g/m^3$).

Room temperature

The room temperature was found to be the most important determinant of the adjusted SBS score. There was a linear correlation between the category of the room temperature and the mean adjusted SBS score (Table 1).

Relative humidity

The mean adjusted SBS score was higher among the workers in the nonhumidified rooms in all three questionnaires, although the difference was statistically significant only in the second questionnaire (Table 2).

Ventilation rate

Before the change in the ventilation in February, the ventilation rates were generally high (mean 26 L/s · person, range 10-70 L/s · person) and no association with the SBS score was found (Table 3). After the reduction of ventilation, a statistically significant association between the ventilation rate and the mean SBS score was seen (Table 4).

Environmental tobacco smoke

The mean SBS score adjusted by sex, atopic tendency and attitude towards psychosocial atmosphere at work, was among exposed 3.3 ($n = 57$) and among unexposed 2.7 ($n = 874$). The difference was statistically significant ($p < 0.01$).

DISCUSSION

Study design

The Pasila Office Center Study was designed primarily to test if the reduction of originally high airflow rates of mechanical ventilation would alleviate the symptoms experienced by the office workers. The results of the short-term trial, presented elsewhere (Jaakkola et al. 1987), showed that the airflows of mechanical ventilation per se do not relate to the SBS symptoms. Here, the epidemiological results of several cross-sectional analyses are summarized and discussed.

The cross-sectional study design is inherent with the basic problem that the time referent of the information on the determinant coincides with that of the outcome. Thus, the possibility exists that the subjects have been selected to the categories of determinants (indoor air factors) according to the outcome (SBS score) or some other factor associated with the out-

Table 1. The adjusted mean SBS score in office workers in different categories of room temperature (°C) in nonhumidified rooms (February).

Room temperature (°C)	n	adjusted mean SBS-score
<22	30	2.1
22-<23	102	2.5
23-<24	135	2.8
>24	50	3.0

Linear trend by regression $p < 0.05$

Table 2. The adjusted mean SBS score (adjSBS) in office workers in the humidified and nonhumidified rooms.

Type of	February		March		April	
Rooms	n	adjSBS	n	adjSBS	n	adjSBS
Humidified	122	2.5	78	2.4 *	78	2.2
Nonhumidified	132	2.8	98	3.1	98	2.8

* analysis of covariance: $p < 0.05$

Table 3. The adjusted mean SBS score in office workers in different categories of ventilation rate (February).

Ventilation rate (L/s/person)	n	adjusted mean SBS-score
10-<15	75	2.6
15-25	181	2.7
>25	250	2.6

analysis of covariance: n.s.

Table 4. The mean SBS score in office workers in different categories of ventilation rate (April).

Ventilation rate (L/s/person)	n	mean SBS-score
<5	28	2.8 *
5-<10	121	2.6
10-<15	52	2.5
15-	363	2.2

* analysis of variance: $p < 0.05$

come. E.g., women who express more symptoms could choose or be assigned to rooms with higher temperature, which would cause a biased estimate of the occurrence relation between the SBS score and the room temperature. Here, the confounding by sex is controlled by statistical analysis, but the most difficult problem is created by the unknown factors which cannot be controlled.

Room temperature

Room temperature was found to be the most important indoor air determinant of the SBS symptoms. The room temperature varied in otherwise similar rooms due to the heating in blocks of four rooms and the lack of individual control of room temperature. This created an exceptional situation for the estimation of the effects of temperature. The variation of the room temperature (21-26°C) was large and the mean temperature was high (23.3°C). There was a linear correlation between the increase in both the SBS symptoms and the sensation of dryness and temperature, as reported elsewhere (Jaakkola et al. 1989). It was also shown that there was an excess of SBS symptoms both when the temperature was considered too cold and too warm. This indicates that these symptoms can be also seen as an expression of general dissatisfaction with the temperature which could be improved by individual control of the room temperature. The association of high temperature with the SBS symptoms was strong but in accordance with earlier studies where the sensation of dryness (Andersson et al. 1975) and mucous membrane symptoms (Valbjörn and Kousgard 1984) were found to be related with room temperature. In our study, the association was found in extremely low relative humidity (10-20%) but sufficient airflow rates ($\bar{x}$ = 26 L/s · person, range 10-70 L/s · person). Low relative humidity modifies the effect of high temperature on the sensation of dryness, as shown in laboratory experiments (Andersen et al. 1973) but possibly also on the SBS symptoms. The effect of low ventilation on the relation between the temperature and the SBS symptoms is not well documented.

Relative humidity and humidification

During February, 78% of the office workers felt that the indoor air was too dry. Although the building was mainly nonhumidified, there were some areas in the floors below the ground where the humidification was used because of work processes. Workers from these rooms and a reference group of subjects working in similar conditions, except without air humidification, was chosen. The groups were also similar with respect to age and sex. The difference in relative humidity between humidified (RH 45-55%) and nonhumidified rooms (RH 10-20% in February, 20-25% in March and April) was remarkable. The humidity was homogeneous in humidified and nonhumidified areas. The rooms are more heterogenous than in the 3 to 8 floors used in the temperature analyses, but no systematic difference can be conceived. The mean adjusted SBS score was higher in the workers of nonhumidified rooms in all three cross-sectional analyses, although the difference was statistically significant only in one cross section.

These results are in contradiction to the results of the two British studies (Hedge et al. 1987; Harrison et al. 1987), if it is focused only on the type of the ventilation system per se. The level of indoor air relative humidity without humidification and the function of the air-conditioning system are probably more important than the presence or absence of humidification when considering the advantages and disadvantages of humidification with respect to human health. It is apparent that the relative humidity indoors in England is rarely or never as low as in Nordic countries during the cold winter days, when the low relative humidity of air causes dryness symptoms. In Nordic winter conditions humidification of indoor air seems to alleviate dryness symptoms, which are a major component of the SBS. Our results also show that air conditioning with humidification does not cause adverse health effects when functioning properly.

In our study, the proportion of subjects with sensation of dryness and dryness symptoms was significantly greater in nonhumidified rooms. The results of the detailed analyses are given in another presentation where the potential positive and negative effects of humidification were studied (Reinikainen et al. 1988). In earlier studies, the relative humidity in the control areas was over 20% also, well above the relative humidity in nonhumidified rooms in the Pasila Office Center in February. Most recent results of a Finnish six-period cross-over study provide more evidence on the possibility of alleviating the dryness and irritation of skin and eyes, and allergic symptoms by the use of air humidification (30-40%) during winter with low natural relative humidity (20-30%) (Reinikainen et al. 1990).

Ventilation rate

During the baseline stage in February, the ventilation rates were well above the minimum airflow rates and no association between airflow rate and SBS symptoms could be seen. There was no association between the room temperature and the ventilation rate. According to our results, a ventilation rate above 10 L/s · person seems to be sufficient with respect to the SBS symptoms. The ventilation rates were reduced in part of the building, one part remaining as unchanged reference. Results after the change in ventilation show that decrease in ventilation rates increases SBS symptoms. There is an increase of symptoms already when the ventilation decreases below 15 L/s · person.

RECOMMENDATIONS

Our recommendations are based on the results of an epidemiologic study in an office building in Helsinki. Our results suggest that indoor air temperature, relative humidity, and ventilation rate are important determinants of SBS symptoms. Also, exposure to environmental tobacco smoke seems to cause similar symptoms. The study was performed in Nordic winter climate which probably limits the generalization of the results.

The following indoor-air-quality requirements are made for healthy office buildings:

1. The recommended room temperature is 21 ± 2°C.
2. There should be an individual control of the temperature.
3. Relative humidity should exceed 20% in all conditions.
4. The minimum airflow rate for good mechanical ventilation is 10 L/s · person.
5. Windows should be openable to give extra individual control of the environment.
6. Involuntary exposure to environmental tobacco smoke should be avoided.

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LETTERS TO THE EDITOR

AN ESTIMATE OF ADULT MORTALITY IN THE UNITED STATES FROM PASSIVE SMOKING

Dear Editor:

Repace and Lowrey (1990a) and Wells (1990) are critical of the points I raised (Lee 1990) regarding the paper of Wells (1988). Some further comment is necessary.

Repace and Lowrey claim that I have argued the diseases of smoking are not even plausible in nonsmokers. This claim is false. As I have clearly stated (Lee 1989a), some effect of environmental tobacco smoke (ETS) is of course plausible. My view is, and always has been, that it is implausible that any effect of ETS might be anything like as large as that indicated by simplistic interpretation of the epidemiology.

One reason for my view is the massive discrepancy between the "epidemiological" estimate of risk of lung cancer from ETS (i.e., that based on taking the fragile epidemiological evidence at face value) and the "dosimetric" estimate (i.e., that based on extrapolating from the risk in relation to active smoking using estimates of relative exposure of passive and active smokers to relevant smoke constituents). Putting aside issues relating to a possible threshold, the size of this discrepancy is well illustrated when one considers that the epidemiological evidence suggests the excess lung cancer risk in relation to ETS exposure is 10-20% of that from active smoking (Lee 1988; 1989b) whereas the dosimetric evidence (Lee 1989a) suggests the factor is more like 0.5% (based on inhaled particulate matter or salivary cotinine) or 0.05% (based on retained particulate matter).

Remarkably, Repace and Lowrey (1990b) have tried to claim this discrepancy does not exist, noting "remarkable agreement" between risk assessments, whether epidemiologically or dosimetrically based. This totally erroneous conclusion has been reached by an analysis which (1) rejects any low dosimetrically based estimate as "being inconsistent with the epidemiology," (2) accepts a spurious dosimetrically based estimate of Fong (1982) which uses an extremely high estimate of exposure in passive smokers, and (3) includes an estimate from the NRC report (1986) as if it were dosimetric when in fact it is epidemiological, while ignoring a much lower dosimetric estimate.

Unlike Repace and Lowrey, this discrepancy is admitted by Wells, though his estimate of the magnitude of it is less than mine. Wells seeks to explain it in terms of differences in chemistry and physics between direct and passive smoking, though his explanation is not persuasive. He notes that particulate matter retention in the lung from ETS exposure tends to be mainly in the alveolar region of the lung, whereas that from direct smoking is predominantly in the tracheo-bronchial region. However, his calculation shows that alveolar retention from ETS exposure is still only 1% of that from direct smoking, far too low to explain the epidemiology even if all the lung cancer arose from deposition in the alveoli, which is of course not the case. It also seems difficult to align Wells' theories with studies by Garfinkel at al. (1985), Pershagen et al. (1987), and Trichopoulos et al. (1983) that suggest an association with squamous and small-cell carcinoma rather than with adenocarcinoma and large-cell carcinoma, as would be predicted.

Wells' argument concerning vapour phase and tar and nicotine are confusing and not clearly thought out. In the first place, tar, by definition, is the particulate phase. I suppose his hypothesis is that the transfer of some substances from the particulate to the vapour phase in ETS gives rise to a greater than expected risk of disease at noncontact cancer sites and of heart disease. However, if this hypothesis were true, and certain "harmful" elements in the particulate phase in mainstream smoke transfer to the vapour phase in ETS and hence do not impact on the lung, one would then clearly expect that the risk of lung cancer associated with ETS exposure would be even smaller from comparison with smokers' exposure than expected from a more simplistic dosimetric comparison, and not larger. Also, chemical considerations indicate that the majority of compounds likely to transfer from the particulate to the vapour phase would be simple hydrocarbons, with chemical classes such as polyaromatic hydrocarbons and nonvolatile nitrosamines staying in the particulate phase. What class of compounds does Wells have in mind that would be associated with disease at noncontact sites, and volatile enough to transfer from the particulate to the vapour phase in ETS?

Wells suggests that smoking might protect against effects of ETS. All things are possible, no doubt, but the evidence cited is scarcely compelling. The work of Remmer (1987), for example, is very unconvincing. Activation of enzymes is normally considered to indicate an increased risk of cancer, and not the reverse.

Wells attempts to reply to my criticisms of his theories concerning susceptible groups by using the erroneous definition proposed by Khoury et al. (1989), in which susceptibility is equated to the proportion getting a disease by a given age in the absence of competing risks. Susceptible means capable of getting disease. By the erroneous definition, people who survive Russian roulette would not be susceptible to bullets!

Publication bias may not be a major issue for lung cancer, although there is some indirect evidence of its existence (studies in the top third of the relative risk distribution are based on significantly lower numbers of cases than studies in the bottom third), but I believe it could be extremely important for heart disease. Here, there is a known large data set. The American Cancer Society's million-person study has published on ETS and lung cancer but has not published on ETS and heart disease (or any other cause of death) despite having information on many thousands of deaths among married neversmokers. Since there is a strong likelihood that no association was found (otherwise it would have been published) and since there are more heart disease deaths in that study than in all the studies Wells considers put together, severe publication bias seems very likely to have occurred.

The question of possible confounding in heart disease studies is still an open one. The only ETS studies that have data on the main confounders such as blood pressure, cholesterol, and body mass, have been based on extremely small numbers of deaths, probably too low for any sort of reliable adjustment.

The possibility that ETS might cause cancers not associated with direct smoking still seems minimal to me, despite Wells' arguments. The difference in ETS exposure between a smoker and a nonsmoker (due mainly to the smoker's exposure to his own cigarettes) seems certain to be higher than that between a smoker married to a smoker and a smoker married to a nonsmoker, so any risk associated only with spousal smoking should be viewed with suspicion. In fact, accumulated evidence to date does not indicate ETS has been consistently associated with any such cancer, chance being a likely explanation for a number of the isolated reports of associations.

The question of the extent of bias due to misclassification of active smoking status is a complex one which cannot be adequately dealt with in a letter. Like Wells, I am publishing separately on this subject, using new material. Some comments are, however, relevant. First, I must agree with Wells that some confusion had arisen in my early work from failure to distinguish the proportion of nonsmokers who are true current smokers from the proportion of neversmokers who are true current smokers. Since the epidemiology concerns neversmokers, misclassification of current as exsmokers is not relevant. At the time when all the early work was published, by myself (1987), by Wald et al. (1986), or by Wells (1986), there was in fact no evidence available on misclassification of current smokers as neversmokers, the cotinine studies considered all relating cotinine to current smoking habits. (It is strange that Wells includes my cotinine study in his evidence as no questions were asked on past smoking habits.) It is only recently that some more strictly relevant data have come to light, but the results are rather variable. Using this and other data on the proportion of exsmokers denying ever having smoked, I estimate that misclassification could explain the whole of the association seen with spousal smoking in U.S. men and a substantial part (some 60%) of the association seen in U.S. women. Misclassification at the level observed would also cause a substantial bias for Asian men but would not cause material bias for Asian women. However, evidence on misclassification rates in Asian women is sparse, though there are some indications it may be very high, e.g., the study of Saito (1988) which found that 55% of Tokyo University student women who smoked reported their family knew nothing about it. One problem in the whole issue that has not been fully recognised is the dependence of the misclassification rate on the particular circumstances of the study, and the need to correct each study individually for its own estimated misclassification rate. Correcting overall (meta-analysis) relative risk estimates for overall estimates of misclassification can lead to totally fallacious results.

Finally, I thank Dr. Hirayama for his comments on the discrepancy between his heart disease reports in 1981 and 1984. It is important to note that, elsewhere, Hirayama (1990) has now noted that his 1981 data were in error and has published revised figures which are consistent with his 1984 data.

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PASSIVE SMOKING: A REPLY

Dear Editor:

This letter is in reference to Lee's criticism (Lee 1991) of my paper (Khoury 1989). I believe the definition given in that paper is not erroneous if the factor of interest and the exposure dose are adequately defined. For example, for a given level of smoking for a certain number of years, x% of people will develop a specific disease from a sufficient cause involving smoking. As discussed in the paper, this measure is affected by many variables including dose, duration, type of cigarettes, etc.

With respect to the example given by Lee, on who is susceptible to Russian roulette, the idea of not being susceptible to bullets if you survive Russian roulette is obviously mixing two kinds of exposure and different doses. Certainly, given enough plays of Russian roulette, everyone would succumb. Therefore, everyone is susceptible to bullets from Russian roulette after numerous trials. One limitation of the sufficient cause model is the deterministic nature of the model. Nevertheless, I believe that the estimation of the proportion of susceptibles is a useful adjunct to other measures of association derived in epidemiological studies.

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PASSIVE SMOKING AND HEART DISEASE

Dear Editor:

Glantz (1990) criticized Lee et al. (1986) for drawing negative conclusions about the association between passive smoking and heart disease based on a study which he, Glantz, stated to have only 3% power (to detect a relative risk of 1.2), the lowest of any such study. In reply, Lee (1990) pointed out that his conclusions were based on the overall evidence, not just one study, and that, in any case, his study had a power of 12%, higher than many of the other studies. This conclusion contrasts with that of Glantz and Parmley (1991), who find that passive smoking significantly increases the risk of heart disease in nonsmokers. To resolve the discrepancy between the power values, we have reviewed each other's estimation procedures. While there are statistical difficulties in power calculations arising from the limited and differing material available in the various studies, two points clearly emerged. First, Lee had based his calculations on the total data for the sexes combined, whereas Glantz considered data for females and males separately. Second, there was an unfortunate error in the computer program used by Glantz which rendered his original power calculations incorrect. Glantz subsequently corrected his program and we now agree that the power of Lee's study (around 4-6% for the males or females individually and 10-12% for the combined sexes) is quite low, and substantially less than that of the Hirayama and Helsing studies. It is, however, greater than many of the other studies and is not the least powerful study of passive smoking and heart disease.

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AN ESTIMATE OF ADULT MORTALITY IN THE UNITED STATES FROM PASSIVE SMOKING; A RESPONSE TO CRITICISM

Dear Editor:

Lee (1991) has made further comment on my paper (Wells 1988) in Environment International. It is heartening that Lee now agrees that his earlier analyses (Lee 1987, 1988) of the bias introduced by misclassification of smokers as neversmokers were not carefully done. He agrees that he had confused the proportion of nonsmokers (neversmokers plus ex-smokers) who are true current smokers with the proportion of neversmokers who are true current smokers. This "confusion" approximately doubles the calculated bias. Also doubling the bias is Lee's practice, as noted earlier (Wells 1990a), of mixing male data based on neversmokers with female data based on neversmokers to calculate the bias for studies of females. Lee also now agrees that he should have calculated a bias for each study separately instead of applying U.K. smokers' risk and smoker prevalence to studies from other areas of the world where these values are much lower, a practice that again substantially inflated his calculated bias. Lee has retreated from his earlier position that misclassification of smokers as nonsmokers is a major source of bias to a position that it does not cause material bias for Asian women but still causes 60% of the association observed in U.S. women. Calculations that Professor Walter Stewart of John Hopkins University and I have carried out (Wells 1990b) indicate that misclassification of smokers as neversmokers may account for up to 2% of the association observed in Asian women and up to 28% of the association observed in U.S. women. For all 28 studies worldwide, that are now available on females, this type of bias may account for up to 9% of the association, hardly a "major" source.

There are two main reasons why Lee gets 60% and we get 28% for U.S. women. Both we and Lee rely on general community surveys of two types. In one, people are asked if they smoke. Then shortly thereafter, they are tested for cotinine level. In the other, people are asked at two different points in time if they had ever smoked, and discordant answers are noted. However, 1) Lee continues to mix male data with female data from these studies, and 2) he uses suspect data sources. For example, he (Lee 1989) relies on the large Haddow (1987) study whereas the authors of that paper strongly recommend that the cotinine data in it not be used for misclassification estimates re passive smoking (private communication from Dr. Knight). Instead, they recommend the data in their 1986 and 1988 papers (Haddow 1986; Haddow 1988) where the data gathering was much closer to what would occur in epidemiological studies on passive smoking. So far, Lee has ignored the 1988 paper (Lee 1989). Lee also implies that misclassification rates among Asian women are higher than among other women, but Dr. Koo (Koo 1990), who participated in and had access to the cotinine data from the recent IARC study in 13 areas around the world, reported not much difference between the Asian misclassification rates and such rates elsewhere.

There is also reason to believe that even the bias estimates that we have made are too high. For ex-ample (Wells 1990b), the general community surveys that we have used indicate that 5.7% of eversmokers are exsmokers who are misclassified as neversmokers, whereas in the five passive-smoking epidemiological studies where misclassification estimates were made by the authors, only about 1.0% of eversmokers are exsmokers found to be misclassified. The other evidence, that the misclassification factors we have used are probably too high, comes from the studies on males. In the usual male cohort, there are far fewer reported neversmokers (17% to 35%) than in female cohorts (41% to 86%). In calculating the passive risk corrected for smoker-misclassification bias, it is necessary to subtract the current and exsmokers misclassified as neversmokers from the number of reported neversmokers. When one uses the misclassification factors generated from the community surveys, the neversmoker correction deletions exceed the total number of reported neversmokers for three of the eleven male cohorts and drive the corrected risk substantially below unity for another four. This can only mean that the misclassification factors derived from the community surveys are too high. Thus, until we can get better misclassification data on which to base male correction calculations, it is probably best to do as the U.S. Environmental Protection Agency has done (USEPA 1990), namely to use the corrected female passive smoking risk as a proxy for the male corrected risk. Meanwhile, Lee's calculations of the part of the observed passive smoking association due to smoker misclassification for either U.S. men (60%) or Asian men (substantial) can be regarded as meaningless.

As Lee says, there is a discrepancy between the relative risks one observes in the epidemiology for various diseases associated with passive smoking and the relative risks one calculates by ratioing down dosimetrically from the risks associated with active smoking. But is this a reason to throw out the epidemiology in favor of a calculated effect? I think not, especially since no confounder has yet been found that can explain the differences. A better assumption is that the dose response curves for passive smoking and active smoking are different due to three main reasons, 1) the nature of the smoke deposition is different, 2) there is a balance of toxic and protective effects that varies by disease and is different for active and passive smoking, and 3) there is a difference in average susceptibility for each disease between the relatively small proportion of the population who die of passive smoking and the relatively much larger proportion who die of active smoking.

Glantz and Parmley (1991) have published a comprehensive review of the effects that passive smoking has on the functions of the heart and circulatory systems. They demonstrate conclusively that one cannot predict the effects of passive smoking on heart disease by using calculations based on dose relative to active smoking.

For cancers other than lung there are not only the overall studies referenced earlier (Wells 1988, 1990a) but a number of studies of specific cancer sites. There are now seven studies (Buckley 1981; Brown 1982; Hellberg 1983; Sandler 1985; Hirayama, private communication; Slattery 1989; Butler 1990 and private communication) of passive smoking and cancer of the cervix with 466 cases of neversmokers and relative risks ranging from 1.26 to 4.1 for an average of about 1.6. The studies on breast cancer and passive smoking have recently been summarized (Wells 1991) showing a relative risk of 1.4. In addition, studies exist for several other sites, and my calculations of total deaths by site agree remarkably well with my estimates from the total cancer data.

The effect of vapor-phase tar in ETS may have a bearing on the relatively high risks observed for these non-lung or non-contact sites. Lee notwithstanding, tar is usually defined as that part of "freshly generated" cigarette smoke, less water and nicotine, that is retained on a Cambridge filter. What Pritchard et al. (1988) found was that 70% of sidestream tar, so defined, evaporates into the air as ETS ages. Their marker, cetyl iodide, has a boiling point of 380°C, placing it between the three-ring and four-ring polyaromatic hydrocarbons. The particulate phase has a low retention factor in the respiratory tract, about 15% (Wells 1988), but the tar constituents in the vapor phase, like other organic vapors (Bond 1985), would be essentially completely retained in the respiratory tract. Thus there is the probability that the total retention of vapor phase tar from ETS could be (70/30) (100/15) = 15 times the retained particulate. Grimmer et al. (1988) have shown that most of the lung carcinogenicity, for rats at least, is in tar compounds of four or more rings, although about one sixth is in the two-and three-ring fraction. Their cut point is somewhat lower than Pritchard's so we might guess that about one-fourth of the lung carcinogenicity is coming from the vapor phase of ETS. The higher molecular weight carcinogens, those over 200 and contained in the ETS particles, are retained for long periods in the lung (Henderson et al. 1988), thus contributing carcinogenicity. However, the vapor phase material with molecular weights of 100 to 200, and including such compounds as quinoline, methyl quinoline, benzoquinoline, phenanthridene, nornicotine, β-naphthyl amine, nitroso pyrolidine, nitroso nornicotine, pyrene, fluoranthene, phenol, the cresols, 2,4-dimethyl phenol, catechol and the methyl catechols (all of which have some type of carcinogenic activity) would clear from the lung into the body fluids more quickly and would add to the potential for cancers at other sites. What we don't know, but suspect, is that much of the carcinogenicity of mainstream smoke is lost because so many of the large mainstream particles are cleared rapidly into the mouth and swallowed, only to go out with the feces, unmetabolized and unabsorbed anywhere in the body (see, for example, Bond et al. (1986) on loss of inhaled nitropyrene particles to the feces). In any case, the presence of a large amount of vapor-phase tar entities accompanying the particles of ETS enhances its lung carcinogenicity and increases—to an even greater extent—the potential for cancer elsewhere in the body.

Lee must really be looking the other way not to believe that there is a range of susceptibility among individuals to smoking-induced cancer in the light of all the recent work on tumor suppressor genes and related genetic research. Dr. Khoury (Khoury 1991) has replied separately to criticism of his work on individual susceptibility. However, it stands to reason that if there is a range of susceptibility to cancer from cigarette smoke—and all the recent work indicates that there is—the most susceptible individuals are going to die younger and/or will be affected by lower doses than a larger but, on average, less susceptible group. We may not know exactly how to quantify this difference yet, but intuitively such a difference must exist.

Re publication bias, Lee continues to hope that the American Cancer Society will publish its data on ETS and heart disease. Perhaps the reason they haven't, is best described in Dr. Cuyler Hammond's words since he was responsible for gathering those data in the first place. He says (Hammond 1981) that he "would have liked to estimate lung cancer death rates in relation to amount of "passive" smoking among female subjects who never smoked. He refrained from attempting to do so for the following reasons: Since his prospective study was not designed for that purpose, no special information on the subject was obtained. Information was available on the smoking habits of the husbands of many of the married women in the study; but not on the smoking habits of the former husbands of women who were widowed, divorced, separated or married for the second time. More important, in America at that time, women were not generally barred from public and social gatherings where men were smoking; and working husbands who smoked generally did much if not most of their smoking away from home". Dr. Hammond and Dr. Selikoff then go on to point out why studies in Greece and Japan are more likely to yield a meaningful result because of the traditional segregation of married women from men other than their husbands in those societies. After the lung cancer work was published (Garfinkel 1981) it soon became evident, as Hammond had predicted, that the study had serious weaknesses. The American Cancer Society then probably decided that publishing the heart data would be even less meaningful since the passive-smoking heart relative risks are lower than the lung cancer risks.

The difficulties of carrying out meaningful passive smoking studies in the United Sates, or Western Europe, is emphasized by the data of Cummings (1990). He found, in Buffalo, New York, that nonsmoking women whose husbands smoked had urinary cotinine levels only 55% higher (10.54 ng/mL vs. 6.78 ng/mL) than women whose husbands did not smoke. The indicated high background level of ETS exposure means that it is very difficult to get a statistically significant effect of passive smoking on lung cancer in the U.S. unless this background effect is taken into account. My current estimate of relative risk for lung cancer from passive smoking based on the U.S. studies on females is 1.17 after correction for smoker misclassification. Correcting for background, using Cummings' data, increases this risk to 1.7. It is interesting that, even in the West, studies can be carried out with low bias corrections if the smoking prevalence, and hence the background, is low. For example, Trichopoulos et al. (1983) and Kalandidi et al. (1990) in Greece, where the respective female eversmoking prevalences were only 10 and 17% and where married women don't mix with men other than their husbands, both found a passive lung cancer risk of 2.1, and Butler (1990), among female Seventh Day Adventists in California where the eversmoker prevalence was 14%, found a passive lung cancer risk of 2.0. For all three of these studies the calculated bias due to smoker misclassification is very low, 0.2% or less.

In summary, there has been no good reason so far advanced that warrants discarding the epidemiological results on passive smoking. Particularly, there is no good reason to discard them in favor of simplistic dose approaches such as those advanced by Mr. Lee. The best available risk assessments for passive smoking deaths in the U.S. continue to be those such as Wells (1988) that are in the 50000/y range.

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OBSERVATIONAL VS EXTRAPOLATIVE MODELS IN ESTIMATING MORTALITY FROM PASSIVE SMOKING

Dear Editor:

Lee (1991), in his reply to our criticism (Repace and Lowrey 1990) of his negative views on passive smoking and lung cancer (Lee 1990), now concedes that some effect of environmental tobacco smoke (ETS) on lung cancer among nonsmokers is plausible. However, Lee disputes our contention that there is "remarkable agreement" among risk assessors using different approaches to estimate the risks of passive smoking (Repace and Lowrey 1990a, 1990b). To the contrary, Lee asserts that there is a "massive discrepancy" between risk ratios for lung cancer derived from passive smoking epidemiology and risk ratios "dosimetrically" estimated by extrapolation from effects in smokers to those in nonsmokers.

A discrepancy exists only if one's pre-conceived notion is that the dose-response relationship between tobacco-smoke dose and lung cancer must be linear over three orders of magnitude. Lee implicitly assumes such linearity, but offers no evidence. There is no intrinsic reason for biological phenomena such as carcinogenesis to be linear over several orders of magnitude of exposure. In fact, nonlinearities between cigarettes smoked per day and lung cancer rates are evident in studies by both Hirayama (1974) and Doll and Peto (1981) even over the single order of magnitude dose range between light and heavy active smoking (Repace and Lowrey 1985).

Let us compare the predictions of hypothetical linear and nonlinear dosimetric models for the risk of lung cancer from passive smoking. This will test Lee's hypothesis that dosimetric models are "massively discrepant" with epidemiology. Equation 1 represents a linear form of dosimetric model for risk R(d) as a function of dose d, and Equation 2 represents an equally arbitrarily chosen non-linear model:

$$R(d) = R_{as}\, d/D_{as} \qquad (1)$$

$$R(d) = R_{as}\left\{1 - e^{-(kd/D_{as})}\right\} \qquad (2)$$

where R(d) is the excess risk (above background) from exposure to tobacco smoke (in units of lung cancer deaths (LCDs) per 100 000 person-years) as a function of inhaled dose. For a background rate of $B = 9$, $R_{as} = 316 - 9 = 307$ LCDs per 100 000 person-years, is the average risk of active smoking above background; D_{as} is the dose from average active smoking: the average active smoker smokes 32 cigarettes per day and is estimated to inhale a dose of $D_{as} = 544$ mg of tar per day (at 1980 average mainstream tar levels); k is a constant arbitrarily chosen to be 10. (Other constants from Repace and Lowrey 1985.) Repace and Lowrey (1985) have estimated that the most-exposed and average passive smokers inhale doses d of 14 mg and 1.4 mg tar respectively from ETS per day. The ratio $d/D_{as} = 544/544 = 1$, for average active smoking; $14/544 = 0.026$, for heavy passive smoking; and $1.4/544 = 0.0026$, for average passive smoking.

Let us now compare the predictions of these two models based upon the parameter values for d/D_{as} given above. Equation 1, the linear extrapolation, predicts an excess risk of 8 LCDs per 100 000 person-years for heavy passive smoking, and 0.8 LCDs per 100 000 person-years for average passive smoking. By contrast, Equation 2, the non-linear extrapolation, predicts an excess risk of 72 LCDs per 100 000 person-years for heavy passive smoking, and 8 LCDs per 100 000 person-years for average passive smoking, which are nearly identical to the risk values calculated by Repace and Lowrey (1985). We now use the values derived from each model to compute the expected risk ratios for passive smoking.

The risk ratio for passive smoking, ρ, may be calculated from Equation 3:

$$\rho = [(R(d) + B)/B] \qquad (3)$$

For the non-linear extrapolation model for passive smoking, $\rho = [(8 + 9)/9] = 1.9$ for the average case, (similar to the value of 1.8 found by Hirayama (1981) in his cohort study of 91 540 female Japanese passive smokers). By contrast, the linear model predicts a risk ratio of $\rho = [(0.8 + 9)/9] = 1.09$ for the average case (about what Lee found in his own case-control study of 168 British passive smokers). Thus, it is clear that the predicted risk of passive smoking is a function of the choice of extrapolation model, and, contrary to Lee's assertion, dosimetric extrapolation models are not massively discrepant with observational data from epidemiology.

In the absence of experiments to determine the shape of the dose-response curve, the only way to validate any model is to compare it with observable human epidemiological data. We chose to reject a linear dosimetric model because it was inconsistent with the bulk of human observational data. Lee chooses to accept a linear extrapolation model despite its inconsistency with observational data. How else would a proposed risk assessment model be validated other than by comparison with human observational data? We do not favor extrapolation models in general because of the uncertainties introduced by extrapolation over several orders of magnitude from high exposures in smokers to low exposures in nonsmokers. Rather, we chose a phenomenological approach relating environmental risks in nonsmokers related to environmental exposures of nonsmokers. We validated our model by predicting—to within 5%—the risk ratios and risk rates observed in U.S. cohort and case-control studies (Repace and Lowrey 1985, 1986, 1987). By contrast, Lee has unconvincingly attempted to explain away the observational data by a mathematically possible but physically improbable explanation for lung cancer mortality ratios from passive smoking epidemiology. Under Lee's hypothesis, the rate of smokers misclassified as nonsmokers differs significantly from Asia to North America, and yet is (implausibly) of the exact magnitude on both continents and in each study as to produce similar but "spurious" positive results (odds ratios clustered between 1 and 2) in more than two dozen different epidemiological studies around the globe.

Similarly, Lee also unconvincingly attempts to explain away the virtual absence of negative studies of passive smoking and heart disease mortality by assuming without proof the existence of publication bias, ignoring the overwhelming biological plausibility for an effect (also non-linear) as demonstrated by Glantz and Parmley (1991). Lee expects us to accept that there has been publication bias in the American Cancer Society (ACS) study, on the basis of his unfounded belief that the ACS looked into heart disease mortality, found no association, and therefore did not publish. Since there was no data-base from which to draw conclusions in this area, we created one. According to Lawrence Garfinkel, recently retired Vice President for Epidemiology of the ACS, the ACS had in fact never examined its data for heart disease mortality from passive smoking.

Finally, we would like to observe that our own calculations of lung cancer from passive smoking, published six years ago in this journal, estimated a mortality ratio of 1.7, adjusted for workplace passive smoking, for the ACS cohort studied by Garfinkel (Repace and Lowrey 1985). This is in agreement with the recent meta-analytic value of 1.7 calculated by Wells (1991), adjusted for non-domestic ETS exposures, based on new studies of cotinine levels in U.S. nonsmokers.

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The opinions expressed in this letter are those of the authors, and do not necessarily represent the official policies of their respective federal agencies.

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BOOK REVIEWS

Geochemistry of Sulfur in Fossil Fuels, edited by Wilson L. Orr and Curt M. White. American Chemical Society, Washington, D.C.; 1990. 708 pp., US$109.00.

Most people, if asked about sulfur in the environment, would indicate its contribution to acid rain. However, sulfur is a necessary nutrient for biota. The critical problem is maintaining its concentration and forms at an optimum biological level in the environment.

The book is devoted to sulfur in fossil fuels. It attempts to explain its origin and its chemical form.

All fossil fuels contain sulfur, but the sulfur content varies from traces to greater than 10%, and the chemical forms are diverse. The presence of sulfur exacts economic penalties at all intermediate stages of exploitation, from recovery (oil and gas production, mining, storage, transportation) to processing (refining, cleaning, upgrading), the extent depending on sulfur's abundance and chemical form. In short, removing sulfur from fuels means greater costs to industry, consumers, and government. These costs can be minimized by increasing the basic understanding of the sulfur system in fossil fuels.

Major advances have been made in the past decade, largely because of improved analytical techniques that have made easier the identification of organic sulfur compounds at the detailed molecular level. These advances have established sulfur-compound biomarkers that have greatly clarified the understanding of how and when most of the sulfur is introduced into the surviving biogenic materials that eventually become fossil fuels. The latest advances included in this volume have many implications for practical applications. Quantitative evaluations of compound abundances and distributions in specific fossil fuels in relation to their geologic history and settings and case studies of sedimentary depositional environments will help to integrate and consolidate the understanding of the geochemistry of sulfur in fossil fuels.

The book fills a significant gap in the technical literature. It will be a valuable reference to a diverse audience: marine, fuel, and environmental scientists; analytical and organic chemists; and government administrators and technical staff for energy and environmental programs.

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Handbook of Chemical Property Estimation Methods, by Warren J. Layman, William F. Reehl, and David H. Rosenblatt. American Chemical Society, Washington, D.C., 1990. US$49.95 hardcover.

A proper assessment of the risk—to man and the environment—created by exposure to chemicals generally includes attempts to measure or predict the concentrations in various environmental compartments in conjunction with toxicological data. Frequently, however, neither the concentration data nor the toxicological data are adequate for a realistic assessment. In addition, basic physical and chemical data are often unavailable. If properties of chemicals could be estimated, their transport and fate in the environment could be better understood and the eventual environmental concentrations might be predicted.

In September 1978, with support from the U.S. Army Medical Bioengineering Research and Development Laboratory, Arthur D. Little, Inc. undertook a preliminary problem definition study to answer the following questions: (1) What are the important properties of organic chemicals with regard to their transport and fate in the environment? (2) What methods are available for the estimation of these properties? (3) What limitations and/or uncertainties are associated with these methods? and (4) Can a comprehensive user's manual incorporating the basic elements of these methods be prepared so they become not only easy to comprehend and use, but hard to misuse? This handbook attempts to summarize the findings.

The content of the handbook includes conventional properties of pure materials (e.g., density, boiling point, refractive index), some properties that describe how a chemical behaves or interacts with a second substance (e.g., solubility in water, diffusion coefficient in air, interfacial tension with water), and a set that describes the fate of trace concentrations of the chemical in specific environmental situations (e.g., rate of hydrolysis in water, atmospheric residence time, and volatilization from soil). The latter group is related more to environmental fate than to physicochemical properties, because certain models require information on the environmental compartment of concern as well as chemical-specific properties.

Two important properties, rate of aqueous photolysis and rate of biodegradation, are included in this handbook even though the current state of the art does not permit quantitative estimation. These stress the importance of photolysis and biodegradation in environmental fate and should allow a qualitative determination of the susceptibility of an organic chemical to these forms of degradation. Additional research is required before quantitative estimation methods can be developed.

The basic limitation of this handbook is that only single-component (i.e., pure) organic chemicals are covered. Future editions may be able to cover organic mixtures (e.g., gasoline, fuel oil, or simple two-component mixtures) for some properties. Extensions to include polymers, salts, solutions, and inorganic chemicals are not presently contemplated.

Another problem is the limited capability of many of the recommended methods to provide estimates either as a function of temperature and pressure, or to provide estimates at temperatures and pressures outside of the normal range of ambient values. In addition, the value of many properties such as solubility, adsorption coefficient, and rate of hydrolysis, may be affected by other environmental factors in ways that are not understood.

Nevertheless, the handbook is of importance for all interested in environmental chemistry and modeling of pathways of chemicals in the environment. Each environmentally oriented library should have it as a source of basic physicochemical data.

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Basic Mutagenicity Tests—UKEMS Recommended Procedures. David J. Kirkland, ed. Cambridge University Press, Cambridge, UK, 1990. 144 pp. (ISBN 0-521-39347-7) $59.50 hardcover.

This volume provides a brief but important summary of the essential tests that need to be performed on all new compounds, whether they be new drugs, pesticides or food additives, before they can be registered for use in the United Kingdom. These basic tests for mutagenicity were originally drawn up by the United Kingdom Environmental Mutagen Society (UKEMS) in 1983. They have now been fully revised by expert working groups from academia and industry under the auspices of UKEMS and in collaboration with the UK Department of Health. This volume therefore provides the latest official guidelines and recommendations for all scientists involved in the testing and registration of new compounds, not only in the UK, but in a wider international context. The four main test procedures for measuring mutagenicity described in this volume are: bacterial mutation assays, metaphase chromosome aberration assays *in vitro*, gene mutation assays in cultured mammalian cells, and *in vivo* cytogenetics assays. Each of these tests is fully explained and described in practical and procedural detail, with additional information on the presentation and data-processing of results. The volume will be essential for all toxicologists, pharmacologists, and other scientists involved in regulatory affairs, mutagenicity testing, and the successful registration of new chemical products. It is highly recommended for individuals and libraries.

Effective Risk Communication. The Role and Responsibility of Government and Nongovernment Organizations. Vincent T. Covello, David B. McCallum, Maria T. Pavlova, eds. Plenum Publishing Corporation, New York, 1989. 370 pp. (ISBN 0-306-43075-4) hardcover.

The Task Force on Environmental Cancer and Heart and Lung disease is an interagency group established by the Clean Air Act to recommend research to determine the relationship between environmental pollutants and human disease and to recommend research aimed at reducing the incidence of environment-related disease. The Task Force sponsored a workshop to explore existing federal risk communication activities, identify gaps in research and practice that need to be addressed, and develop effective strategies for interprogram and interagency cooperation in risk communication activities. The workshop, held in Alexandria, Virginia, on January 21-23, 1987, involved government policy-makers, program administrators, and public health professionals from federal, state, and local governments, as well as experts in risk communication from the academic community, citizen and environmental groups, media, business, and industry. The book contains the results of the workshop. It is highly recommended as a reference book.

Readings in Risk. Theodore S. Glickman and Michael Gough, eds. Resources for the Future, Washington D.C., 1990. 262 pp. (ISBN 0-915707-55-1) softcover.

"Readings in Risk" reflects the sharp growth in scholarly inquiry into risk assessment, risk management, and risk communication and the mounting concern within industry and government and among the general public about the health and safety hazards posed by environmental contaminants and technological systems. Developed for use as a convenient reference work, the book is a unique collection of authoritative yet accessible journal articles about risk. Drawn from a variety of disciplines including the physical and social sciences, engineering, and the law, the articles deal with a wide range of public policy, regulatory, management, energy, and environmental issues. The selections are accompanied by introductory notes, questions for thought and discussion, and suggestions for further reading. This book is recommended as an introductory textbook in risk analysis.

Statistical Evaluation of Mutagenicity Test Data. David J. Kirkland, ed. Cambridge University Press, Cambridge, UK, 1989. 294 pp. (ISBN 0-521-36605-4) $54.50 hardcover.

This volume draws upon the expertise of toxicologists and statisticians to provide a rigorous and practical account of the interpretation of mutagenicity test data. New chemicals, such as drugs, food additives and pesticides, need careful screening to eliminate potentially mutagenic compounds. Although guidelines exist on the performance of these tests, advice on data evaluation—other than "Appropriate statistical tests should be used"—is scarce. This volume fills that gap by providing the statistical background necessary for toxicologists to understand, design and interpret mutagenicity tests. A large team of contributors and editors, working under the auspices of the United Kingdom Environmental Mutagen Society (UKEMS), has contributed a wealth of first-hand experience in compiling this useful volume. The volume will be of immense practical use to toxicologists in the pharmaceutical, chemical, agrochemical, cosmetic, food additive and tobacco industries, to cancer research scientists, regulatory authorities and contract-research staff. This authoritative volume is highly recommended to the investigators dealing with mutagenicity.

VDI Codes and Standards. Verein Deutscher Ingenieure. VDI-Kommission Reinhaltung der Luft, Düsseldorf, 1990.

The Association of German Engineers (Verein Deutscher Ingenieure) publishes consensus standards on topics of technological interest. The following standards have been published recently and are available from VDI-Kommission Reinhaltung der Luft (VDI-RdL) d-4000 Düsseldorf 1: VDI 3489 Part 1: Particulate Matter Measurement. Methods for Characterizing and Monitoring Test Aerosols (Survey) (Jan 1990); VDI 2268 Part 2: Chemical Analysis of Particulate Matter. Determination of Arsenic, Antimon and Selenium in Dust Emissions by Atomic Absorption Spectrometry after Separation of their Volatile Hydrides (Feb 1990); VDI 3491 Part 10: Particulate Matter Measurement. Generation of Test Aerosols from Fibrous Powders Using a Vibrating Bed Aerosol Generator (Jan 1990); VDI 3491 Part 11: Particulate Matter Measurement. Generation of Test Aerosols Using Ultrasonic Atomizers (Jan 1990); and VDI 3491 Part 12: Particulate Matter Measurement. Generation of Test Aerosols Using Centrifugal Atomizers (Jan 1990).

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ERRATUM

Graeffe, G.; Keskinen, J.; Lehtimäki, M. Small ion concentration in houses with enhanced radon concentration. Environment International 15, pp. 309-313; 1989.

The authors regret that, because of a software error, the averages of the measured data are averages of the measuring periods only (e.g., 2-4 d). The results and conclusions of the paper should be considered to be based on the shorter measuring periods.

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NEW PATENTS

This Section contains abstracts and, where appropriate, illustrations of recently issued United States patents and published patent applications filed from over 30 countries under the Patent Cooperation Treaty. This information was obtained from recent additions to the Pergamon PATSEARCH[R] online database in accordance with interest profiles developed by the Editors. Further information about Pergamon PATSEARCH[R] can be obtained from Pergamon Orbit InfoLine Inc., 8000 Westpark Drive, McLean, Virginia 22102, U.S.A.

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4933371

CONTROLLING TICKS AND FLEAS WITH LINALOOL

W Fredric Hink, Thomas Duffey assigned to Shirlo Inc

Method of treating animal hosts or their environment for ticks and fleas by applying thereto a toxic amount of linalool.

4934458

SMALL DIAMETER DUAL PUMP POLLUTANT RECOVERY SYSTEM

James Warburton, John F Hurst

A groundwater pollutant recovery system using the cone of depression approach, in which a sensing probe having liquid level sensors responsive to both water and pollutant levels and having attached to it the pollutant intake is deployed in a recovery well above the submerged water and pollutant pumps. The pollutant intake on the sensing probe is attached to the pollutant pump by an extendable hose so that the sensing probe may be raised and lowered in response to changing hydraulic conditions in the well without the necessity of changing the water or pollutant pump positions. The recovery sequence is controlled by a microprocessor under the control of a program responsive to the liquid levels indicated by the sensors in the sensing probe.

4935148

PROCESS FOR MICROAQUACULTURE AND POLLUTION CONTROL

Charles D Van Ry

Method for producing and removing dissolved and particulate matter from natural bodies of water and wastewater in situ for the production of organic biomass such as feedstocks, for the removal of pollutants, nutrients, toxins and other substances, and for other purposes. A gas is introduced through a diffuser into a body of water to form bubbles. The bubbles rise within a lifting tube, gathering dissolved and particulate matter on their surfaces. The bubbles produce a foam at the surface of the body of water, the foam being collected in a reservoir, concentrated and drawn off.

4935726

DRAINAGE SYSTEM MONITORING APPARATUS

Timothy Buro, Donald Hollenbeck, Robert A Rauch assigned to Underground Sensor Systems Inc

This invention is directed to an apparatus or system which is used for monitoring a storm drain system in order to detect the presence of hydrocarbons or the like therein. The apparatus includes a sensor unit which is arranged to float on the surface of the storm drain effluent. A suitable alarm system is connected to the sensor unit to indicate an activation of the sensor unit. The storm drain is, typically, modified to provide a uniform sensing area adjacent to the sensor unit.

4935969

METHOD AND DEVICE FOR THE CONTROLLED DISPOSAL OF HUMAN WASTE

Orin J Farnsworth

A method and device for the sanitary disposal of human waste are disclosed. The method includes completely covering the seat and toilet bowl interior of a toilet with a toilet flushable, human waste disposal means to contain viruses and bacteria in the toilet bowl and prevent a toilet occupant from contacting the toilet seat and bowl interior. The method further includes discharging waste into the disposal means, covering the disposal means and flushing both the disposal means and waste matter with minimum bathroom contamination. The disposal means includes a toilet seat cover means having a central cutout portion and a waste collecting means which depends therefrom. Thus, an imperforate barrier isolates the toilet bowl interior when the device is installed on a toilet prevents a toilet occupant from contacting the toilet seat and bowl interior. The collecting means contacts water in the toilet to support the waste and has depending tails at each end to pull the device into the water when the toilet is flushed. Side flanges help support the collecting means on the water and twist the device into a rope-like spiral when the toilet is flushed. A lid has a first open position extending over the front of the toilet bowl to protect the toilet occupant when using the toilet and a second closed position sealing the waste material in the collecting means when the toilet is flushed.

4938060

DOWNHOLE INSPECTION SYSTEM

Phillips S Sizer, Henry Arendt, Charles Cobb assigned to Otis Engineering Corp

A system and methods for the inspection of a well borehole and the formation around said borehole. The system includes a coiled tubing unit for injecting flexible coiled tubing into a wellbore through a wellhead, a pump and valves for control of injection of fluids such as water, nitrogen, light-hydrocarbons, natural gas, and carbon dioxide through the coiled tubing into the wellbore, and a sensor for visually inspecting and/or acoustically examining the wellbore and a region around the sensor within a slug of fluid injected into the wellbore from the coiled tubing. The method includes the steps of injecting coiled tubing having an inspection sensor into a wellbore to a selected location, injecting an optically transparent or acoustically homogenous fluid into the wellbore through the coiled tubing to form a slug of such fluid around the sensor, and transmitting signals from the sensor representative of well conditions to the surface. The method may be practiced to inspect only the region around the sensor at a selected depth in the well or may be continuously practiced to examine the length of the wellbore by producing the well and retrieving the coiled tubing and sensor at a controlled rate synchronized with the rate of well production.

4938241

RV SANITARY DUMPING BAY AND POTABLE WATER SYSTEM

James M Teel

A dumping bay for the disposal of recreational vehicle waste at a campsite and includes a drain for receiving waste from the holding tank of a recreational vehicle through a dump hose. The dumping bay includes a water control facility which can supply flushing water to the drain and which can also provide an independent supply of potable water to a recreational vehicle. The potable water is supplied through an articulated hand-held nozzle and it can also be used for providing additional flushing water to the drain and water to clean components if required. The components of the invention are incorporated into a central serviceable unit accessible to users.

4940010

ACID GAS CONTROL PROCESS AND APPARATUS FOR WASTE FIRED INCINERATORS

Peter Kubin, Jiri Stepan assigned to Ogden-Martin Systems Inc

An apparatus for incinerating waste material and for reducing noxious byproducts of the incineration process. The apparatus consists of a furnace having a turbulent reaction zone whereby an overfire air header and additive distributor and lime injection nozzles connected to the incinerator through a plurality of nozzles located at even distances about the arrangement is the turbulent reaction zone of the furnace such that an additive mixture is injected into the turbulent zone through and distributed evenly during combustion across the entire width of the turbulent area. As a result, a reaction between the combustion products and the additive is optimized resulting in an overall reduction in acid gas content, acid dewpoint temperature and the corrosion levels inside the incinerator and auxiliary equipment.

4940327

METHOD AND APPARATUS FOR REAL TIME ASBESTOS AEROSOL MONITORING

Pedro Lilienfeld assigned to TRC Companies Inc

A real time asbestos aerosol monitor and method are provided. An ambient air sample is passed through a first sensing zone where fibers in the sample are electrically aligned and oscillated as they are illuminated perpendicular to the fiber axes with high intensity laser light. The scattered light signal pulse train from a first detector is analyzed to determine the presence and size of fibers in the sample. The air sample is then passed through a second sensing zone including a hybrid electric/magnetic field to electrically align and magnetically oscillate asbestos fibers. The sample in the second sensing zone is illuminated perpendicular to the fiber axes, with the scattered light signal pulse train from a second detector being analyzed to determine whether each fiber detected in the first sensing zone is an asbestos fiber. Advantageously, clean air is circulated across illumination optical surfaces to protect against abrasive elements in the air sample. Zeroing and calibration are also provided.

4940405

PULSE COMBUSTION DRIVEN IN-FURNACE NOX AND SO2 CONTROL SYSTEM FOR FURNACES AND BOILERS

John T Kelly

Pulse combustors and associated air mixers are used to process fuel and calcium based sorbent outside of a furnace or boiler. liquid or solid fuel is rapidly volatilized in the air mixer of the first pulse combustor, producing high gaseous fuel content and a highly reactive char or soot. This material is then injected into the upper part of the furnace, above the conventional burners, to create a fuel rich zone which reduces previously formed nitrogen oxide (NOx) pollutants. The calcium based sorbent is injected into a second pulse combustor, located higher in the furnace. The sorbent is flash calcined in the air mixer of the pulse combustor yielding a high surface area sorbent. This material is then injected into the furnace above the first pulse combustor to reduce previously formed sulfur oxide (SO2) pollutants. In addition, the stream from this combustor and air mixer provides the air needed to completely burn out the coal fuel from the first pulse combustor. Besides a combined NOx and SO2 control, the system can be configured to only reduce either NOx or SO2.

4940539

GREASE TRAP CONSTRUCTION

Myer M Weber assigned to Semco Laboratories Inc

A grease trap construction comprising a housing having an inlet to receive waste water containing grease and foreign material and having an outlet. An air conduit having a plurality of outlet ports spaced along its length is located in the lower end of the housing and is connected to a source of air under pressure, so that air will be discharged through the ports into contact with the waste water. The waste water within the housing is heated by an electric heating element which is immersed in the waste water and the heating element is controlled by a thermostat to maintain the temperature of the waste water within a given range. An aqueous composition containing a mixture of enzymes and bacterial spores is introduced into the housing into contact with the waste water. The enzymes and bacterial spores act on the grease, fats and other material in the waste water to provide a substantial reduction in total solids and an increase in soluble solids, as well as a substantial reduction in the BOD level of the waste water.

4940551

METHOD FOR PH CONTROL

James B Riggs, R Russel Rhinehart

A method for controlling pH of an effluent stream or batch process is provided in which multiple in-process reagent concentration and pH data pairs are used to characterize the titration curve of the influent stream or batch fluid. Reagent is added in two or more portions in either space or time to generate several resulting pH readings and to provide rapid, reliable, and locally valid titration characterization. The titration curve can then be used to determine the required reagent addition.

4941415

MUNICIPAL WASTE THERMAL OXIDATION SYSTEM

G Michael Pope, Donald F Kerr assigned to Entech Corporation

An air-starved, batch burn, modular, municipal waste incinerator. It is designed to oxidize unsorted loads of heterogeneous materials in quantities ranging from 5 to 500 tons per 12 to 15 hours. The unique aspect of this system design is that through research in air mixing, air turbulence, and temperature control, it is possible to burn this material with a highly favorable stack emission product, without the need for bag houses, dry scrubbing, or other elaborate down stream air processing equipment. The incinerator includes a primary combustion chamber connected to a secondary combustion unit by a gas transfer tube. Solid material in the primary is oxidized-or gasified-without live flame. This flammable gas stream is vented into the secondary for ignition. Combustion gases from the primary chamber are completely burned in the secondary combustion unit as the gases pass upwardly through the air mixing ring and tangentially disposed re-ignition burners. The tangential orientation of the re-ignition burners forms a vortex of flame through which the combustion gases travel before exiting from the stack.

4941981

MODIFIED NON-POLLUTING LIQUID PHASE SHALE SWELLING INHIBITION DRILLING FLUID

Alphonse C Perricone, Dennis Clapper, Dorothy P Enright assigned to Baker Hughes Incorporated

The present invention provides a modified liquid phase drilling fluid having desirable properties of shale swelling inhibition, lubrication, and high temperature performance. The fluid does not rely on the incorporation of inorganic salts or high molecular weight water soluble polymers for control of shale swelling or shale disintegration and exhibits performance characteristics, approaching those of oil base drilling fluids, without the objectionable properties of hydrocarbon oils or its potential hazardous impact on the environment. The fluid is comprised of the following: (1) a liquid phase containing: (a) a water phase comprising fresh water, seawater, brine, simulated brine, or mixtures thereof; and (b) a water-soluble component selected from the class consisting of polyhydric alcohols, glycol, glycol ethers, polypropylene glycols, polyethylene glycols, ethylene oxide-propylene oxide copolymers (EO-PO), alcohol-initiated EO-PO copolymers and/or mixtures thereof, the ratio of said water-soluble component in the total liquid phase being from about 5% to about 50% by volume; (2) a viscosifier for suspension of solids in said liquid phase; and (3) a filtration control agent. The fluid with the water soluble component will exhibit a lubricity coefficient lower than that for substantially the same fluid without the water soluble component as determined by the American Petroleum Institute's Procedure for Determination of Lubricity Coefficient (Tentative) (1980), and the linear swelling on a reconstituted gumbo shale inserted for about 60 minutes of said drilling fluid being from lower than that for substantially the same fluid without the water soluble component, as measured by the Swelling Test , Rigsite Shale Evaluation Techniques for Control of Shale-related Wellbore Instability Problems , SPE/IADC Paper No. 16054, pages 52-53, (1987).

4942736

METHOD OF AND APPARATUS FOR PRODUCING POWER FROM SOLAR ENERGY

Lucien Bronicki, Yavne, Israel assigned to Ormat Inc

The present invention provides a method of and apparatus for producing power from solar energy wherein a solar collector heats gas supplied to a gas turbine; compressors compress the gas, the gas being compressed and stored gas during a first period of time, with the stored compressed gas being supplied to the gas turbine during a second period of time to produce power by driving an electric generator. Preferably, the first period of time is during periods of off-peak electricity, which normally occur at night. The second period of time is during the day. The solar collector preferably comprises tracking reflectors for focusing solar radiation and a receiver for receiving the focused solar radiation and also heating the gas. The solar radiation receiver preferably comprises a rotating ceramic member. Furthermore, a combustion chamber is preferably provided to heat the gas entering the gas turbine and is operated by a temperature sensing/control unit when the solar radiation received by the receiver is insufficient to heat the gas entering the gas turbine to the required temperature. The electric motor used to operate the compressors preferably comprises the electric generator of the gas turbine. Furthermore, heat generated during the compression of the gas and contained therein is transferred to another fluid in a heat exchanger which comprises part of waste heat converter for producing electrical power therefrom.

4943201

MECHANISM FOR HANDLING GARBAGE PAILS

Jean Billon, Saint Vallier, France assigned to Compagnie Plastic Omnium S A

The invention relates to a mechanism in a bin-dumping device for gripping portable bins, to empty them into a truck for collecting waste, particularly household garbage, the gripping mechanism comprising a chassis connected to the dumping device and having at its upper part one or several shaped sections, particularly in the shape of a comb, adapted to be engaged under a collar provided at the upper end of the frontal wall of the body of the bin. It comprises, at the lower part of the chassis (1), at least one support devices (7) adapted to come into contact with the frontal face (5) of the bin (4), preferably at its lower half, said one or more devices being controllable for being applied forcefully to the bin during at least part of its path of displacement, during the operation of the dumping device.

4943929

CHEMICAL AGENT MONITOR AND CONTROL INTERFACE

Adam Simonoff assigned to The United States of America as represented by the Secretary of the Navy

A chemical monitor interface is generally comprised of three identical circuit boards each linked together through fiber optics. One of the circuit boards is electrically connected to a Chemical Agent Monitor (CAM), an off-the-shelf product, while another circuit board relays control information to the first connected to the CAM. A third circuit board relays only visual status to an observer by using a plasma display, while the first two boards can also control the CAM as well as display status. The interface allows the CAM to run without human intervention, thus allowing the U.S. Naval Fleet, and other U.S. military field units, to meet a need for remotely detecting life-threatening chemical attacks without harm to personnel. The chemical detector is able to purge itself of chemical agents and is immune to shock, vibration and radiations such as EMI.

4944260

AIR INTAKE HEATER SYSTEM FOR INTERNAL COMBUSTION ENGINES

Patrick R Shea, Robert Niemczyk assigned to Cummins Electronics Inc

An air intake heater system for internal combustion engines is disclosed including a microprocessor controller, intake manifold air temperature sensing means, water in fuel sensors, electrical air heating elements actuated by the microprocessor, and system status indicators. Additionally, fuel injector timing is altered by the microprocessor depending upon intake manifold air temperature. Air intake heating is provided to assist cold weather starting of engines as well as for minimizing white smoke pollutants produced by diesel engines. Power consumption of the device is maintained below a predetermined level by judicious use of the microprocessor controller in conjunction with the electrical heating elements.

4944873

DEWATERING SYSTEM FOR SLUDGE REMOVAL

Jack R Williams

A dewatering system for use in the treatment of waste water which includes a tank, an inclined filter bed having a plurality of filter elements and means for inducing a flow of air through the filter bed to accelerate drying of the removed solids. Also disclosed are means for adjusting the angle of inclination of the filter bed and mechanical means for removing solids from the filter elements.

4944305

BLOOD PRESSURE MONITORING APPARATUS

Nariyasu Takatsu, Hidenobu Nakashima, Kasugai, Japan assigned to Colin Electronics Co Ltd

A blood pressure monitoring apparatus for repetitively measuring blood pressure of a subject, including a measuring device for measuring a blood pressure of the subject at each of repetitive measuring cycles, and a display device for displaying a time-wise varying trend of the repetitively measured blood pressures in a two-dimensional table defined by a first axis indicative of time and a second axis indicative of blood pressure.

4945249

REMOTE SENSING SYSTEM

Andrew I Grant, Martyn T MacPherson, David Stevens, Surrey, United Kingdom assigned to The British Petroleum Company plc

Apparatus for detecting an anomaly, (e.g. the presence of a hydrocarbon seep) at or near a water or land surface comprises means for generating a beam, preferably a pulsed beam, of primary light radiation, preferably ultra-violet light, and directing the beam towards the surface. The beam is sufficiently intense and of such a spectral composition that the beam causes the anomaly, if present, to emit secondary light radiation. The apparatus also comprises means for collecting the secondary light radiation, or means for collecting solar induced secondary light radiation, spectral analysis means for analysing the spectrum of the secondary radiation, and a high resolution, multi-element digitizing detector for recovering the analyzed secondary radiation. The detector has a plurality of detection channels positioned across the spectrum of the backscattered primary radiation and emitted secondary radiation, the channels being software configurable and under the control of a digitally addressable computer-operated controller. The concentration of used channels across the plurality of channels is adjustable and increasable in the regions of the spectrum of greatest interest and decreasable in the regions of least interest.

4945362

MICROWAVE SHIELDING FOR SATELLITE EARTH STATIONS

Bernhard E Keiser assigned to The Reinforced Earth Company

A construction for shielding an item against interference from a microwave radio frequency radiation is disclosed, having a wall structure adapted to minimize radio frequency interference in the vicinity of an antenna. The wall is composed of a plurality of modular wall panels, each having a layer of electrically conductive materials that substantially reflects interfering electromagnetic microwave signals. The wall structure includes a top construction creating a thin, horizontal gap in the conductive material at the wall's top that acts to control diffraction over the wall. In the preferred embodiment, the layer of electrically conductive material is a mesh of expanded metal embedded in the wall modules. The gap comprises the space between the top of the mesh and a pair of vertically adjustable metal strips mounted on the wall. In the preferred embodiment, the wall panels are precast concrete that may be horizontally positioned with a joint allowing up to 180 degrees of relative movement.

4945758

METHOD AND APPARATUS FOR MONITORING THE INTERIOR SURFACE OF A PIPELINE

Samm Carpenter, Dhahran, Saudi Arabia assigned to Arabian American Oil Company

A sidestream pipeline, adapted for attachment to a mainstream pipeline, is provided with end closures to permit the introduction of mechanical cleaning devices or chemical compositions to the sidestream pipeline to remove biofilm and treat corrosion-causing constituents; also provided are a plurality of removable coupons closely fitting within holes in the sidestream pipeline wall, and duplicating the material and configuration of the interior surface of the mainstream pipeline. The coupons can be individually withdrawn from the lowermost surface position during cleaning operations to avoid contact with the mechanical cleaning devices and can be isolated from teh chemical treatment. The coupons are removable for laboratory study and analysis.

4945759

VEHICLE PERFORMANCE MONITORING SYSTEM

Gary F Krofchalk, Richard F Dickey, Courtne Hall assigned to Krofchalk Gary F

Apparatus for monitoring the operating performance of a vehicle. The vehicle speed, engine operating speed and manifold pressure of the vehicle are compared to corresponding preset threshold values. The total time during which each of the vehicle speed, engine operating speed and manifold pressure exceed its threshold value is recorded and provided to the driver in a real-time display. The total time during which the engine is operating and the total time during which the engine is idling are also recorded and provided to the driver in a real time display.

4945760

COMBINED MOTOR TESTER AND PULSE TRAIN MONITOR FOR STEPPER MOTORS

Thomas F Hornung

A combined stepper motor tester and pulse train monitor is disclosed for use with a vehicle engine idle air control system. The motor tester comprises a driver pulse generator for generating a pair of pulse trains for energizing the two coils of a stepper motor. It is provided with a manually actuated switch for controlling the phase sequence and time duration of the pulse trains applied to the motor. The operation of the motor by the motor tester, with the vehicle engine running, causes the engine computer module to generate a pair of pulse trains in response to the changing engine conditions. A pulse train monitor, plugged into the output of the engine control module includes a pair of bi-polar LEDs, one for each of the pulse trains generated by the engine control module. The bi-polar LED for each pulse train will alternately flash without both LEDs being off at the same time in response to an uninterrupted pulse train.

4945775

INERTIAL BASED PIPELINE MONITORING SYSTEM

John R Adams, Patrick S Price, Jim Smith, Calgary, Canada assigned to Pulsearch Consolidated Technology Ltd

A pipeline monitoring system for determining profile, ovality and displacement of oil, gas and products pipelines. The system comprises one or more pig carriers housing a plurality of sensors including a strapdown inertial measurement system, a secondary sonar measurement system, digital recorder, weld detector and odometer. The inertial measurement system detects primary acceleration and orientation data of the monitoring system within a pipeline and the secondary system generates redundant data for verifying the acceleration orientation information provided by the inertial system. The digital recorder records all of the information generated by the various measurement systems and sensors for post ash processing analysis to determine the aforementioned features of profile, ovality and displacement of pipelines.

4946311

CO-DISPOSAL POLLUTION CONTROL METHOD-II

Edward C Rosar, Maurice Pattengill assigned to NaTec Mines Ltd

Process for disposal of a waste ash by addition thereto of sodium salts, preferably sodium sulfur oxide salt Na2SOx where x is 3 and/or 4, in an amount ranging from 5-85 weight percent (dry basis) and adjusting the water percentage to within the range of 6-35%, preferably 15-28%. The coefficient of permeability of the ash and sodium salt is reduced from 102 cm/sec to the impermeable standard of 10-6 and below. The preferred mixes also call for a smectite clay additive present in the range of from 0.1% to 5%. A flocculant in amounts of 0.01% to 1% can be substituted for about 3-5% of the water content. A principal source of the Ma2SOx is sodium FGD waste, preferably from the use of Nahcolite (a natural mineral form of sodium bicarbonate) as an SOx sorbent in the Nahcolite FGC process. The resulting co-disposal process simultaneously renders the highly soluble Na2SOx (102 g/L) an ash impermeable, and suitable for geomorphologically stable landfill disposal by known techniques to heights in excess of 200'. Any waste ash may be used, for example, municipal or industrial incinerator ash, fly ash and/or bottom ash from industrial or power plants burning fossil fuels for steam or eneryg, or scrubber sludges. The scrubber sludge may be from sodium or calcium sorbent scrubbers and may contain fly ash and/or bottom ash. Waste ash sources may be mixed and disposed by the process.

4946588

FLUID TREATMENT OR MONITORING ASSEMBLIES

John R Wise, Cootham, Storrington, West Sussex, United Kingdom

A fluid treatment or monitoring assembly has a number of elongate, parallel elements (7) such as filters mounted in a closed vessel (1). Each element (7) is held in place by an individual spring-loaded locator (15) bearing down on one end, holding its other end against a seat. The locators are mounted on a common plate (16) which is secured by screw rods (12) parallel to the filters. Each rod (12) carries a projection (20) and as it is rotated the projection engages any locator (15) that is not properly retaining a filter element (7), thus preventing completion of the assembly. But if all the filter elements are present and properly located, the rods (12) can be fully screwed down. In addition, the vessel cover (2) may be impossible to fit unless all the rods (12) are screwed down.

4946669

HISTOLOGICAL FIXATIVES

Barry Siegfried, Eugene Holland

A mercury and formaldehyde free histological fixative. The fixative employs standard non-toxic components comprising one or more alkanols, one or more diols and triols such as ethylene glycol, and one or more acids such as acetic and formic acid in an aqueous solution. A salt of a metal ion having an oxidation state of at least two may be added as an optional mordant. Osmotically active substances such as sodium chloride may be used as an option as desired to control osmotically induced cell volume changes.

4946705

INTEGRATED EXPOSURE MONITORING DEVICE

Charles R Manning, Leroy Pinto assigned to Assay Technologies Inc

A simple, inexpensive, and versatile device for measuring gaseous substances and a method for manufacture of such devices are described. The device comprises a reflectant backing which is disposed a layer which is composed of microparticles coated with a reagent and then with a diffusion layer which contains a diffusion moderator and binder, and optionally a plasticizer. A variety of useful configurations of this device are described.

4947045

SYSTEM FOR INSPECTING LARGE SIZE STRUCTURAL COMPONENTS

Albert S Birks, James R Skorpik assigned to Battelle Memorial Institute

The present invention relates to a system for inspecting large scale structural components such as concrete walls or the like. The system includes a mobile gamma radiation source and a mobile gamma radiation detector. The source and detector are constructed and arranged for simultaneous movement along parallel paths in alignment with one another on opposite sides of a structural component being inspected. A control system provides signals which coordinate the movements of the source and detector and receives and records the radiation level data developed by the detector as a function of source and detector positions. The radiation level data is then analyzed to identify areas containing defects corresponding to unexpected variations in the radiation levels detected.

4947339

METHOD AND APPARATUS FOR MEASURING RESPIRATION, OXIDATION AND SIMILAR INTERACTING BETWEEN A SAMPLE AND A SELECTED COMPONENT OF A FLUID MEDIUM

Ja Czekajewski, Leif B Nennerfelt assigned to Czekajewski Jan

Atmospheric air is introduced into reference and sample chambers, whereupon alternating circulation of the gases in the two chambers through a carbon dioxide sensor, an oxygen sensor, a pressure sensor and a pressure regulator occurs before the gases are returned to their respective chambers. The calculation of rate of production or consumption of carbon dioxide and oxygen by a tissue or other sample in the sample chamber is controlled by a microprocessor which receives signals from the carbon dioxide, oxygen and pressure sensors and controls the circulation of the gases. Sensor drift is compensated for in the calculation through the use of multiple reference chamber readings and through volume determinations for the reference and sample chambers and the sensors.

4947492

SWIVEL NOZZLE FLUSH TOILET SYSTEM

Ray T Vincent assigned to Weber Aircraft

A lavatory system suitable for use on a commercial passenger aircraft includes a toilet bowl for receiving waste and a waste-holding tank in fluid communication with the toilet bowl for receiving waste from the toilet bowl. A flapper valve is provided in the bottom of the toilet bowl and operates to control the passage of the toilet bowl contents into the waste-holding tank. Water, which may be from the potable water supply system, is directed into the toilet bowl to wash the sides of the toilet bowl and to assist in moving waste material to the waste-holding tank. A water inlet valve controls the introduction of water into the toilet bowl by actuation of a flushing switch. The water is introduced into the toilet bowl through a single nozzle which moves and progressively directs the flow of the water onto the entire interior of the toilet bowl in such a manner that a minimal amount of water is utilized per flush.

4947860

NON-INVASIVE METHOD AND APPARATUS FOR MEASURING MIXED VENOUS CARBON DIOXIDE PRESSURE (PVCO2) AND OTHER PHYSIOLOGICAL VARIABLES

Josep Fisher, Thornhill, Ontario, Canada assigned to Fisher Josep

A method of determining the mixed venous PCO2 (PvCO2) is disclosed, the method comprising the steps of: (a) measuring the PCO2 of the gases inhaled and exhaled by the patient under controlled conditions without rebreathing; (b) causing the patient to inhale a test gas containing at least a small concentration of CO2 and continuing to measure the PCO2 of the inspired and expired gases, the patient taking at least two breaths without rebreathing; (c) determining the PCO2 of the inspried gases (PICO2) and the end tidal PCO2 of expired gases (PECO2); (d) determing the differences between the end tidal PCO2 and inspired PCO2 under control and test conditions, and relating it to the inspired PCO2 used in the determination of the difference. This relationship can be used to calculate the mixed venous PCO2.

4947885

BRINE MONITOR

Paul Hart assigned to Betz Laboratories Inc

In the desalter operation of a petroleum refinery, a method which measures and regulates the stability of the oil-in-water emulsion. A device located downstream of the desalter monitors the electrical charge of oil droplets in the effluent brine. This charge reflects emulsion stability. The amount of charge streaming past a point defines a current. When a predetermined streaming current threshold is crossed, the monitoring device electrically sends a signal proportional to the excess to a metering pump or valve which adds a predetermined proportional quantity of emulsion breaker to the petroleum/water mixture in the desalter.

4948010

WASTE LIQUID COLLECTION AND DISPOSAL APPARATUS

E Todd Wiggins

In a liquid waste collection and disposal apparatus, liquid waste gravity flows to a tank through a check valve equipped inlet line. A vertical guide float within the tank controls the liquid level therein. A two-way tank venting solenoid operated valve supplies gas, under pressure, to the tank for evacuating liquid therein. An electrical circuit connects a source of electrical energy with liquid upper and lower limit magnetic switches disposed in the path of travel of the float for energizing the actuator of the solenoid valve to evacuate the fluid therein through a check valve equipped discharge line in response to the float closing the upper limit switch. When the float reaches the limit of its downward movement, the normally closed lower magnetic switch is opened to interrupt gas pressure to the tank.

4948342

METHOD AND DEVICE FOR AUTOMATIC CIRCULATION IN A WASTE WATER PUMP STATION

Folk Landquist, Balsta, Sweden assigned to Flygt AB

The pressure side of the pump unit is provided with a valve (6) which during certain periods opens a connection between the pump and the pump station to obtain circulation in the station. The valve (6) is opened and closed by a valve ball (9) which is controlled by the pump pressure.

4948364

LIME KILNS

Jeffery L Thompson

An annular, vertical shaft kiln comprising a cascading process path with varying cross sectional area, in which the coarse charge particulants tend to follow the longer path near the walls as does the gas being injected into the midregion of the kiln, while the fine particulants tend to take the straighter, shorter path near the middle, thus resulting in an even calcination of varying diameters of charge particulants. The briquetted fuel which may be made of hazardous waste, is heated slowly to safely destroy such wastes in the processing. Because of the limited range of the ratio of the smallest to the largest diameter of the charge particulants, the charge particulants are sorted through wire mesh screens into bins according to diameter. The kiln's computer then receives data on the process at various points along the path and controls the process by regulating the charge particulants injection, the rate of the fuel injection and/or the speed of the air injection.

4948402

MODULAR AIR SCRUBBER SYSTEM

H Forbes Davis assigned to Davis Water & Waste Industries Inc

A modular air scrubber system is provided for removal of pollutants from air and includes a plurality of modular scrubbing towers adapted for side-by-side interconnection to provide multiple stage filtering of air to be treated, each tower having a lower reservoir portion for a scrubber solution, and an upper portion containing contact media, each modular tower also provided with air inlets outlets and scrubber solution inlets and outlets. A specific arrangement of these modules adapted to accommodate a counterflow arrangement of air and scrubber solution for the removal of hydrogen sulfide from air is disclosed, in conjunction with a scrubber solution feed and control unit.

4948510

BIOLOGICAL PHOSPHOROUS REMOVAL FROM WASTEWATER USING MULTIPLE RECOMBINABLE BASINS

Michael D Todd, Raleigh L Cox assigned to United Industries Inc

A process for treating wastewater to biologically remove phosphorous as well as lowering ammonia, TSS and BOD levels is provided. The process employs a plurality of basins which may be individually controlled to achieve anaerobic, anoxic or aerobic conditions. The basins are reconfigurable in that the flow of influent to a basin, transfer of mixed liquor between basins and effluent discharge from a basin can be varied to create a treatment cycle which has features of both continuous and batch processes while minimizing recycle rates and hydraulic level changes.

4949528

METHOD AND MEANS FOR RECLAMATION AND RECYCLING

Robert Palik

A recycling bag assembly is formed from a series of plastic bags similar to trash or garbage bags temporarily secured together by heat tacking or otherwise. The individual bags are usually color coded to facilitate identification of the solid waste material that is to be collected in them for collection and transport to a disposal facility. A method of widespread regular controlled distribution of the bag assemblies is also provided by inserting or otherwise combining the bag assemblies with newspapers prior to delivery of such papers and subsequent delivery of the bag assemblies with such papers.

4949704

SOLAR COLLECTOR FOR THE GENERATION OF HIGH TEMPERATURE

Antoni Pfluger, Bonn, Federal Republic Of Germany assigned to Forshung e V Fraunhofer-Gesellschaft zur Forderung der angewandten

A solar collector for the generation of high temperatures including a tub-like housing defining a cavity, a glass plate for sealingly closing the cavity, a selective absorber and a trasparent thermal insulation structure located on the inside of the glass plate. An air gap separates the selective absorber from the glass plate. The solar collector is operated at a vacuum of less than 10000 pascal by means of a vacuum pump. The transparent thermal insulating member reduces the air convection and acts similarly to a mulitple pane for the reflected, diffuse thermal radiation. High efficiencies are thus achievable even at large temperature difference between the absorber and the area outside the solar collector. The thermal insulation effect of the air gap and at the same time of the microporous thermal insulation located in the bottom of the housing is varied by regulation of the degree of vacuum. A higher air pressure results in greater thermal losses of the absorber toward the thermal insulation member and the microporous insulation, whereby the temperature of the absorber is controllable.

4950471

ACETATE SELECTED BACILLUS THURINGIENSIS AND THE METHOD OF USE

Russell S Travers, Phyllis A W Martin assigned to The United States of America as represented by the Secretary of Agriculture

Methods and mutant Bacillus thuringiensis strains are provided for controlling lepidopteran insects. Sporogenic, crystalliferous mutant strains for B. thuringiensis having the identifying characteristics of NRRL B-18195, NRRL B-18196 and NRRL B-18197 are provided for use as biocontrol agents. Said strains have the ability to produce a bypyramidal crystal composed of toxic protein and require a leucine and valine containing nutrient medium for growth, sporulation and crystal production.

4950594

MICROBIOLOGICAL ASSAY USING BIOLUMINESCENT ORGANISM

Arthur Stiffey assigned to The United States of America as represented by the Secretary of the Navy

A microbiological assay based on bioluminesce employing the bioluminescent dinoflagellate Pyrocystis lunula. An oil well drilling fluid sample is prepared according to E. P. A. procedures to obtain a suspended particulate phase sample. An aliquot of the sample is added to a growth medium containing Pyrocystis lunula in suspension. The mixture is agitated to subject the Pyrocystis lunula to a shear stress. Light emitted as a result of the shear stress on the Pyrocystis lunula is measure and compared with a control to determine if there is diminution of light produced by the Pyrocystis lunula in the mixture. Diminution of light production is an indication of the presence of a toxic substance in the sample.

4950668

PYRAZOLE DERIVATIVE, INSECTICIDAL OR MITICIDAL COMPOSITION CONTAINING THE SAME AS THE EFFECTIVE INGREDIENT

Itaru Okada, Shuko Okui, Yoji Takahashi, Toshiki Fukuchi, Shiroyama, Japan assigned to Mitsubishi Kasei Corporation

A novel pyrazole derivative and an insecticidal or miticidal composition containing the derivative as the effective ingredient are disclosed. The pyrazole derivative of the present invention has an excellent controlling effect also against harmful insects and mites exhibiting resistance to conventional insecticides and does not disturb the ecosystem since it is less toxic and less residual.

4951583

THERMAL DESTRUCTION SYSTEM FOR TOXIC SUBSTANCES

Eugene C McGill, Bob R Cartwright assigned to McGill Environmental Systems Inc

A process for the thermal destruction of waste materials of unknown volatility disposed within a container, the process comprising the steps of (a) placing the open container in a combustion chamber of a pyrolysis furnace; (b) providing the pyrolysis furnace with a reducing atmosphere and raising the temperature in the pyrolysis furnace to remove volatile components of the material until a preselected temperature is reached; (c) maintaining the temperature in the pyrolysis furnace while controllably adding air until all the combustible materials are pyrolyzed; (d) continuing to add air during a final oxidation period to achieve combustion of all nonvolatile combustible materials; and (e) processing all volatilized materials in a secondary combustor fluidly communicating with the pyrolysis furnace.

4951738

METHOD AND APPARATUS FOR RECOVERING HEAT ENERGY FROM POLLUTED WATER

Lennar Litzberg, Stockholm, Sweden assigned to Sical AB

A heat exchanger is provided in the form of cylindrical, hollow panels in upstanding, spaced, concentric relationship for a first medium flow, and a casing surrounding the panels for a second medium flow. The upper edges of the panels are mutually level. The heat exchanger also includes a carrying arm rotatable in the horizontal plane above the upper edges of the panels and carrying vertical cleaning arms extending between the panels. The second medium flow is downwardly taken into the casing under the inmost panel, and is taken out downwards from the casing outside the outmost panel the liquid surface of the second medium flow is allowed to rise to a level between the upper edges of the panels and the lower part of the carrying arm. A substantially constant gas volume is maintained in the casing above the liquid surface of the second medium flow, by arranging a control for sensing the liquid level (25) of the second medium flow. A gas pump (25) is arranged to maintain the gas volume in the casing above the liquid level substantially constant in response to the control.

4951871

SOUND-PROOF TYPE ENGINE WORKING MACHINE WITH WASTE HEAT RECOVERY APPARATUS

Tsugunori Hata, Akira Inoue, Toshihik Teramoto, Kazuhiko Ogura, Isamu Kubomoto, Osaka, Japan assigned to Kubota Ltd

In a sound-proof type engine working machine with a waste heat recovery apparatus, including a sound-proof type engine working machine which comprises a liquid cooled internal combustion engine and a working machine such as an electricity generator, a compressor and the like adapted to be driven by the engine and a waste heat recovery apparatus adapted to recover the waste heat from the engine, the engine cooling liquid within the water jacket of the engine is adapted to circulate through a waste heat recovery heat exchanger and a radiator, as well as the heat to be radiated in the radiator is adapted to be controlled by means of a radiated heat control device, and the engine and the working machine are horizontally arranged side by side each other within the sound-proof casing in a longitudinal direction thereof, an upper support frame is fixed on the upper side of the sound-proof casing, and the radiator and a radiator fan associated therewith are disposed on the upper support frame.

4952237

METHOD AND APPARATUS FOR RECOVERY OF NON-FERROUS METALS FROM DROSS

Ghyslai Dube, Jean-Paul Huni, Serge Lavoie, Wesley D Stevens, Jonquiere, Canada assigned to Alcan International Limited

A method and apparatus for treating non-ferrous metal drosses in order to recover the free metal contained therein. The dross is heated by a plasma torch in a rotary furnace, preferably to a temperature above 800 degrees C. The plasma heating and rotary motion make it possible to recover metal from the dross without employing the conventional salt bath. This means that the gases exiting the furnance can be treated more easily to remove pollutants and the solid residues can be discarded without risk of causing environmental pollution. By controlling the speed of rotation of the furnace, large dross lumps can be accommodated and so the conventional grinding and screening procedure of the dross can advantageously be eliminated.

4952283

APPARATUS FOR VENTILATION, RECOVERY OF HEAT, DEHUMIDIFICATION AND COOLING OF AIR

Ferdinand K Besik, Mississauga, Ontario, Canada

An apparatus for ventilation, recovery of heat, dehumidification and cooling of air or industrial gases for use in industrial processes and in air conditioning of residential, commercial and industrial building comprises a highly effective valveless periodic flow type dehumidifier-heat exchanger in which a countercurrent flow of two gaseous streams through a stationary matrix of a desiccant and a solid heat exchanging material is achieved by an air fan controlled by a variable timer controller. The stationary matrix may include a single bed or two beds of solid materials with distinguished mositure and heat sorption properties, a heater and a wet filter to provide simultaneously an effective transfer of heat and moisture, removal of particulates and adiabatic cooling of the two gaseous streams. The released sorption heat is temporarily stored within the matrix material and then used in reactivation of the desiccant. If required, the additional heat may be conveniently provided by a fossil fuel, electric, solar or waste heat energy sources. Small amount of power is used in operation of the air fan that may also provide ventilation of the air conditioning building.

4952518

AUTOMATED ASSAY MACHINE AND ASSAY TRAY

Larry J Johnson, Stephen Coates, Rueymin Loor assigned to Cetus Corporation

A machine for transferring liquids to and from the wells of assay trays in a controlled, automated manner and a solid phase assay tray for use with the machine. The machine includes a horizontally translatable table (15) that holds the tray (46), a plurality of liquid dispensing manifolds (54) for dispensing liquids into the tray wells (50) and an aspirating manifold (65) for aspirating liquid from the well. The dispensing and aspirating manifolds are mounted on a vertically translatable head (16) above the table. Each dispensing manifold is equipped with a row of dispensing tubes (56) and is connected via a pump (58) to a liquid container (62). The aspirating manifold is equipped with a row of aspirating tubes (66) and is connected via a pump (69) to a waste liquid receptacle (73). A microprocessor (85) controls the movements of the table and manifolds and operates the pumps. The tray wells include means, such as sloping bottoms (74) or subwells (83), that cause the solid phase (76) to occupy a particular position in the wells and sumps (75), (84) that are positioned relative to the location of the solid phase such that they may be accessed vertically by the aspirating tubes without danger of disturbing the solid phase. The bottoms of the sumps have optically flat areas so that beams of light may be passed vertically through the liquid contents of the wells without intersecting the solid phase to make optical measurements of the liquid contents.

4952911

SCANNING INTRUSION DETECTION DEVICE

George C D'Ambrosia, Christopher A Ludden assigned to Eastman Kodak Company

A scanning intrusion detection device is capable of monitoring a large volume of either interior or exterior space from a single relatively inexpensive unit. This intrusion detection device comprises a radiation emitter arranged to scan a beam of infrared radiation about a field of view and means for receiving the radiation of the beam reflected from the field of view. The receiver is arranged to generate a signal indicative of the distance from the device at which the beam has been reflected for each of a plurality of azimuthal sectors of the field of view during a selected time period. A ram is also provided for storing a plurality of reference signals which are indicative of the distance of reflection of the beam from each azimuthal sector of the field of view during a reference time period. The signals from a selected time period are compared with the reference signals and an output signal is generated if one of the signals is different from the respective reference signal.

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Editorial: Software Survey Section

The purpose of the Software Survey Section in *Environment International* is to encourage the open exchange of information on software programs unique to our professional field. With the rapid penetration of computers into academic and industrial institutions has come a parallel increase in the number of scientists and researchers designing their own software. The existence of much of this software remains unknown to even those of us who could most benefit from its use. We believe that it is of vital importance to our readers that such information be made available. We believe also that a professional journal is the best place to share such information. Your contribution would be most welcome.

The questionnaire on the following pages is designed to assist you in reporting on software that you may have developed or be in the process of developing. By completing this form, your information will reach thousands of your colleagues who may benefit from your work and may possibly offer suggestions for further enhancements to your software. Please complete the form and return it to:

Barbara Moghissi
Environment International
P.O. Box 7166
Alexandria, VA 22307

We do not intend to review or comment on the contents of the questionnaire. It will be published as is in order to expedite the information cycle process. We would welcome any comments you may have.

THE EDITORS

JOURNAL NAME ENVIRONMENT INTERNATIONAL

P E R G A M O N   P R E S S

SOFTWARE DESCRIPTION FORM

Title of Software Program: ______________________________

____

Contributor: ______________________________

Institution: ______________________________

Address: ______________________________

____

Telephone: ______________

Type of program: [ ] Application [ ] Utility [ ] Other __________

Category: __________________ (ie., Psychological Assessment, statistics, thermodynamics, etc.)

Potential users: ______________________________

Field/s of interest: ______________________________

Developed for (name of computer/s): ______________________________

in (language/s): ______________________________

to run under (operating system): ______________________________

available on: [ ] Floppy diskette Specify:

Size ________ Density ________ [ ] Single-sided [ ] Dual-sided

[ ] Magnetic Tape Specify:

Size ________ Density ________ Character set __________

Hardware required: ______________________________

Memory required: __________ User training required: [ ] Yes [ ] No

Documentation: [ ] None [ ] Minimal [ ] Self-documenting

[ ] Extensive external documentation

Source code available: [ ] Yes [ ] No

Stage of development: [ ] Design complete [ ] Coding complete

[ ] Fully operational [ ] Collaboration welcomed

Is program in use? [ ] Yes How long? ________ How many sites? ________

[ ] No

Is the contributor available for user inquiries?: [ ] Yes [ ] No

Distributed by: ______________________________

Cost of program: __________

Demonstration disk available? [ ] Yes Cost: __________

[ ] No

(continued)

Description of what software does (maximum of 200 words):

RETURN COMPLETED FORM TO:

Barbara Moghissi
Environment International
P.O. Box 7166
Alexandria, VA 22307

Reference number ____
(assigned by Editor)

[This Software Description Form may be photocopied without permission]

ENVIRONMENT INTERNATIONAL

Aims and Scope

Environment International, published bimonthly, is a multidisciplinary forum for the publication of original environmental literature. Vital data, causes of pollution, and methods for protection are all featured. Covering the entire field of environmental protection, *Environment International* includes contributions from the following areas

- Concentration of elements and compounds, notably pollutants
- Transport of polllutants in the environmental media
- Control technologies
- Public policy alternatives including legislation
- Release rates of pollutants from various sources
- Health and ecological effects of pollutants
- Description and interpretation of laws, regulations, and standards
- Information which will contribute to the understanding of environmental behavior of pollutants or will promote environmental protection
- National and international recommendations and practices to help bring about lasting improvement in environmental protection

From time to time *Environment International* will publish issues devoted exclusively to special topics, e.g., specific pollutants. These issues will discuss such problems as environmental concentrations, health and ecological effects, environmental kinetics, production and release rates, legislative and regulatory aspects, control technologies, and other pertinent data. Other special issues will be devoted to pollution problems in selected geographical areas. Authors and readers are encouraged to send in suggestions to the Editor-in-Chief recommending topics for these topical issues

Information for Contributors

Since the journal will serve a multidisciplinary audience, authors are urged to write for nonspecialists. In particular, they are discouraged from using expressions which are understandable only to a select audience. Clarity should be the guide when preparing manuscripts. All the contributions will be subjected to peer reviews. Owing to the broad coverage of *Environment International,* no single format can accomodate all contributions. Manuscripts must be submitted in English. Mail manuscripts to the Editor-in-Chief, *Environment International*, P.O.Box 7166, Alexandria, VA 22307, U.S.A. The following categories of contributions will be considered for publication in the journal

Articles—Previously unpublished information including data from routine monitoring operations will be published in this category. Papers dealing with new analytical techniques should contain data indicating their usefulness in environmental measurements. Similarly, basic biological effects data should be related to environmental pollutants.

Discussions—This section is intended as a forum for the readers to express their views on environmental problems on a global or national basis. Letters to the editors, editorials, contributions containing personal opinions and comments on articles published in the journal or elsewhere will be included in this section.

Book Reviews—Solicited and unsolicited reviews on relevant books will be considered for inclusion in this section.

News—This section will contain newsworthy items in the scientific, technological, governmental and political areas relating to the environment. Readers are encouraged to suggest subjects for inclusion in this section.

Preparation of Manuscripts—The journal is produced using a computer-based desktop publishing system. Accordingly, the processing time of manuscripts submitted in a computer-compatible form is greatly reduced.

Manuscripts should be typed double-spaced on one side of bond paper with wide margins. Each paper should include a title page with the title of the paper, name(s) of author(s), affiliation(s) and mailing address. In the case of co-authors, it should be clearly indicated which is to receive correspondence and proofs for correction.

All tables and figures must be camera-ready. Use a new ribbon for typing tables. Photocopies, blue ink or pencil are not acceptable. Use blue ink for lettering figures. The lettering should be large enough to be legible after the diagram has been reduced in size for printing. In the interest of conserving space, it is desirable that figures are drawn so they will reduce to the single column width of 8.5cm (3.35 in). Type figure legends double-spaced on a separate sheet of paper. Write article title and figure number lightly in pencil on the back of each piece of artwork.

Submissions in a computer-compatible form require a disk, one original copy on paper containing the original figures and tables, and a second paper copy. The system requires compatibility with IBM computers and can accept 13.5 cm(5.25 in) and 9 cm (3.5 in) disks. The WordPerfect word processing system prepared with an IBM-compatible (MS-DOS or PC-DOS) computer is the preferred submission. If WordPerfect is unavailable, WordStar, MultiMate, Revisable-Form-Text (IBM DCA Format) can be used. If none of these is available, use ASCII (American Standard Code for Information Interchange) or DOS text file. Indicate which program was used. In the absence of a computer, one original and two copies are required.

References—The journal generally follows the referencing style of the *Council of Biological Editors.* In the text, refer to the author(s) and the year. Examples for one author, two authors and more than two authors are: Wolf(1984); Repace and Lowrey(1985); Smith et al.(1979). If there is more than one listing of the same author and year, use a, b, c, etc. Prepare a list in alphabetical order containing all literature cited. In this list of references, include initials and surnames of the authors, title of the paper, name of the journal using the *World List of Scientific Periodicals* abbreviations, volume number and page number(s). Note that et al. is not acceptable in the reference list unless the publication has more than six authors. The following examples should be used as a guide:

Article: Repace, J.L.; Lowrey, A.H. A quantative estimate of nonsmokers' lung cancer from passive smoking. Environ. Int. 11:3-22; 1985.

Report: NIH (National Institutes of Health). Report of the National Institutes of Health ad hoc working group to develop radioepidemiological tables. NIH 85-2748. Washington, D.C : U.S. Department of Health and Human Services; 1985.

Book: Henderson, P. Inorganic geochemistry. New York, NY: Pergamon Press; 1982.

Regulation: USEPA (U.S. Environmental Protection Agency). National primary drinking water regulations: fluoride. 40 CFR Parts 141, 142 and 143. Fed. Reg. 50:47142-48933; 1985.

Proceedings: Swedjemark, G.A.; Mjönes, L. Exposure of the Swedish population to radon daughters. Berglund, B.; Lindvall, T.; Sundell, J., eds. Proc. 3rd international conference on indoor air quality and climate. Vol. 2. Stockholm: Swedish Council for Building Research; 1984:37-43.

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