Developing Human Response and Exposure Criteria for Evaluating Indoor Environments

by

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(ABSTRACT)

Current building codes and standards may not be adequate to assure occupant well-being or to prevent problems such as the Sick Building Syndrome (SBS). As building codes and standards are based at least implicitly on human response criteria, the objective of this dissertation was to define human response criteria and measures, and to identify links with exposure parameters, exogenous factors and methodological effects.

A characterization, consisting of four domains based on two objects of evaluation: environment and personal state, and two aspects of evaluation: perceptual and affective, was used as a framework for identifying human response criteria. Through a literature review and evaluation synthesis of ten published studies, a hierarchy of exogenous factors that can be linked to the four domains was identified. Potential methodological effects associated with three types of methodologies were identified and linked to one or more domains. Then, links between human responses and exposures were identified from the literature.

A conceptual model, synthesizing the combined impacts of exposures, exogenous factors and methodological effects on human response was developed. A selected portion of the conceptual model was tested empirically in two open-plan, non-industrial work spaces.

The empirical study showed that for the selected spaces, exogenous factors explained more of the variation in human responses than did exposure parameters. Based on the empirical study, the major conclusions of the dissertation were that: (1) the concept of the four domains is useful in specifying criteria, (2) a hierarchy of exogenous factors is linked to the four human response domains, (3) control of exogenous factors such as the social environment and adaptive factors may all be needed to achieve healthy buildings, or to resolve problems associated with the Sick Building Syndrome, (4) occupant characteristics must be considered in developing exposure criteria, and (5) for levels of exposures typically found in indoor environments, it is necessary to consider their multifactorial impacts rather than the impacts of individual stressors.

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CHAPTER 1

INTRODUCTION

1.1 THE PROBLEM

Current building codes and standards, usually expressed in terms of exposure criteria, system performance or prescriptive criteria, may not adequately address the primary objective of indoor environmental control, namely, the provision of occupant well-being, not just the prevention of deleterious conditions. Additionally, symptoms related to the Sick Building Syndrome (SBS), characterized by the absence of routine physical signs and clinical laboratory abnormalities, may exist even when specific contaminants cannot be identified to explain their existence (Kreiss, 1989). Several field studies have failed to find consistent relationships between measured environmental parameters and symptoms related to SBS (e.g., Nelson et al., 1991). SBS is caused multifactorially, by combinations of exposure factors, often at low concentrations (Molhave et al., 1990). These exposure factors or 'stressors' in the indoor environment can be broadly categorized in terms of thermal, air quality, lighting and acoustic parameters. Occupants perceive these multiple stressors in the indoor environment, and subsequently experience comfort or discomfort. Alternatively, even when perceived stressors such as strange odors are not recognized, discomfort may be experienced by occupants (Woods et al., 1988). Exposure criteria for the evaluation and design of buildings should, therefore, be predicated upon predetermined human response criteria. However, as noted in the literature, there is considerable confounding with respect to: (a) the definition of human response criteria, and (b) the identification of exposure parameters corresponding to these human response criteria. These two issues are addressed in this dissertation. The dissertation is expected to lead to a better understanding of the combined impacts of physical environmental stressors, exogenous factors, and methodological effects on human responses to the indoor environment. The results of this dissertation are expected to be useful in the development of standardized protocols for building diagnostics, as well as in the development of codes and standards for building design and evaluation.

1.2 GOAL AND OBJECTIVES OF RESEARCH

The overall goal of this research is to define human response measures and criteria for the evaluation of building environments, and to develop and empirically test a conceptual model that will identify links between those human response measures and criteria, exposure parameters, exogenous factors, and methodological effects. The ultimate application of this dissertation is expected to be in the definition of exposure criteria that can be used in the design and modification of building systems.

The objective of building evaluations or 'diagnostics' is to identify problems where they exist, or to provide assurance that a building is 'healthy'. The first step to achieve this goal is to define human response measures and criteria that accurately reflect the objective(s) of the building evaluation. Additionally, it is proposed that different criteria may be needed for evaluating suspected problem buildings and buildings without known problems. The second step in achieving the goal of this research is to identify exposure parameters that can be associated with the selected human response criteria. The specific objectives of this research and their corresponding tasks are outlined as follows:

Objective one *To define human response criteria for the purpose of evaluating the performance of actual and virtual buildings*

The tasks for this objective include:

1-1 The development of a theoretical framework that can be used to define human response criteria for the evaluation of building performance.

The existing literature on the assessment of human responses to indoor environments is reviewed to develop a characterization of human response that can be used to define human response measures and criteria. Human responses targeted for this dissertation exclude those that have a clinical basis (i.e., clinical signs of illness), as the cause-effect relationships for these are fairly well established. The characterization, described in chapter 3, identifies four domains of human response, based on two objects and two aspects of response.

1-2 The definition of human response criteria for assessing actual and virtual buildings.

It is proposed that actual (i.e., existing) and virtual (i.e., buildings that exist in the mind of the designer and in the form of working drawings and specifications (BRB., 1985, p.IX)) buildings may require a different approach to the setting of criteria for the assessment of building performance. It is important to note that although human response criteria are the focus of this dissertation, other criteria (e.g., economic) may also be required to adequately assess building performance.

Objective two *To develop a conceptual model that assesses the impacts of thermal and air quality stressors in the indoor environment, as well as exogenous factors and methodological effects on human response.*

The selection of thermal and air quality stressors is based on the predominance of these stressors in the literature with respect to problems such as SBS. Additionally, such problems are caused by combinations of stressors rather than individual stressors.

The tasks for this objective include:

2-1 The identification of exogenous factors and methodological effects that influence human responses, in addition to physical exposure factors.

A literature review identifies exogenous factors and methodological effects that influence the four domains of human response, developed as part of task 1-1. An evaluation synthesis is also undertaken to examine reported empirical evidence with respect to relationships between human response domains and exogenous factors.

2-2 The identification of conceptual and empirical links between the human response domains developed in task 1-2 and exposure parameters.

A review of the literature on the physiology of human response and on psychophysical methods is undertaken to identify conceptual links between human responses and physical exposure parameters (i.e., stimuli). This dissertation focuses on the impact of two primary stressors, thermal and air quality. The evaluation synthesis of ten field studies referred to earlier also investigates empirical evidence, reported in the literature, that links human response domains to exposure parameters.

2-3 The development of a conceptual model that describes the combined impacts of physical environmental factors, extraneous factors and methodological effects on human responses.

The results of tasks 1-2, 2-1, and 2-2 are synthesized in developing this model.

Objective three *To conduct an empirical study to test a selected portion of the conceptual model developed as part of objective two.*

The following task addresses this objective

3-1 To validate the model developed in task 2-3, a field study is undertaken for non-industrial work environments, as these typically limit occupant control of indoor environmental parameters and have an impact on a large occupant population. Non-industrial, rather than industrial environments are targeted, as the focus of indoor environmental control strategies in the latter has been on specific contaminants that may have toxicological impacts. On the other hand, exposures to low levels of multiple stressors are of primary concern in non-industrial environments. Problems such as SBS are usually found in non-industrial environments that typically include more susceptible populations who may experience adverse health effects after exposure to toxicologically insignificant levels of indoor contaminants. It is anticipated that the results could be generalized to other environments such as residential, by adjusting the parameters of the relevant exogenous factors identified in this research.

1.3 SCOPE OF THE DISSERTATION

This dissertation focuses on two of four primary stressors (Woods, 1988), namely, thermal, and air quality. Thermal and air quality stressors predominate in the literature with respect to problems such as SBS. The other two primary stressors, namely, lighting and acoustics are accounted for as exogenous factors, i.e., as variables that may influence human responses to thermal and air quality stressors. Also, as stated earlier, the dissertation focuses on non-industrial work environments.

1.4 OUTLINE OF DISSERTATION

Chapter 2 of this dissertation is a literature review that describes the current status of human response and exposure criteria development. The rationale for this dissertation is also discussed.

Chapter 3 presents a characterization of human response, an identification of human response measures within each of the resulting four domains of human response, and definitions of human response criteria for actual and virtual buildings.

Chapter 4 includes the identification of exogenous factors and methodological effects that may influence each human response domain. Also reported are the results of an evaluation synthesis, undertaken to assess the usefulness of the characterization of human responses in identifying and controlling for exogenous factors.

Chapter 5 includes the identification of sets of exposure parameters related to human responses to thermal and air quality. Finally, information from chapters 3,4, and 5 is synthesized to develop a conceptual model that describes the combined impacts of exposures, exogenous factors and methodological effects on human responses.

Chapter 6 describes procedures used to conduct a field study to assess a selected part of the conceptual model. Chapter 7 consists of the results of the field study and an interpretation of these results. Finally, Chapter 8 discusses the implications of the results with respect to the conceptual model, and outlines avenues where further research is needed.

CHAPTER 2

BACKGROUND: CURRENT DEFINITIONS OF HUMAN RESPONSE AND EXPOSURE CRITERIA FOR THERMAL AND AIR QUALITY

2.1 INTRODUCTION

The focus of this dissertation is on the development of human response and exposure criteria that can be used to design and evaluate the quality of thermal conditions and air quality in indoor environments. The following review of the literature attempts to identify the current status of research related to the development of criteria that can be used by designers to create indoor environments that meet the emerging goals of comfort and health for the occupants of these indoor environments.

Health and comfort are presently considered to be the primary objectives of indoor environmental control. Historically, criteria for indoor environments have tended to focus more on one or the other of these two criteria at different times. The definition of health has also been expanded to include not only the absence of disease or ill-health, but also the presence of physical, mental and social well-being (WHO, 1946). Operational definitions of health and comfort, however, are still inadequate. There is also a need for the development of criteria that can be used in the design and construction of buildings to meet these goals. Section 2.2 of this chapter is a historical perspective based on available literature, that attempts to identify human response criteria that have been used implicitly or explicitly as the basis for performance or prescriptive criteria for building design and construction. This review is limited to the literature related to thermal and air quality control, although the indoor environment comprises, in addition to these, other factors such as lighting and acoustics. The scope of this review reflects the focus of the dissertation. Additionally, this section provides a brief overview of the evolution of indoor environmental criteria for work environments. The focus of this dissertation is on non-industrial work environments. However, the inclusion of industrial work environments is useful in tracing the evolution of criteria for indoor work environments, as early efforts to improve the quality of work environments in terms of safety and the prevention of ill-health were focused on industrial environments.

Section 2.3 is a review of five standards currently used in the United States and Europe for thermal and air quality control. The intent of this review is to identify what is known about relationships between the goals of these standards, expressed in terms of human response, and exposure or system (performance and prescriptive) criteria. A key issue addressed in this section is that of assessing whether exposure or system criteria specified in these standards achieve the human response criteria upon which they are predicated. This section also describes the rationale for this dissertation, namely, the development of human response criteria that can be rationally translated to exposure criteria. The determination of human response-exposure links is based on a rational approach to the development of system performance and prescriptive criteria for building design and evaluation.

Section 2.4 reviews current definitions of human response and exposure criteria used in the evaluation of suspected problem buildings or of buildings without known problems. Two disciplines, namely, Building Diagnostics and Environmental Design Evaluation are concerned with the evaluation of the quality of indoor environments. Relevant literature related to each of these bodies of literature will be reviewed to extract implicit and explicit evaluation criteria that are currently used to assess indoor environments. This section identifies gaps in our existing knowledge of links between human responses and exposures.

2.2 GOALS OF INDOOR ENVIRONMENTAL CONTROL IN THE WORKPLACE: AN HISTORICAL PERSPECTIVE

The avoidance of ill-health may be considered to have been the primary objective of the first attempts at developing air quality criteria for indoor environments. However, Yaglou's experiments during the 1920s and 1930s also addressed comfort concerns with respect to air quality, namely, the control of odors (Yaglou et al., 1936). Woods' (1995) review of historical perspectives in determining health and comfort criteria provides evidence that early ventilation standards focused on the avoidance of ill-health. He reports that what might be considered the first ventilation code was instituted by King Charles I in 1609 as a response to his concern with the spread of plague and other diseases in London. By 1857 it was recognized by Professor Max von Pettenkofer that carbon dioxide at levels exceeding 1000 ppm may increase susceptibility to disease by weakening bodily functions and decreasing energy (Woods, 1995). Consequently, in 1893, a physician, J.S. Billings found a relationship between ventilation rates and the prevalence of tuberculosis (Woods, 1995).

McFadden (1978) presents a historical overview of indoor air quality standards. According to this review, psychologists LeBlanc, Herman, Flugge and others showed that the undesirable effects of air and sensation of uncomfortable conditions had a physical basis -

i.e., temperature and humidity (p.13). The New York State Commission Ventilation study, published in 1923, based its recommendations for ventilation rates on the control of carbon dioxide as well as odor (Woods, 1995). Yaglou et al. (1936) also use odor as a criterion for developing ventilation requirements. In addition to odor, feelings of stuffiness, often described as a lack of freshness were also expected to be used by subjects rendering judgments about the quality of the air (i.e., good ...bad). Thus, it is evident that as early as the 1900s, criteria for air quality were already predicated upon comfort considerations.

Thermal criteria were also focussed, even in the early years, upon the objective of thermal comfort. As early as 1845, Woods (1995) reports that Walter Bernan documented the need for artificial heat for 'personal comfort'. Criteria for thermal environments have focussed on the achievement of 'thermal comfort' in indoor environments. It is possible that the difference in focus between air quality (i.e., health) and thermal (i.e., comfort) criteria in the early years may be attributed to the fact that in inhabited spaces, thermal conditions do not, in general constitute physical hazards (Griffiths,1975). The distinction between thermal and air quality criteria may however not be clearly marked, as temperature, humidity and air movement have interactive effects upon the thermal and chemical characteristics of an indoor space. For instance, Kerka et al. (1956) report on the role of temperature and humidity on odor perception. Janssen et al. (1982) report on the role of carbon dioxide on thermal perception.

Health and comfort in the workplace

Since the early 1900s, the workplace has been the focus of efforts to create conditions that promote the health and well being of its occupants. As Pelletier points out, "..work consumes most of an individual's life for the most important years, and is usually second only to sleep in the sheer number of occupied hours (Pelletier, 1984, p.1)." The importance of environmental control of work environments is also attributed to the fact that individuals have little control over the environmental determinants of health that they are exposed to in the workplace. The following account describes the evolution of the goals of indoor environmental control in work environments.

As discussed in the following paragraphs, '*health*' was the primary focus of indoor environmental control in the workplace in the early years. Additionally, the objective of accident prevention or '*safety*' preceded control of chemicals in indoor environments. The objective of '*comfort*' may be seen to have emerged as a result of improved building technology and debates about the impacts of improved environmental conditions on worker productivity.

Safety in the workplace

Industrial work environments were the first targets of efforts to develop environmental control measures, as these presented greater health hazards to their occupants than non-industrial environments. Efforts were focussed on protecting workers from unsafe actions and environmental conditions (Hoover et al., 1989), i.e., on accident prevention. The steel and railroad industries were the first to adopt measures to increase the safety of workers (Hoover, et al. 1989). The National Safety Council (NSC) was established in 1913 through collaborations of safety professionals, management leaders, public officials and representatives of insurance companies to reduce high accident and injury rates. Standards and codes for increasing the safety of industrial work environments were developed by the American Engineering Standards Committee (AESC), which was the predecessor of the American National Standards Institute (ANSI).

Avoidance of disease related to workplace exposures

One example of early concerns related to the chemical environment in industrial settings is the process that led to the recognition of the occupational origin of lung disease in the case of mine workers in the United States. Derickson (1991) discusses the difficulties associated in determining cause-effect relationships between environmental exposures and diseases. Even when the links had been made, however, the issue of toxic exposures was initially focused on obtaining higher wages and shorter working hours rather than on controlling hazardous exposures. The American Association for Labor Legislation (AALL) expected that higher insurance premiums resulting from the payment of worker compensation would indirectly provide incentives for employers to control hazards in the workplace (Derikson, 1991).

Control of chemical exposures in the workplace has been the subject of much of the research conducted by the National Institute for Occupational Health and Safety since the Occupational Safety and health Act (OSHA) was passed in 1970. Considerable success has been achieved in identifying and setting criteria for several hazardous chemicals. However, Sundin et al. (1989) report that out of the 10,000 or more potentially hazardous exposure agents in industrial settings, only 500 to 600 could be measured by sampling and analytical techniques present at the time that the paper was written. Additionally, these authors also point out that innovations in technology introduce new sources whose long-term effects on health are not immediately evident. To address this issue, NIOSH has developed surveillance systems such as SENSOR that are used throughout the country to provide inputs about occupational disease and injury to a center that collects and analyzes data, treats the individuals affected, directs action towards co-workers at risk, and coordinates or carries out interventions at the worksite (Baker, 1989). The creation of large databases permits trend monitoring that can be used to identify instances of injury, disease or death related to environmental exposures. Currently, the goals of chemical exposures in the industrial workplace are still predominantly related to the avoidance of ill-health. 'Safe' exposure levels of indoor contaminants are determined based on the results of toxicological research (Tardiff et al., 1987). Thus the primary criteria for 'safe' or 'acceptable' exposures are based on considerations such as the determination of acceptable levels of chronic risk, the determination of concentrations at which there is virtually no risk of acute disease in the general population, and the determination of concentrations that will not cause ill-effects in the most hypersensitive individuals (Light et al., 1992).

Comfort and well being in non-industrial work settings

The objective of indoor environmental control to provide for 'comfort' and 'well being' of occupants in non industrial work settings can be attributed to three factors: (1) the emergence of Sick Building Syndrome (SBS), (2) the recognition of the role of physical environmental factors in increasing worker productivity, and (3) the development of new technology for improving environmental control and for monitoring indoor exposures. Each of these are discussed in the following pages.

1. The emergence of SBS "Sick Building Syndrome is suspected when occupant complaints of certain symptoms associated with acute discomfort (e.g., headaches, fatigue, eye irritation, sore throat, nausea) persist for more than two weeks at frequencies significantly greater than 20 percent; the cause or causes of the complaints are not recognizable; and a substantial percentage of the complainants report almost immediate relief upon exiting the building (Woods, 1988. p. 3.)." Kreiss (1989) describes SBS as "complaints of mucous membrane irritation, fatigue, and headache occurring in high prevalence among office workers, and with a temporal correlation with being in a building (p.576)." The energy crisis of the 1970s stimulated efforts to conserve energy. Buildings were designed and constructed to be 'tighter', to conserve energy for heating and cooling in addition to compromising thermal comfort. This also meant that infiltration of air could no longer be relied upon to control contaminant concentrations by dilution. Levin (1989) reports that the heath effects of most VOCs (volatile organic compounds) emitted from building materials, usually at low concentrations, are not well understood. He also reports that contaminants from other sources such as occupant activities can contribute to indoor concentrations of contaminants.

The emergence of SBS has required a move away from the goal of 'avoiding ill-health', as symptoms related to SBS may not constitute clinical signs of illness. These symptoms are described more accurately as 'discomfort' (e.g., headaches, fatigue, sore throat, nausea). Additionally, these symptoms cannot be related to the presence in the indoor environment of one chemical. Rather, SBS is caused multifactorially, by a combination of stressors, often at low concentrations (Molhave, 1990). The goal of indoor environmental control, to prevent the occurrence of SBS should therefore be expressed in terms of an absence of discomfort.

2. Links between indoor environments and worker productivity Several studies have found improved worker performance and worker satisfaction related to improved furniture, furniture and facilities, and individual environmental elements such as lighting and acoustics (Springer, 1986). Woods (1989) compared the costs of owning and operating buildings including the annual costs of leased or rented space, utility costs, capital assets, construction costs and the cost of salaries and wages. The latter were significantly higher than the other cost components. He also demonstrated through an example that energy savings may be counterproductive if unacceptable environmental conditions result in decreased worker productivity. Springler (1986) also reports that research conducted by BOSTI in 1984 shows a ratio of personnel to building costs of 13:1 for new construction and 5:1 for leased space. Productivity has been assessed in a number of different ways by different researchers, and productivity measures for different indoor spaces are necessarily different. Woods (1989) recommends that productivity be measured in terms of the function provided in the occupied space. Examples of productivity measures include lost time or lost productive concentration periods of employees in office environments. Additionally, Pelletier (1984) points out that it is in the interests of employers to keep their workers healthy in order to keep health care costs down. Thus, improved productivity together with lower health care costs may provide incentives for employers to provide environments that promote comfort and well being for their employees.

3. **Effects of new technology** New technology for building construction has improved the degree of control of indoor environments. Thus, it has become possible to maintain standards of comfort in buildings without considering external influences (Cooper, 1982a). Methods for monitoring contaminants in indoor environments have also improved.

A redefinition of goals

The preceding discussion illustrates the development of the goals of indoor environmental control that form the basis for codes and standards related to different aspects of the indoor environment. Health has been redefined to deal holistically with physical, social and mental well being. Additionally, comfort and well being are the current goals of indoor environmental control. Section 2.3 discusses five standards and examines the potential efficacy of the standards in meeting these goals.

2.3 DO EXISTING EXPOSURE CRITERIA MEET THE STATED GOALS OF THERMAL AND AIR QUALITY STANDARDS?

Each of the standards examined herein is assessed in terms of: (1) the stated goals of the standard in terms of human response, (2) the exposure criteria that are specified, and (3) the rationale for the adoption of the specified values, wherever possible.

Ventilation for Acceptable Indoor Air Quality (ASHRAE standard 62-1989)

The stated purpose of the standard (ASHRAE, 1989) is "To specify minimum ventilation rates and indoor air quality that will be acceptable to human occupants and are intended to avoid adverse health effects (p. 3)." Human response criteria are specified in terms of 'acceptability' as well as 'adverse health impacts'. Further, acceptable indoor air quality is defined as "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction (p.3)."

Criteria to achieve acceptable indoor air quality are defined in two ways: (1) the Ventilation Rate Procedure which specifies the quality and quantity of air to be supplied to a space, and (2) the Indoor Air Quality Procedure which specifies the limits of selected contaminants that are expected to result in acceptable air quality. The Ventilation Rate Procedure prescribes the outdoor air quality acceptable for ventilation, outdoor air treatment where needed, and ventilation requirements. The levels of outdoor air contaminants that are considered to be acceptable are adopted from the EPA's standards for ambient air quality, as well as on one-tenth the Threshold Limit values specified by the American Conference of Governmental Industrial Hygienists (ACGIH) for contaminants not included in the ambient air quality standards. The recommended values are based on the avoidance of health impacts, usually determined through toxicological studies using animals or epidemiological studies (McFadden, 1978). If the recommended contaminant limits are exceeded, outdoor air treatments are recommended to assure that the offending contaminants are controlled.

Finally, ventilation rates are specified in terms of volume of outdoor air per person or space for several types of indoor spaces (ASHRAE, 1989). These rates are predicated on control of carbon dioxide (CO_2), particulates, odors, and contaminants expected in the space. CO_2 level is a primary criterion for the control of odors, based on physiological requirements for respiration air (ASHRAE, 1989, Appendix D). This level is derived primarily on the basis of a CO_2 generation rate by human occupants and may not take account of odors that can be attributed to other sources in the indoor environment. It is not yet determined whether the criteria specified in the ventilation rate procedure are adequate for assuring 'acceptable' air quality, as specified in the standard.

The Indoor Air Quality Procedure addresses the 'subjective' criterion for air quality, i.e., acceptability judgments by the occupants. This procedure specifies levels of contaminants that are deemed to be acceptable. As in the Ventilation Rate Procedure, these are adopted from several sources including EPA's standards for ambient air quality, The U.S. National Academy of Sciences Committee on Toxicology, The Food and Drug Administration and the National Council on Radiation protection and Measurement.

Additionally, guidelines are provided in terms of standards developed in Canada and the World Health Organization. These exposure levels can be considered to be based on the avoidance of health impacts, and may, consequently not address 'acceptability'. As specified in the Indoor Air Quality Procedure, however, the subjective criterion must also be met; i.e., impartial observers must judge the air to be acceptable. The procedure, does not, however, specify a course of action in the case where exposure criteria are met, but subjective criteria are not. Additionally, there is no standardized procedure for subjective evaluation. One suggested method recommends that acceptability judgements should be made by at least 20 untrained observers within 15 seconds after they enter the space. The method does not specify the composition of the panel of 20 observers, or the question that should be asked of these observers.

Woods et al. (1986) compared the two procedures, I.e., the Indoor Air Quality Procedure and the Ventilation Rate Procedure, incorporated in the standard. They report that equivalency exists between the two procedures for seven of the nine contaminants that they investigated. Equivalency was not found, however, for particulates and butyric acid. The former may be attributed to non-uniform mixing that could not be accounted for in the steady state model that was used. The authors attributed the latter finding to the value that was selected as an 'acceptable' concentration for this contaminant. It can be concluded, from the examination of this standard, that: (a) human response criteria need to be specified in operational terms to enable their assessment, and (b) links between human responses and exposures need to be identified, to enable exposure and system performance and prescriptive criteria to meet the specified human response criteria.

Ventilation for Buildings: Design Criteria for the Indoor Environment (CEN/TC156/WG6. 1992)

The European Committee for Standardization (CEN, 1992) develops standards that must be used in all European countries, substituting national standards. The approach of the CEN is to use existing ISO (International Organization of Standardization) standards as CEN standards, and to develop new standards only where ISO standards are not available (Olesen, 1992a). Compliance with ISO standards is currently voluntary. A draft of standard CEN/T156/WG6 (1992) examined herein, incorporates thermal, air quality and acoustic criteria. The draft did not include the section on air quality criteria; therefore only thermal criteria will be discussed here. The stated purpose of the standard is "..to provide a comfortable indoor environment with a low health risk for the occupants (p.1)." However, this goal is operationalized in terms of "..the percentage of persons who find an environmental parameter unacceptable (percent dissatisfied) (p.1)". The 'percent dissatisfied' criterion forms the basis for three levels of indoor spaces, namely, categories A, B, and C.

The standard is based on data that relate the percent dissatisfied to physical exposure criteria. For the response of the body as a whole to the overall thermal environment, a seven point thermal sensation scale is linked to the 'percent dissatisfied'. For local thermal discomfort, 'percent dissatisfied' is linked to exposure parameters, e.g., for vertical temperature difference, 'percent dissatisfied' is linked to the air temperature difference between head and feet. Thus, links between human responses and exposure parameters have been identified for 'dissatisfaction'. However, it is not clear if an absence of discomfort necessarily leads to 'comfort', which is the stated goal of the standard.

Indoor Climate - Air Quality (NKB Publication No 61E. 1991)

This document (NKB, 1991) is intended to serve as a basis for regulations by different regulatory authorities concerned with indoor climate for the five Nordic countries: Denmark, Finland, Iceland, Norway, and Sweden. It defines satisfactory quality of air as follows: "The quality of air is considered satisfactory if the great majority of visitors, on entry into the room, perceive the air as acceptable (do not express displeasure), if the air does not cause irritation to skin, mucous membranes or airways, not even in persons who are somewhat more sensitive than normal, if there is no risk of sensitization and if the risk of health effects after long term exposure is negligible. Nor must the quality of air give rise to disease (p. 9)." The definition can be described as comprehensive, dealing with the avoidance of discomfort and symptoms, as well as adverse health effects after long term exposures. This document does not, however, make direct links between these human response criteria and exposure or system criteria that can be used by designers to achieve the required human response.

Classified Indoor Climate Systems: Guidelines and Specifications (SCANVAC. 1992)

The guidelines for indoor climates recommended in this document (SCANVAC, 1992) are intended for voluntary application in Scandinavia. The primary human response criterion specified herein is 'the percentage of dissatisfied' for the thermal environment, and 'frequency of a large group of persons affected by the factor under consideration' for air quality (p.13). Four categories of thermal environments are specified, and three categories of environments are specified for air quality. Interrelationships between the specified human response criteria and exposure values are derived by results obtained using a large group of persons. For the thermal environment, exposure values are available for operative temperature, air velocity, vertical temperature difference, radiant temperature asymmetry, rate of change of temperature, air humidity, floor temperature, and temperature variation amplitude. For air quality, exposure values are available for carbon monoxide, carbon dioxide, ozone, nitrogen dioxides, volatile organic compounds (VOCs), particles from tobacco smoke, dust, mildew and bacteria.

This standard states explicitly the human response criteria for different quality environments. It does not, however, provide guidance on how the human response criteria can be evaluated; i.e., it is assumed that if the specified exposure criteria are met, then the human response criteria are also satisfied. The interrelationships between human responses and exposures are derived from several sources, including field and laboratory studies. As discussed later, differences may be expected in the results obtained from these two types of studies. Additionally, it is not clear whether the avoidance of discomfort necessarily results in 'comfort' or 'well being' which is the intended goal of indoor environmental control.

Thermal Environmental Conditions for Human Occupancy (ASHRAE, 1991).

This standard uses an 'acceptability' criterion for human response. The stated purpose of the standard is "To specify the combinations of indoor space environment and personal factors that will produce thermal environmental conditions acceptable to 80% or more of the occupants within the space (p.1)." However, acceptability is operationalized in terms of 'percent dissatisfied'. Thus, the recommended limit for general thermal discomfort criterion is 10%, while the recommended limits for local thermal discomfort are 5%, 10% and 15% for radiant temperature symmetry, floor temperature, and draft respectively. The use of the 'percent dissatisfied' criterion may be attributed to the availability of data that links exposure values to this human response criterion. The different levels of dissatisfaction recommended seem to be based on expert judgments about the amount of control for each parameter that is possible in practice, as well as on the observation that it is impossible to specify a thermal environment that is satisfactory to all occupants (p. 6-7).

The exposure values that correspond to the specified human response criteria include: operative temperature, humidity, air speed, temperature cycling, temperature drifts or ramps, vertical air temperature difference, radiant temperature asymmetry, and floor temperature. Concentrations of humidity are specified on considerations of dry skin, eye irritation, respiratory health, microbial growth and other moisture related phenomena (p.15), i.e., on health criteria.

Conclusion: Do present standards adequately address the goals of indoor environmental control?

The review of five standards presently being used in the United States and Europe suggests that current knowledge on links between human responses and exposures have been identified for 'dissatisfaction' with different elements of thermal and air quality. It is not clear whether a lack of dissatisfaction implies 'satisfaction with' or 'acceptability of' the indoor environment. There is, consequently, a need to adequately define the human response criteria upon which exposure criteria must be predicated. Then, exposure parameters must be identified that can be linked to the selected human response criteria.

A rational approach can be used to translate human response criteria into exposure criteria which can then be translated into system performance and prescriptive criteria. A conceptual model defines relationships between human responses, exposures, systems, sources and economics (Woods et al., 1993). As shown in Figure 2.1, Human responses to indoor environments result from exposures of the primary physiological receptors that sense environmental conditions to four primary stressors: thermal, air quality, lighting and acoustic. The role of building systems is to provide acceptable exposures by responding to loads (e.g., contaminant, thermal, illumination, and acoustic) that accrue from outdoor and indoor sources. These can be characterized in terms of thermal, contaminant, illumination and acoustic loads. Economic implications of these interactions are critical to the acceptable design and operation of building systems.

Based on this conceptual model, a four step process can be used to develop performance and prescriptive criteria that can be used in building design and construction. (Woods et al., 1993) First, human response criteria are determined. Second exposure criteria that can be linked to human response criteria are derived. Third, system performance and prescriptive criteria are developed based on rational transformations of exposure criteria. Finally, these criteria can be assessed with respect to economic and energy criteria.

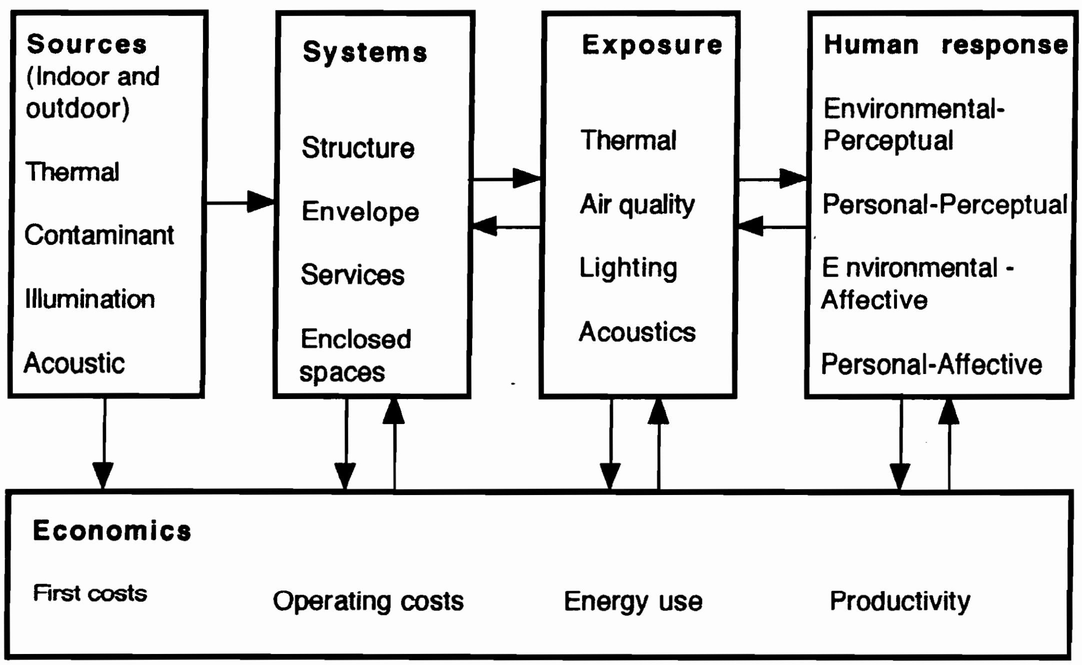


Figure 2.1 Conceptual model relating human response to indoor environmental factors

(Source: Woods et al., 1993, p.472)

2.4 HUMAN RESPONSE AND EXPOSURE CRITERIA USED IN BUILDING DIAGNOSTICS AND ENVIRONMENTAL DESIGN EVALUATIONS

Post Occupancy Evaluations (POEs), and environmental design evaluations may be defined as "An appraisal of the degree to which a designed setting satisfies and supports explicit and implicit human needs and values (Friedman et al., 1978, p.2)". A major objective of such evaluations is to provide information that can improve the practice of design (Friedman et al., 1978). Post occupancy evaluations may be conducted: (1) to provide a client immediately useful information, or (2) to enhance basic understanding about how people relate to the designed environment (Zimring et al., 1985). These authors assess the practice of setting goals for POEs. They contend that the purpose of the evaluation, whether applied or basic, requires a different approach to the setting of goals; i.e., it is adequate for a 'finetuning' study to identify problem areas, but evaluations conducted for the purpose of basic knowledge must suggest 'evidence of cause'.

It is not clear, however, whether the findings of an evaluation provide guidance to designers on how identified existing or potential problems may be rectified. Friedman et al. (1978) comment on the need to link data that addresses user's values, perceptions and behaviors to the physical environment to which they relate. Marans et al. (1982) comment on the usefulness of evaluations of office environments: "A major shortcoming (of past evaluations) for example, has been their failure to specify the criteria to be used in determining the degree to which an environment is successful......Another failing has been the lack of a carefully constructed conceptual link between physical environmental attributes and various levels of worker responses to those attributes (p.335)." It appears, therefore, that there is a need, within the field of POE and environmental design evaluation to define human response criteria and link them to physical environmental parameters that can be used in the *design and construction* of built environments.

Building diagnostics is another discipline that is concerned with the evaluation of building performance. It may be defined as " ...a process in which a skilled expert draws on available knowledge, techniques and instruments in order to predict a building' s likely performance over a period of time (BRB, 1985, p.1)." Building diagnostics may be used to investigate a building with suspected problems or to provide assurance that a building is healthy. Additionally, building diagnostics can be used to assess building performance at all stages of a building's lifecycle. The three overall goals in assessing building performance may be described as: suitability (i.e., the degree to which a building or building system or component meets user needs), reliability (i.e., probability that a building system or component will continue to perform as intended throughout its life), and flexibility (i.e., the building's ability to accommodate changing function and occupancies during its lifetime) (BRB, 1985). There is an emphasis in building diagnostics on translating these goals into "specific, quantitative, performance specifications that can serve as guides to designers, builders and building managers (BRB, 1985, p.9)." As discussed in section 2.3., however, standards typically used for the evaluation of a building's performance may not adequately address the human response criteria upon which they are predicated.

To conclude, human response criteria are the predominant criteria used in environmental design evaluations and POEs. Further, although diverse methods may be used for the evaluation, they are grounded in social science (Friedman et al., 1978). Links to physical exposure or system parameters are therefore lacking. In building diagnostics, human response, exposure and system criteria may all be used, as most building problems call for an interdisciplinary approach. As current knowledge about links between human response and exposures is still inadequate, however, there is a danger of false negative results in diagnostics procedures that emphasize exposure criteria.

2.5 CONCLUSIONS

The development of human response criteria has evolved over time to include considerations of comfort and well being along with the objectives of health and safety. Improved building design and construction technology as well as the widespread awareness of the productivity implications of improved environmental conditions have been instrumental in this evolution. Current standards have attempted to address these changing human response goals. However, there is considerable confounding with respect to the operationalization of these goals. Additionally, it is not clear if compliance with exposure and system performance or prescriptive criteria in these standards assures compliance with human response criteria. Based on a rational approach to the development of criteria for building design and construction, there is a need to better identify links between human responses and exposures. This dissertation therefore focuses first on the definition of human response criteria, and then the identification of links with exposure parameters for the development of exposure criteria. The review of literature related to environmental design evaluations, POEs, and building diagnostics reinforces the need for additional research to bridge gaps in current knowledge of the links between human responses and exposures.

CHAPTER 3

DEFINING HUMAN RESPONSE CRITERIA FOR ACTUAL AND VIRTUAL BUILDINGS

3.1 INTRODUCTION

Human response criteria are implicitly or explicitly used in the design and evaluation of buildings. As discussed in chapter 2, current exposure or system performance and prescriptive standards for thermal and air quality may be predicated on diverse human response criteria. Additionally, human response measures are often needed, in addition to physical exposure measures in building diagnostics, especially in investigations of suspected sick buildings. However, results of human response and exposure methodologies are often inconsistent (e.g., Nelson et al., 1991), leading to possible inaccuracies in the diagnosis of sick and healthy buildings. These inconsistencies may be attributed to one or more of the following: (a) inconsistent definitions of human response criteria or exposure criteria, (b) inadequate control of exogenous factors and methodological factors that may influence human response in addition to physical indoor environmental factors, and (c) inappropriate matching of human response measures and one or more exposure measures. The first step towards the development of human response and exposure criteria, therefore, is to develop a *unified* framework for the assessment of human response that can be used as the basis for the selection of human response criteria for the evaluation of building performance. For the purpose of this dissertation, existing exposure criteria are assumed to be valid and reliable. "Validity is a descriptive term, used of a measure, that accurately reflects the concept that it is intended to measure (Babbie, 1989, p.G8)." As relationships between some human sensory responses and exposure measures have been demonstrated, the latter may be said to have predictive validity. Reliability refers to the repeatability of data (Babbie, 1989). Exposure measures, taken by means of physical instruments may be judged to have high reliability.

Section 3.2 is the development of a characterization of human response that can be used as a framework for investigating links between human responses and exposures as well as for identifying exogenous factors that may have an impact on human responses to physical environmental factors. The most commonly used human response criteria are identified from: (a) questionnaires used in the evaluation of buildings, and (b) stated goals and human response criteria upon which the standards reviewed in chapter 2 are predicated. The criteria thus identified, are redefined, based on an understanding of the physiological basis of human response. The rationale for such a characterization comes from: (a) the need to integrate and interpret the diverse findings of several field studies in an effort to identify appropriate human response criteria that will permit more explicit fault detection in building diagnostics, and (b) the need to develop standardized human response criteria and procedures for assessing them. Section 3.2 also identifies measures of human response that are included in each human response domain.

Section 3.3 uses the characterization of human response, in prescribing criteria for the investigation of buildings, both actual and virtual. It is proposed in this section, that different sets of criteria may be required to permit explicit fault detection in the investigation of actual and virtual buildings.

3.2 CHARACTERIZATION OF HUMAN RESPONSE

Section 3.2.1 identifies several human response measures that have been used in building evaluations, as well as human response criteria that form the bases of exposure and system performance criteria specified in current standards. Section 3.2.2 presents a characterization of human response that provides a framework for redefining these diverse human response measures to enable a systematic investigation of the determinants of these responses. It is expected that the proposed characterization will enable the identification of sets of exposure parameters that can be linked to specific human response measures.

3.2.1 Human response measures for the evaluation of building performance

Several human response measures have been used to evaluate indoor environments. From a review of thirteen questionnaires used in building evaluation studies or investigations, the most frequently used measures of human response related to thermal and air quality in indoor environments have been identified. In ten of these questionnaires, attributes of environmental parameters such as intensity of temperatures are described in negative terms, e.g., "temperature *too* warm (Hedge et al., 1991)." Respondents are asked to report on the frequency that these conditions occur, whether these conditions were present at the time that the questionnaire was answered, or on the disruption of work caused by the listed environmental conditions. Several of these human response measures include: (a) a sensation component; i.e., they are dependent upon a response in a receptor caused by a stimulus (ASTM, 1968), and (b) an evaluative component; i.e., they require respondents to make a *judgement* about sensations. An example of such confounding of human response measures is a rating scale for thermal conditions that includes categories ranging from 'too cold' to 'comfortable' (Vischer, 1989).

Two of the questionnaires reviewed (Wallace et al., 1991; Nelson et al., 1991) ask respondents to identify the odors that they perceive; i.e., to identify the character of the odor (e.g., body odor, tobacco smoke, and odors from new carpets). Eight of the questionnaires include questions about symptoms recognized as being related mainly to SBS. The nature of these questions varies, however, and more than one of the following types of questions may be asked in a single questionnaire item. For example, respondents may be asked to: (1) identify the frequency of occurrence of symptoms over the specified period of time, (2) report if symptoms improve or worsen away from work, and (3) assess how these symptoms affect their work. Some human response measures are clearly evaluative in nature. These include questions about the 'acceptability' of specified environmental parameters, 'comfort', or 'satisfaction' with the indoor environment.

All the five standards reviewed in chapter 2 specify human response goals in evaluative terms, but confounding may occur when these goals are operationalized. ASHRAE standard 62-1989 defines human response criteria for air quality in terms of 'acceptability'. However, the criterion is operationalized in terms of the percent of people exposed who 'do not express dissatisfaction'. ASHRAE standard 55 (1981R) also uses an acceptability criterion for thermal conditions. Standards developed in Europe (CEN, 1992; NKB, publication 1991; and SCANVAC, 1992) are based on a 'percent dissatisfied' criterion. It is important to note, however, that in addition to these evaluative criteria, the criterion of 'no adverse health effects' is implicit in each of these standards. In keeping with the goals of indoor environmental control, it is necessary to identify the determinants of evaluative responses, and to examine relationships between responses that can be described as 'perceptions' and those that can be described as 'judgements'. This relationship is important to establish, as most early research that was used as the basis of these standards focused primarily on the relationships between thermal sensation and thermal exposure parameters such as temperature and humidity. Yaglou et al. (1936), in their studies on ventilation and comfort use both types of responses, i.e., odor intensity (perceptual), and quality of the air (judgmental).

To conclude, measures frequently used in building evaluations and standards may be described as perceptions, evaluations, or a combination of the two. Additionally, the goals expressed in standards may differ from the operational definitions used to assess building performance. Section 3.2.2 integrates these diverse definitions of human response criteria to develop a characterization of human response.

3.2.2 A characterization of human response

To identify links between human response and exposure measures, it is useful to synthesize information from diverse building evaluations and standards. The first step towards such a synthesis is to resolve inconsistencies in the use of human response measures. Section 3.2.1 has demonstrated that there may be confounding with respect to the perceptual and evaluative aspects of human response measures used in the evaluation of building performance. Additionally, it has been suggested that evaluative criteria such as 'acceptability' and 'lack of discomfort' may not yield the same results. Similarly, the measures 'comfort' and 'acceptability' include a wide range of meanings and are also sometimes used interchangeably. The human response measures and criteria identified in section 3.2.1 are redefined and classified here into four domains. Existing terms and definitions are used as far as possible in developing this characterization of human response.

Figure 3.1 illustrates the four domains of human response resulting from a scheme of classification based on: (a) two aspects of response, namely, perceptual and affective, and (b) two objects of response, namely, the personal state and the environment. The International Organization for Standardization (ISO,1992.) in its recommendations for subjective evaluations of thermal environments, introduces the four terms used in this typology. For the purpose of the characterization illustrated in Figure 3.1, ***perceptual responses*** are defined in this dissertation as those in which respondents are used as *sensing* devices, and ***affective responses*** are those in which respondents are used as *judging* devices. Klemmer (ASTM, 1968) made the distinction between 'sensing' and 'judging' in his definition of the term 'subjective response'.

Perceptual responses can be expected to precede affective responses, since it is necessary to perceive a stimulus in order to be able to evaluate it (Morressi et al., 1975). It is important to note, however, that perceptual responses themselves imply some amount of subjective 'judgement'. This may be best illustrated in terms of the distinction made between 'sensation' and 'perception'. Coren et al. (1979) explain that although the distinction between sensation and perception is not always clear, "The study of sensation, or sensory processes, is concerned with the first contact between the organism and the environment (p. 8)." Perception, on the other hand, is concerned with the conscious experience of objects and relationships between objects. The category of perceptual responses, in the characterization described above, may include both sensory (e.g., How warm is the room), and perceptual responses (e.g., Do you recognize that odor?), and the terms may also be used interchangeably.

Aspect of response / Object of response	PERCEPTUAL	AFFECTIVE
ENVIRONMENT	External Sensory Response	Acceptability Preference
PERSONAL STATE	Internal Sensory Response General Physiological Symptoms	Comfort Wellbeing

Figure 3.1 Characterization of human response (ref. Sensharma et al. 1993a)

Perceptual responses are not, however, conscious judgements of the personal state or environment. The latter are defined in this characterization as affective responses. This is in keeping with the distinction made by St. Thomas Aquinas who divided the study of behavior into two parts, namely, 'cognition', referring to how we know the world, and 'affect' that includes emotion and feelings (Coren et al., 1979).

Human responses, designated as ***environmental-perceptual*** in the characterization are external sensory responses; i.e., responses that can be directly linked to a sensory receptor and that refer to responses made about the environment (e.g., the room is hot). Baird et al. (1975) refer to two types of perceptions, namely, external perceptions that can be attributed to the environment (e.g., draft, temperature, and fresh air), and internal perceptions that can be attributed to the human body (e.g., irritation, itchy skin) or the personal state. Adapting these terms for the proposed characterization, two types of ***personal-perceptual responses*** are defined: (a) internal sensory responses; responses that can be directly linked to a sensory receptor and refer to the personal state of the respondent (e.g., I am hot), and (b) general physiological symptoms; responses related to the personal state of the respondent and that are likely to be linked to a combination of sensory receptors (e.g., I have a headache).

Environmental-affective *responses* such as acceptability and preference are predicated on an evaluation of the environment (e.g., the thermal environment of the room is not acceptable). ***Personal-affective responses*** such as comfort are associated with an individual's personal state (e.g., I am thermally uncomfortable). The importance of the distinction between perceptual and affective responses is demonstrated in chapter 4.0, in which the factors influencing these two categories of responses are identified through an evaluation synthesis of several field studies. Respondents "construct their own definitions of what comfort means to them, and (who), in so doing, create their own criteria by which to evaluate the acceptability of interior environments (Cooper, 1982b)." Thus, in addition to acceptable perceptual responses, criteria for comfort also include other psychological or attitudinal criteria.

3.2.3 Human response measures within the four domains

Measures related to the two stressors, thermal and air quality, which are the focus of this dissertation are defined and discussed in this section.

Perceptual responses:

The categories of internal and external sensory responses and general physiological symptoms include several measures. This section provides operational definitions for some of the human response measures within each of these categories that relate to thermal and air quality parameters in the indoor environment. The specific senses that relate to these two parameters are: (a) the cutaneous senses (mainly thermal) and, (b) the chemical senses (mainly odor). There are, however, interrelationships between sensory responses (ASTM,1968). Responses for each of the two parameters are identified in terms of the four basic problems of psychophysics, namely, detection, recognition, discrimination, and scaling (Coren et al., 1979). Existing methods for the evaluation of these measures usually pertain to laboratory settings. As the evaluation of building performance must often be conducted in the field, questions used in self-administered questionnaires are included for each of the four types of measures. Although pain is recognized as including both a perceptual and affective component, the characterization of human response proposed in this dissertation operationalizes it as a perceptual response, i.e., it is expressed in terms of detection thresholds, intensity, etc., as in the case of other sensations.

In general, perceptual response measures include detection, recognition, and intensity. The problem of *detection* refers to the problem of how much of a stimulus relative to zero energy level is necessary for an individual to say that the stimulus is heard, tasted, smelled or felt (Coren, 1979, p.13). *Recognition* of the occurrence of one of a number of possible alternative stimuli (Coren, 1979, p.24) is the other measure used.

External sensory responses (environmental-perceptual) include the following:
Odor detection: Odor detection (or awareness of odor) is measured in terms of odor thresholds. An odor detection threshold may be defined as "The lowest concentration of a substance in a medium relating to the lowest physical intensity at which a stimulus is detected as determined by a maximum likelihood criterion (ASTM, 1979,p.36)." Conventionally, the Best Estimate Threshold (BET) for an individual observer is the concentration that he or she can detect 50% of the time (Meilgaard, 1991). The BET for a group is the geometric mean of the individual BETs (Meilgaard, 1991). Odor detection thresholds can be assessed using a variety of methods involving the presentation of stimuli, e.g., ascending and descending dilution series, randomized dilution series, multiple sample and forced choice methods. These methods are mostly confined to laboratory settings. In field settings, the question of the type "Do you perceive an odor?" may be described as an odor detection measure.

Odor recognition: The odor recognition threshold may be defined as "The lowest concentration of a substance in a medium relating to the lowest physical intensity at which a stimulus is recognized as determined by the maximum likelihood criterion (ASTM, 1979,p.36)." This can also be assessed using several methods in laboratory settings. In field settings, questionnaires have included items that require respondents to identify the odors they perceive, e.g., environmental tobacco smoke (ETS) (e.g., Wallace et al., 1991).

Odor intensity: Odor intensity is the strength of the perceived odor sensation (NAS, 1979). This may be measured using category scaling, magnitude estimation and reference sample scales. Odor intensity questions have been used in questionnaires in terms of rating scales ranging from 'no odor' to 'overpowering odor' (e.g., Fanger et al., 1988a,1988b). This has been linked with acceptability measures that attempt to link the intensity of odor that is likely to lead to dissatisfaction (Fanger. 1988a,1988b).

Odor difference: The odor difference threshold is a measure of discrimination (Coren et al., 1979) and may be defined as the minimum concentration change needed to produce a just-noticeable-difference (JND) in the perceive stimulus. This measure has not been widely used in field studies, probably because the primary concern is the identification of odor intensity that is likely to lead to unacceptable indoor conditions.

Odor character: "The character of odor refers to the array of odor notes of the odor sensation that permit one to distinguish odors of different substances on the basis of experience (NAS, 1979, p.119)." Thus, odors are different if they differ in character notes. There have been several efforts to develop a system to identify 'primary odors' or those which cannot be broken down any further (Morressi et al., 1975). Human subjects can be measured by direct comparison profiling or by comparison with descriptor words. In building evaluations, the character of the air rather than odor character is investigated. The former, may include the latter, but may also be dependent on other characteristics of the air such as stuffiness. Thus, questionnaire items include descriptor words such as 'musty'. 'dusty', etc. To describe the indoor air.

Intensity of thermal attributes (e.g., cold or warmth, air movement, and moisture): The measure 'intensity of warmth or cold' has been extensively used in developing criteria for thermal comfort both in laboratory and field settings. The 7-point ASHRAE scale is a rating scale (+3 = very hot to -3 = very cold) that is used to assess the thermal condition of the environment. There is some debate about whether this measure represents an evaluation of the thermal intensity of the environment or that of the individual person. However, if a period of adaptation is allowed, the two measures are likely to be similar (Fanger, 1972). Scales comparable to those related to temperature can be developed for air movement and moisture.

Internal sensory responses (personal-perceptual) include the following measures:
Thermal intensity of the personal state: Fanger's approach to the measurement of thermal comfort was based on the assumption that a person senses his or her own temperature, not that of the environment. No studies could be identified that compare two types of responses, namely, environmental-perceptual responses (e.g., this room is hot) and personal-perceptual responses (e.g., I am hot) with exposure measures such as dry bulb temperatures. Price et al. (1975) found that subjects, when asked to estimate how hot their environment is (i.e., environmental-perceptual response) gave responses that were closer to dry bulb temperature than to two other heat indices. They also found that their perceptions of their performance did not affect their estimates of dry bulb temperature.

However, that study did not assess subjects' estimation of the thermal intensity of the personal state (personal-perceptual response). This measure could be assessed in the same way as thermal intensity of the environment, i.e, in terms of rating scales.

Detection and intensity of responses to irritation: Irritation can be defined as a 'local action on the skin or mucosal tissue" (ASTM,1968, p.81). Irritation causes an increase in circulation of the irritated area, leading to perceptions that are described by respondents especially in sick buildings as irritation of the skin, pain, reddening, smarting, itching sensations, dry skin, scaling or itching of scalp or ears and dry hands. These may vary with the part of the body that is irritated. For example, pain is the main sensation resulting from eye irritation; sneezing and coughing are caused by irritation in and beyond the nose respectively, and intense irritation of the gastro-intestinal tract produces vomiting, purging, abdominal pain and shock.

General physiological symptoms (personal-perceptual responses) are usually linked to several receptors and can be broadly classified in terms of (a) Neurological / general health symptoms, and (b) Hypersensitivity reactions. These categories are identified from symptoms commonly related to the Sick Building Syndrome (Molhave, 1990). The former includes headache, sluggishness, mental fatigue, reduced memory, reduced capacity to concentrate, dizziness, intoxication, nausea and vomiting, tiredness, feeling heavy-headed, chills or fever, toothache, pain or numbness in the shoulder or neck, upper or lower back and arms and wrists, diarrhea, nosebleeds, puffiness of eyes, blurred vision, digestive or menstrual problems. The latter includes runny nose and eyes, asthma-like symptoms among non-asthmatics, sounds from respiratory system, chest tightness and difficulty breathing. Although these responses, may not, strictly be described as 'perceptions', i.e., they may include an affective component, they are not 'judgements' about the environment or personal state, i.e, they are reports about the state of the body.

Affective responses

The human response measures related to the environment may include 'acceptability'. 'Dissatisfaction' and 'preference'. The only measure that has been identified from the literature that relates to the personal state is 'comfort' and 'discomfort'. It is important to note that comfort may not be a dichotomous variable, i.e, a lack of comfort may not imply discomfort. Additionally, comfort has also been used in the literature as an environmental-affective response (e.g., comfortable thermal environment).

Personal-affective responses Comfort may be defined as "a state of ease and content (Ehrlich et al., 1980)". Thermal comfort is defined as "...that condition of mind in which satisfaction is expressed with the thermal environment (ASHRAE, 1989, p.8.16)." Although comfort requirements may vary over time and from individual to individual, there exists for each individual, an "..ambient temperature interval, a comfort zone inside which he feels reasonably comfortable (Fanger et al., 1975, p.140)." Within this zone, there exists a narrow interval within which the individual does not know whether he would prefer a warmer or cooler environment. Comfort with respect to the quality of air, however, may be defined only in terms of 'transparency' (Woods. 1992), i.e., the person does not notice the quality of the air. In negative terms, the personal-affective response for air quality may be defined in terms of the ill-effects of the indoor air.

Environmental-affective responses: Acceptability is the response that is most commonly used in standards related to thermal and air quality for practical application in building design and maintenance. The common definition of 'acceptable' in the case of environments could be stated as a 'tolerable' (Ehrlich et al., 1980, p.6) environment or one that is fairly good or pleasant and / or one that can be endured (Houghton Mifflin Co., 1985). For thermal environments, acceptability is defined in ASHRAE standard 55 (1981R) as "An environment which at least 80 percent of the occupants would find thermally acceptable (p. 2)." The acceptability of air quality is defined as "..air in which there are no know contaminants at harmful concentrations and with which a substantial majority (usually 80%) of the people exposed do not express dissatisfaction (p. 3)." Acceptability is influenced by odor intensity, hedonic value and the context (NAS, 1979). Thus, an odor that may be rated as 'pleasant' on the hedonic scale may be unacceptable because it is not expected in a particular environment.

As stated earlier, 'comfort' has often been used in the literature as an environmental-affective response. Sakurai distinguishes between comfort and acceptability as follows: "An acceptable environmental condition is not restricted to the comfortable range and probably includes a slightly uncomfortable range in our daily life (Sakurai et al., 1990, p.170)". Thus, it may be concluded that even when comfort is used in terms of the environment, it may not be analogous to acceptability in the minds of respondents.

3.3 HUMAN RESPONSE CRITERIA FOR ACTUAL AND VIRTUAL BUILDINGS

Building diagnostics has been defined as "...a process in which a skilled expert draws on available knowledge, techniques and instruments in order to predict a building's likely performance over a period of time (BRB, 1985, p.1)." The diagnostics process is not limited to existing buildings, but may also be used during the planning or design phases of virtual buildings. Development of criteria for evaluating building performance are an important part of the diagnostics process. This dissertation proposes that different criteria may be needed for the evaluation of virtual and actual buildings. Virtual buildings are always designed to be healthy, and therefore, the criteria by which these buildings must be judged should be those that characterize healthy buildings. Conversely, existing buildings may exist at different levels of performance. If the objective of a diagnostics effort is failure detection, as in the case of suspected problem buildings, the application of healthy building criteria may indicate that the building is not healthy. However, it may not indicate whether the building is a problematic one or if it falls within the marginal category (definitions for these three categories of buildings are provided in the following paragraphs).

The development of human response criteria for actual buildings is based on a concept of continuous building degradation (Woods, 1991). This classification includes four building performance categories, namely, healthy buildings, undetected problem buildings, sick buildings, and buildings manifesting Building-Related Illness (BRI) (see figure 3.2). If the latter two categories of buildings are combined to form a 'problematic building category', the resulting three category format , including the categories of healthy, marginal and problematic buildings, permits the determination of diagnostic accuracy. Two types of errors can occur in diagnostics: false positive; i.e., detecting problems that do not exist, and false negative; i.e., failing to detect problems when they exist (Swets, 1988). Lane et al. (1989) recommend that building diagnostics performed for problem buildings should maximize true-positive outcomes and minimize false negative outcomes. Thus, some false positive outcomes are accepted. For healthy building evaluations, these authors

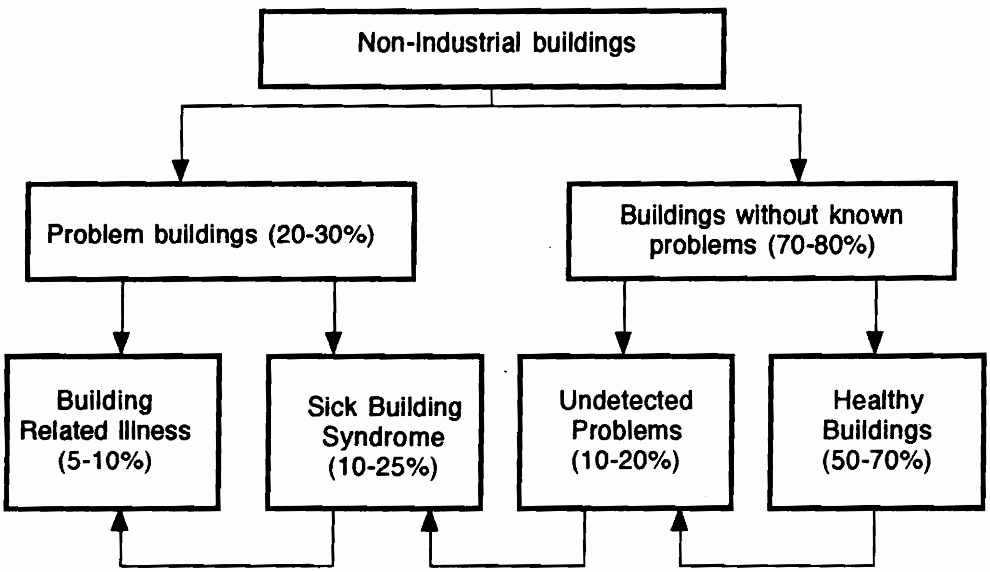


Figure 3.2 **Concept of continuous building degradation: Building performance categories** (ref. Woods, 1990)

recommend that true negative outcomes be maximized while minimizing false positive errors. Thus, some false negative errors are accepted. By adopting a three category format, both types of errors can be minimized. The definitions for these three types of building performance categories may be stated as follows (Woods et al., 1995):

> ***Healthy building:*** A building or area within it is considered healthy if no clinical signs of illness are detected and it complies with specified measurable parameters related to human response, exposures, system performance and economic performance.
>
> ***Marginal building:*** A building or area within it is considered marginal if no clinical signs of illness or excessive frequency of symptoms are detected, but non-compliance with other measurable parameters related to system and economic performance are detected.
>
> ***Problematic building:*** A building or area within it is considered problematic if clinical signs of illness or excessive frequency of symptoms is detected.

The three building categories defined above may be arranged in a hierarchy, each associated with appropriate human response domains for specifying evaluation criteria (see Figure 3.3, Sensharma et al., 1994). To characterize problem buildings, personal-perceptual responses that can be described as symptoms may be the most sensitive criteria. These may include both internal sensory responses (e.g., pain) as well as general physiological symptoms (e.g., headaches). Symptoms refer to phenomena experienced by an individual as a "departure from normal function, sensation or appearance, generally indicating disorder or disease (Houghton Mifflin Co., 1985, p.1232)". To characterize marginal buildings, some personal-perceptual responses

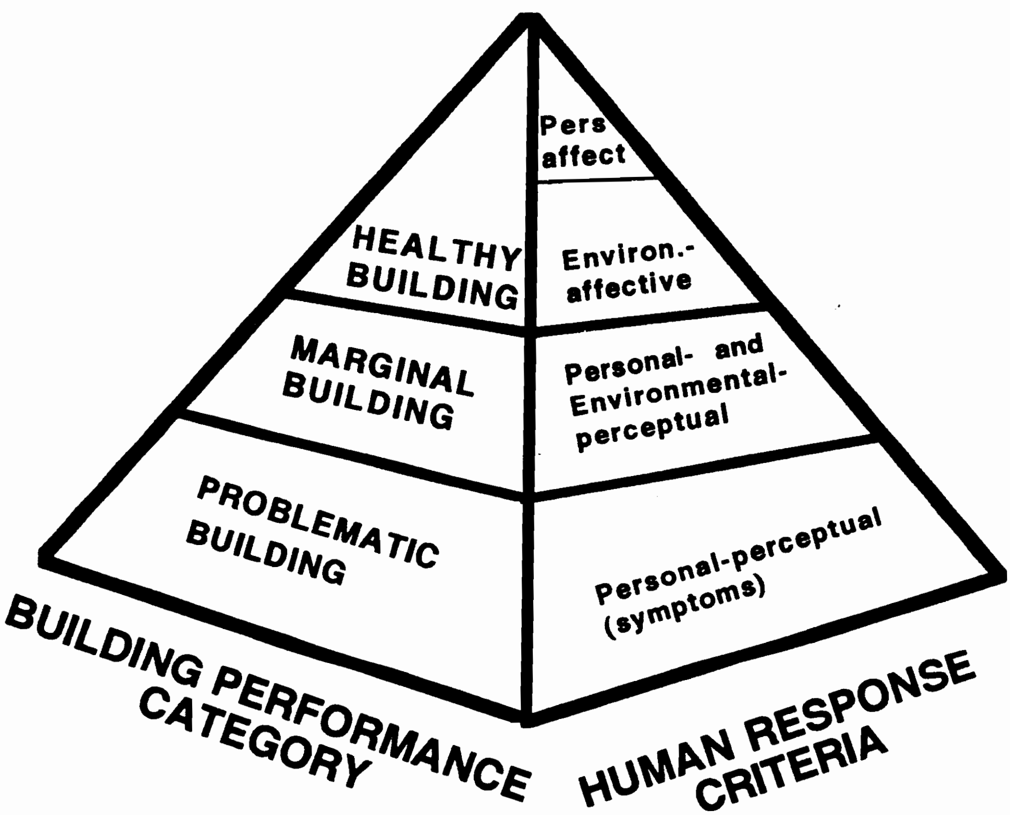


Figure 3.3 Hierarchy of building performance categories and human response criteria (Ref. Sensharma et al. 1994).

(e.g., thermal sensation) as well as some environmental-perceptual responses (e.g., thermal conditions in the space) are more useful to identify potential perceived stressors. These can be used to detect deviations in the optimal levels of environmental stressors. For instance, a thermal sensation response may detect deviations in temperature ranges that may not yet indicate unacceptable conditions or cause symptoms.

Environmental-affective responses may be most useful to determine design and evaluation criteria for healthy buildings. In addition, desirable objectives can be defined in terms of personal-affective responses to define increasing levels of wellness in buildings. This approach of setting criteria for healthy buildings is more likely to be able to reach the primary goal of indoor environmental control: occupant well being. It is important to note that this approach is different from the approach used in current standards formulated in Europe (e.g., CEN, 1992; SCANVAC, 1992), that specify three or more levels of building performance by increasing the required 'percent acceptability' criterion. Having established an approach for the definition of human response criteria, it is necessary to identify the determinants of human response criteria. Chapter 4 identifies exogenous factors and methodological effects and Chapter 5 identifies exposure parameters that together influence human responses.

CHAPTER 4

EXOGENOUS FACTORS AND METHODOLOGICAL EFFECTS INFLUENCING HUMAN RESPONSES

4.1 INTRODUCTION

One of the possible reasons for inconsistencies in the results of human response and exposure assessment in building diagnostics may be the inadequate control of exogenous factors and methodological effects. Human response criteria used to assess building performance reflect the consequences not only of physical environmental parameters, but also those of several exogenous factors and methodological effects. Exogenous factors explain in whole or part the observed human response (adapted from Rossi et al., 1989). Methodological effects result from the research process itself (Rossi et al., 1989), in this case, from the process of building evaluation.This chapter uses the characterization of human response presented earlier as a framework for the identification of exogenous factors and methodological effects for each human response domain.

Section 4.2 identifies exogenous factors that may impact human responses to indoor environments in addition to physical exposure parameters. Existing literature on the physiology of human response, as well as the findings of several field studies are used in developing a hierarchy of exogenous factors for each human response domain. Section 4.3 is a summary of an evaluation synthesis that assesses the usefulness of the typology of human response proposed earlier in identifying exogenous factors that can then be controlled to identify links between human responses and exposures. Finally, section 4.4 identifies three types of methodologies from a literature review, and characterizes them in terms of potential methodological effects.

4.2 EXOGENOUS FACTORS INFLUENCING HUMAN RESPONSES TO INDOOR ENVIRONMENTS

This section identifies exogenous factors from past studies and the literature related to the physiology of sensory and perceptual responses. It is hypothesized here, that each human response domain can be associated with a set of exogenous factors, and further, that these can be arranged in a hierarchy as shown in Figure 4.1. The specific measures of these exogenous factors may differ for different human response measures, but are defined here in terms of general categories.

Three factors directly influence environmental-perceptual responses. These have been adapted from Rohles (1971).

> ***Physical environmental factors*** include perceived physical environmental variables other than those being studied. For instance, if the evaluation is concerned with the influence of the mechanical system on thermal sensation, it is also necessary to consider the interaction of lighting factors on thermal response (Woods et al., 1987).
>
> ***Adaptive factors*** are those that influence the physiological characteristics of the response being assessed, and may differ for different responses. They include factors such as ingestion, clothing, length of exposure, time between exposures

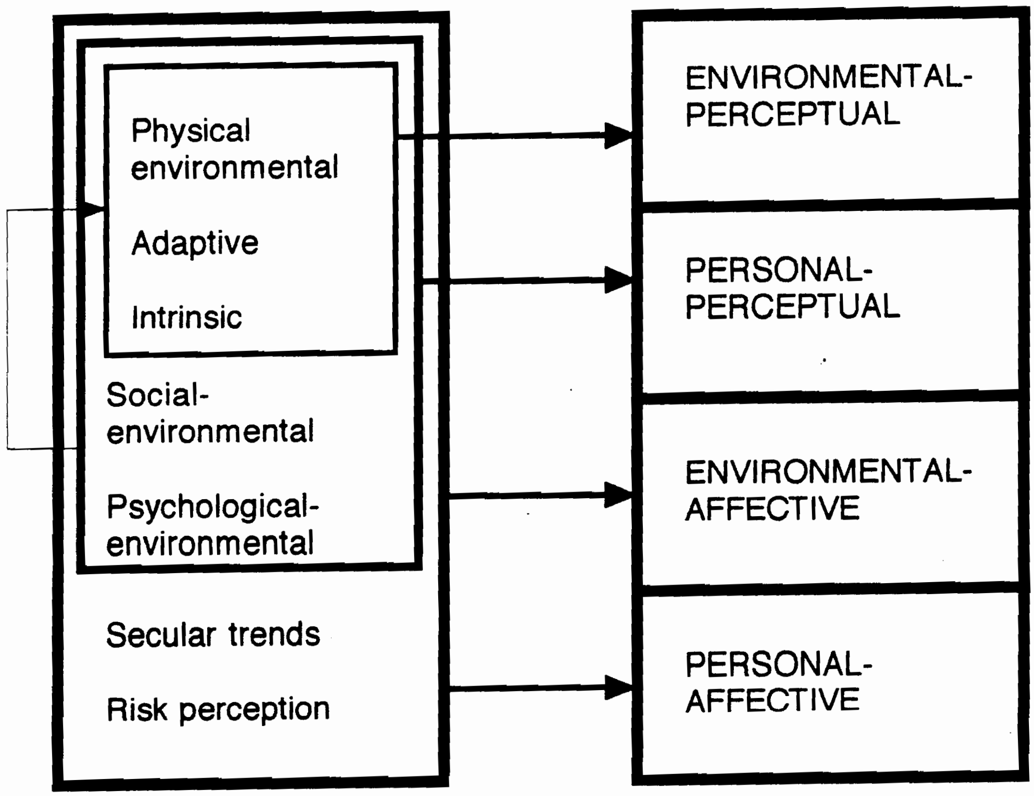


Figure 4.1 **Relationships between human response domains and exogenous factors** (Adapted from: Sensharma et al. 1993a)

and activity levels that increase or decrease the sensitivity of responses (Rohles, 1971; Meilgaard et al., 1991). For instance, in the case of odor responses, a short exposure time may be sufficient to cause adaptation to the odor. Social factors have been excluded from this category because they are hypothesized to only indirectly affect environmental-perceptual responses, as shown in Figure 4.1. As discussed later in this chapter, some personal-perceptual responses may be directly influenced by social factors (e.g., Zweers et al., 1992; Hodgson et al., 1992).

Intrinsic factors are individual characteristics that affect human response. They include factors such as age, gender, health status, lifestyle, predispositions, experience and sensitivity (Meilgaard et al., 1991.; Rohles. 1975).

Exogenous factors influencing personal-perceptual responses include the three listed above as well as two others found in the SBS literature (e.g., Cone et al., 1989). As indicated in Figure 4.1, these may also indirectly affect environmental-perceptual responses. For work environments, they include the following:

Social environmental factors such as job category, complaint handling by the management, control, choice and motivation may influence human response.

Psychological environmental factors refer to the respondent's perception of activities carried out in the space such as job difficulty and complexity.

Exogenous factors influencing environmental-affective and personal-affective response domains have not yet been adequately identified in indoor environmental literature. In addition to the factors that influence perceptual responses, two other categories of factors are proposed. These include the following:

Secular trends (this term has been adapted from Rossi et al., 1989) refers to variables such as public awareness of hazards and their impacts, visibility of specific issues, social norms, past environmental influences and other long or short term political influences. One of the primary factors that affects secular trends is changes in the message about risk as communicated by various means. Risk communication can occur through any private or public communication that informs individuals about the existence, nature, form, severity, or acceptability of risks (Plough et al., 1990).

Risk perception refers to the respondent's perception of the nature of hazards, in this case related to the indoor environment. Research related to risk perception shows that some determinants of perceived risk include voluntariness of risk, immediacy of effect, knowledge about risk (by experts and by people exposed to the hazard), control over risk, newness of risk, chronic or catastrophic potential, common dread, and severity of consequences (Slovic et al., 1980; Rowe, 1977). Brown (1987) contends that the perception of risk may be influenced by knowledge about the hazards under consideration as well as individual factors such as (a) denial of environmental risks due to feelings of helplessness to control hazards or the belief that management is in control, (b) acceptable levels of risk associated with the job as influenced by job satisfaction, quality of life and wage issues, (c) ideas of fairness, and (d) orientation to the future. It can be expected, therefore, that in judging the acceptability of indoor environments, people would consider the risk associated with the indoor environment.

4.3 EMPIRICAL EVIDENCE OF LINKS BETWEEN HUMAN RESPONSE DOMAINS AND EXOGENOUS FACTORS

The objective of this section is to assess the usefulness of the characterization of human response proposed earlier in identifying exogenous factors which can then be controlled to identify links between human responses and exposures. The evaluation synthesis method, which consists of combining and analyzing information from past evaluations and other literature (GAO, 1983) has been adapted to assess similarities and differences between the findings of several field studies with respect to correlations between human response domains and exogenous factors.

Sample selection

Eighteen published field studies were reviewed and ten were selected (identified in Figure 4.1) based on criteria listed below in order of priority (Sensharma et al., 1993b). The first three were required criteria, the others were desirable criteria. The sample of field studies included the following:

1. *Only those studies that used field methodologies.* This criterion is justified, as the findings of the study are intended to be applied to building diagnostic procedures for use in actual and virtual buildings. The choice of methodologies was therefore limited to occupant and / or panel methodologies (defined in section 4.4).
2. *Studies that investigated all or most domains of human response.* The unit of analysis is the human response domain. Therefore, studies covering a wide range of domains were required. However, only one of the studies reviewed included an

examination of personal-affective responses. Taken together with the first criterion, the range of methodologies in the selected sample was further reduced to include only occupant methodologies because only occupant methodologies can be currently used to assess personal-perceptual responses, which require the respondent to be exposed to the environment being investigated for a relatively long period of time. Part of one study uses panel responses as a follow-up investigation to an occupant study (Zweers et al., 1990b).

3. *Studies for which questionnaires were available or in which questions were reasonably identified from the written report.* This condition was essential because the classification of questions into human response domains is central to the analysis.

4. *Studies that had a sample size larger than two buildings.* A larger sample can be expected to reduce biases such as specific buildings or occupant characteristics. In the selected sample, however, this condition was compromised to include the only study (Woods et al., 1982) identified that included an assessment of personal-affective responses.

5. *Studies investigating a range of building conditions (e.g., buildings with and without known problems).* The proposed application of this study is in identifying appropriate human response domains and methodologies for use in diagnostic procedures. This criterion makes it possible to make inferences about the relationships between building condition and human response.

6. *Studies that investigated both exogenous factors and exposures along with human response.* This condition was not met in all cases. Three studies did not report exposures, and few studies reported more than a few exposure parameters.

Analysis procedure

Most of the selected studies did not report on the reliability and validity of the methodologies used. Most were cross sectional studies and did not address the influence of long-term trends on human response. Also, the instrumentation used to assess human response and exposures in the different studies varied. In spite of the limitations of the available data, use of the evaluation synthesis method was expected to give reasonably good information about the questions addressed in this paper because the selected studies met the primary criteria. However, because of the wide variations in data collection instruments and methods as well as data analysis, qualitative rather than quantitative comparisons of data were preferred. Each study was assessed in the following steps.

1. Identification of human response domains assessed. Questionnaires were reviewed and questions categorized according to the appropriate human response domain. It was difficult to distinguish between affective and perceptual responses in cases where multiple dimensions of human response were integrated into a single question.
2. Identification of the exogenous factors assessed. Categories of exogenous factors were identified from the questionnaires. Several exogenous factors probably include multiple dimensions, making classification problematic. However, these were matched as closely as possible with the interpretation provided by the authors of the different studies.
3. Identification of the exposures assessed. The exposures assessed in each study were identified from the study reports.
4. Examination of the reported correlations between human response domains and exogenous factors. Both expected and unexpected correlations were examined.

5. Examination of the reported correlations between human response domains and exposures. Both expected and unexpected correlations were examined.
6. An assessment of the similarities and differences in results across studies. Substantive and methodological factors were identified to explain divergent results.

Results and discussion

Each human response domain was examined for its relationship with categories of exogenous factors (Table 4.1). The results were compared with the proposed relationships between exogenous factors and human response domains proposed earlier (see Figure 4.1). The following is a summary and interpretation of the results:

Environmental-Perceptual responses

In most cases, environmental-perceptual responses were correlated with some intrinsic and adaptive factors as expected. However, in three studies, social and / or psychoenvironmental factors were also found to be correlated with this human response domain, although it was hypothesized that these only indirectly influence environmental-perceptual responses. Thus, job-type (classified here as a social factor) related to environmental-perceptual responses (Kleven et al., 1991) may be more appropriately classified as an intrinsic and / or adaptive factor (e.g., type of workplace, activity levels) characteristic of each job category. The results of our study suggest that the broad categories of exogenous factors need to be further broken down into their component dimensions to clarify the interrelationship between them. For instance, the presence of personal control over temperature, operable windows, job satisfaction and satisfaction

Table 4.1 Evaluation synthesis: Correlations between human response domains and exogenous factors

Study	Human response domains	Relationships between human response domains and exogenous factors					
		Intrinsic	Adaptive	Social	Psycho-env.	Secular trends	Risk Perception
Zweers et al., 1990a, 1992.	EP	x	x	x	x	na	na
	PP	x	x	x	x	na	na
	EA	0	0	0	0	na	na
Zweers et al., 1990b; Skov et al., 1987.	EP	x	0	0	0	na	na
	PP	x	x	x	0	na	na
	EA□	0	0	0	0	na	na
Hedge et al., 1991.	EP	0	0	0	0	na	na
	PP	x	0	0	0	na	na
	EA	0	0	0	0	na	na
Broder et al., 1990.	PP	x	x	x	na	na	na
	EA	0	0	0	na	na	na
Hawkins et al., 1991.	PP	x	x	x	x	na	na
	EA	0	0	0	0	na	na
Kleven et al., 1991.	EP /EA	x	0	x	0	na	na
	PP	x	0	x	0	na	na
Wallace et al., 1991.; Nelson et al., 1991.	EP	x	x	0	x	na	na
	PP	x	x	x	x	na	na
	EA	0	0	0	0	na	na
Hodgson et al., 1992.	EP	0	0	0	0	na	na
	PP	x	0	x	x	na	na
	EA	0	0	0	0	na	na
Burge et al., 1987, 1991.; Hedge et al., 1987.	EP	0	0	0	0	na	na
	PP	x	0	x	0	na	na
	EA	0	0	0	0	na	na
Woods et al. 1982	EP	0	0	na	na	na	na
	PP	0	0	na	na	na	na
	PA	0	0	na	na	na	na

Key: X indicates that significant correlations between the relevant domains of human response and categories of exogenous factors were found; 0 indicates that no significant correlations between human response domains and exogenous factors were found or were not assessed; na indicates that these factors were not assessed.

with complaint handling (classified here as social and psychoenvironmental factors) were found to correlate with environmental-perceptual responses (Zweers et al., 1992). It is possible that some of these factors may, in fact be dependent on physical environmental conditions, rather than an influence on them.

The reported social factors, often referred to in the literature as psychological control issues may have a physical environmental dimension, i.e., occupants may use available control mechanisms to get an 'objective' improvement in environmental quality. In one study (Zweers et al., 1992), naturally ventilated buildings had higher levels of carbon dioxide (CO_2) but lower levels of complaints, pointing to the psychological dimension of control. Thus, although the psychological aspect cannot be overlooked, it is possible that operable windows permit modification of environmental parameters that may have reduced some of the detrimental effects that co-existed with higher levels of CO_2.

Another study (Wallace et al., 1991.; Nelson et al., 1991.) reports relationships between psychological-environmental factors and environmental-perceptual responses. These relationships may be explained in terms of substantive and methodological effects. The study included buildings with suspected problems. It is possible that in such cases, personal-perceptual responses may dominate. People may attribute their symptoms to physical environmental factors and report environmental-perceptual responses that may not have been perceived by others. Thus, social and psycho-environmental factors may influence this human response domain for suspected problem buildings. Methodological effects such as questionnaire design may also explain this unexpected correlation.

Personal-Perceptual responses

Categories of exogenous factors that were found to correlate with personal-perceptual responses include intrinsic and adaptive factors as well as social and psychological-environmental factors, as expected. Zweers et al.(1992) reported that neurological symptoms were more closely related to one psycho-environmental factor (dissatisfaction with job). Another study (Hodgson et al., 1992) reported that the frequency of central nervous symptoms during the year correlated with job stress and satisfaction. Similarly, correlations between irritability and other symptom groups were found to be low (Skov et al., 1987), suggesting a different mix of causal agents, even within the category of personal-perceptual responses. Thus, social and psychoenvironmental factors may be causal factors in personal-perceptual responses, independent of physical environmental factors (Sensharma et al., 1993a). This study reported that each job category was correlated with different personal-perceptual responses. It is noted that factors such as job category may include elements of adaptive and social factors. For the human response domains discussed thus far, there are instances of variant correlations. For instance, some studies found gender to be an important exogenous factor, while others did not. This may be because not all studies assessed the full range of exogenous factors or the relative influence of exogenous factors may differ for different categories of buildings or individual buildings.

Environmental-Affective responses

Although six of the selected studies assessed this response domain, only one (Kleven et al., 1991) reported on correlations between environmental-affective responses and one intrinsic (gender) factor and one social (job type) factor. As most studies in this sample focussed on SBS symptoms (personal-perceptual responses), correlations between environmental-affective responses and exogenous factors were not investigated. Moreover, the categories of secular trends and risk perception proposed in Figure 4.1 were not investigated in any of the studies.

Two studies investigated correlations between personal-perceptual responses and environmental-affective responses. One (Zweers et al., 1990b) reported an association between an environmental-affective response (odor acceptability) and an environmental-perceptual response (odor intensity). Hawkins et al. (1991) reported a correlation between environmental-affective responses and Building Sickness Score (BSS). Thus, perceptual responses can be expected to correlate with affective responses. Within the category of perceptual responses, the relationship between environmental-perceptual and environmental-affective response is likely to be stronger for perceived stressors, and between personal-perceptual responses and environmental-affective responses for unperceived stressors. For instance, in the latter case, even when perceived stressors are not identified, the presence of symptoms may result in a negative assessment of the physical environment (Wallace et al., 1991; Nelson et al., 1991). If perceptual responses are adequately assessed and additional exogenous factors influencing affective responses controlled, affective responses may be estimated from perceptual responses.

Personal-Affective responses

It was not possible to make inferences about relationships between this domain and exogenous factors as the latter were not assessed or reported in the only study (Woods et al., 1982) that investigated this human response domain.

Conclusions

The findings of the evaluation synthesis of ten field studies reported herein indicates that the characterization of human response is a useful framework for the identification of exogenous factors. It is necessary, however, to operationalize exogenous factors in terms that do not include multiple dimensions. By controlling for the relevant exogenous factors, human response-exposure links can be more consistently identified.

4.4 METHODOLOGICAL EFFECTS INFLUENCING HUMAN RESPONSE TO INDOOR ENVIRONMENTS

Methodological effects influencing human response to indoor environments result from the process of building evaluation itself. Rossi et al. (1989) refer to these as 'design effects'. Most criteria incorporated in standards related to thermal and air quality are developed based on human responses assessed in laboratory settings. Several studies have found that results obtained from laboratory studies often cannot be replicated in the field. It is important to examine the impacts on human response of the methodology used in assessing human responses, especially as most building evaluations rely on field methodologies, using occupant responses. For purposes of discussion and to synthesize the information from several studies, it is useful to categorize methodologies into three categories, namely, subject methodologies, panel methodologies, and occupant methodology. These are defined below, and differences between them are further illustrated in Figure 4.2.

> ***Subject methodologies*** refer to methodologies in which respondents may spend a few minutes or hours in a controlled 'laboratory' environment in which intrinsic factors may be controlled or uncontrolled.
>
> ***Panel methodologies*** refer to methodologies in which the respondents are briefly exposed to the environment being evaluated and in which intrinsic and

environmental factors may be controlled or uncontrolled.

Occupant methodologies refer to methodologies in which the respondents' occupancy of the environment being evaluated extends beyond the time that the investigation is carried out, and in which both intrinsic and environmental factors are uncontrolled.

Methodological effects include the effects of missing data, stochastic or chance effects, sample design effects, the reliability and validity of the measures used, and the reproducibility and generalizability of the results. The three categories of human response methodologies defined above are discussed in the following paragraphs with respect to the factors listed above, that can influence results obtained using human response methodologies. Figure 4.2 summarizes the relative impacts of the different methodological effects on the three methodologies.

Methodological effects / Methodologies	Reliability	Sample bias	Test effects	Predictive validity	Generalizability
PANEL	H	H	M	H	L
SUBJECT	H	M	H	H	L
OCCUPANT	L	L	M	L	H

Key: H = high, M = moderate, L = low

Figure 4.2 Methodological factors associated with three types of methodologies (Sensharma et al. 1993a)

Subject methodologies

Control over physical and social environmental factors in subject methodologies increases the reliability of responses, especially if intrinsic factors are also controlled. However, sample bias effects are likely because the group of subjects may not comprise a representative sample (Molhave, 1990). A large sample size may serve to reduce the impact of missing data and stochastic effects on test results. Test effects such as the effects of using intrusive apparatus like sensors may also significantly influence responses. Predictive validity of responses is likely to be high because the relevant parameters can be controlled. Generalizability of results is likely to be low because laboratory conditions are difficult to replicate in the field.

Panel methodologies

The reliability of measures used in panel methodologies is likely to be high. This is achieved by: (a) rigorous selection and training procedures, which also permit the use of smaller samples; and (b) repeated observations in the case of untrained panels, as each panelist serves as his or her own control. However, this methodology introduces sample bias because panelists generally consist of volunteers who may differ in significant ways from the general population, thus excluding the most sensitive populations such as people in ill health. The small sample size can also be expected to magnify the impact of missing data or inter-individual variations resulting from weather conditions, illness, hormonal changes, adaptation, habituation, novelty and contrast (Meilgaard et al., 1991). Predictive validity may be problematic if environmental factors cannot be completely controlled. Finally, different tests are likely to yield different results depending on environmental and intrinsic factors, thus posing a threat to the generalizability of results.

Occupant methodologies

Occupant methodologies are likely to have lower reliability of responses because of the lack of control on extraneous factors and inter- and intra-individual variability. Sample bias is likely to be lower that the other two methodologies when a study or investigation uses the entire population within a building. However, even when samples are taken, they are more likely to represent the population than other methodologies because relevant population characteristics can be more easily identified. The influence of missing data and stochastic effects can be expected to depend on the sample size. Test effects can be reduced by appropriate design and administration of questionnaires. Predictive validity may be low, as suggested by the lack of consistent correlations between human responses and 'objective' measures in SBS studies (Putnam et al., 1985). Generalizability of results is likely to be higher than that of other methodologies if site characteristics are representative of other field conditions.

4.5 CONCLUSION

In this chapter were identified exogenous factors and methodological effects that can be expected to influence human responses to indoor environments. Using the characterization of human response presented in chapter 3, a hierarchy of human responses was presented. An evaluation synthesis of ten field studies suggests that the four domains of human response can be linked to specific exogenous variables, but that the broad categories of exogenous factors need to be further operationalized. Finally, the four human response domains were associated with one or more of three types of methodologies. Methodological effects that are possible to result from the use of each type of methodology were also identified and discussed.

CHAPTER 5

DEVELOPMENT OF A CONCEPTUAL MODEL TO DEFINE HUMAN RESPONSE-EXPOSURE LINKS

5.1 INTRODUCTION

For the purpose of establishing rational human response and exposure criteria, human responses must be expressed in terms that can be linked to exposures. The characterization of human response is used in this chapter to link exposure parameters to the four domains of human response. This chapter also synthesizes the information about the links between human response domains and exogenous factors and methodological effects in the development of a conceptual model to better define human-response exposure links.

Section 5.2 conceptually links human response domains to exposure parameters. Thermal and air quality exposure parameters are discussed in greater detail in keeping with the focus of this dissertation. Section 5.3 reports on the findings of the evaluation synthesis described earlier with respect to empirical links between human response domains and exposures. This empirical evidence is obtained from an evaluation of ten field studies. Section 5.4 presents the conceptual model that syntheses the impacts of the physical environment, exogenous factors and methodological effects on human response.

5.2 CONCEPTUAL LINKS BETWEEN HUMAN RESPONSE DOMAINS AND EXPOSURE PARAMETERS

The literature reports on the multifactorial nature of exposures that is linked to symptoms related to SBS (i.e., personal-perceptual responses) (e.g., Molhave, 1990). Other human responses may also be linked to multifactorial exposures. For instance, Janssen et al. (1982) report that subjects felt warmer (personal-perceptual response related to thermal stressors) with increased CO_2 in the air. Figure 5.1 shows some examples of human responses within each human response domain that can be linked to exposure parameters. The figure illustrates the multifactorial impacts of the four primary environmental stressors especially on personal-perceptual responses (e.g., symptoms), environmental-affective responses (e.g., overall acceptability of the indoor environment), and personal-affective responses (e.g., comfort) as indicated in the shaded portions of the figure. This figure also emphasizes the fact that the four human response domains can be linked to: (a) specific stressors, (b) unspecific stressors, or (c) both specific and nonspecific stressors.

As the focus of this dissertation is on the assessment of thermal and air quality, the following discussion identifies exposure parameters that may be linked to human responses that can be used to assess thermal and air quality. It is hypothesized that thermal and air quality parameters identified as influencing perceptual responses will also apply to the corresponding affective responses, as the difference between perceptual and affective responses is likely to be related to differences in exogenous factors identified in chapter 3.

HUMAN RESPONSE DOMAINS	INDOOR ENVIRONMENTAL STRESSORS			
	THERMAL	AIR QUALITY	LIGHTING	ACOUSTICS
ENVIRONMENTAL-PERCEPTUAL	This room is hot.	This room has an odor / is moldy.	This room has glare.	The background sound in this room is loud.
PERSONAL-PERCEPTUAL	I feel hot.	I smell an odor.	I perceive glare.	I hear a loud background sound.
	I have a headache.	I have a headache / a fever.	I have a headache.	I have a headache.
ENVIRONMENTAL-AFFECTIVE	The temperature in this room is unacceptable.	The odor / mold in this room is unacceptable.	The glare in this room is unacceptable.	The level of background sound in this room is unacceptable.
	The quality of the environment is unacceptable.	The quality of the environment is unacceptable.	The quality of the environment is unacceptable.	The quality of the environment is unacceptable.
PERSONAL-AFFECTIVE	I am uncomfortable.	I am uncomfortable / sick.	I am uncomfortable.	I am uncomfortable.

Figure 5.1 Relationships between human response domains and indoor environmental stressors (Ref. Sensharma et al. 1994)

5.2.1 Identification of exposure parameters influencing human responses to the thermal environment

Human responses to the thermal environment are discussed first by describing the physiological bases of these responses. Next, the stimuli or exposure parameters that result in these responses are identified. The goal of responses to thermal stimuli for human beings is to maintain an optimum body temperature distribution, independent of environmental temperature. The standard core body temperature of humans is within the range of 36° to 37.5° C (Folk. 1974).

The sensory modalities most pertinent to the study of human response to thermal stimuli include the somatosenses, and more specifically, the cutaneous or skin senses. Of these, the sensations of cold and warmth are discussed here, as they relate to the thermal environment. The sensation of pain, often linked to extreme thermal conditions is not discussed, as such extremes of temperature are not likely to be encountered in typical non-industrial interior environments. Specific receptors in the skin can be identified, that respond to thermal stimuli. For instance, free nerve endings detect changes in temperature, cold receptors sense temperatures below neutral and above 45° C, and warmth receptors sense temperature above neutral (Carlson, 1994).

The hypothalamus serves as a thermostat for maintaining a constant body temperature in human beings. The preoptic area in the hypothalamus monitors the temperature of the blood, and the anterior and posterior nuclei in the hypothalamus monitor the temperature of the brain (McIntyre,1980). The anterior hypothalamus provides thermoregulation by vasodilation and sweating when the body is too hot. The posterior hypothalamus provides thermoregulation by vasoconstriction and shivering when the body is too cold.

The hypothalamus thus integrates sensory information from thermal receptors located in the periphery, thermal sensitive cells in the cranial central nervous system, and core receptors located in the core. Human responses to cold and heat differ in the following ways:

Thermoregulation

Responses to cold

Stimulation of the cold receptors in the body results in cutaneous vasoconstriction, i.e., an increase in the effective thickness of the body shell and an increased blood flow to the core (Folk, 1974). A simultaneous increase in heart rate and pilo-erection results. The latter may be a mechanism to increase insulation of the skin. At lower temperature, metabolism is increased by involuntary contraction of the skeletal muscles, i.e., shivering. Shivering increases the metabolic rate, thus serving to minimize the loss of heat from the body. This is accompanied by occasional bouts of vasodilation to increase skin temperature and possibly postural changes to reduce the exposed surface area. Chemical increase of heat production is brought about by epinephrine, norepinephrine, and thyroxin (Folk, 1974).

Responses to heat

Stimulation of the warmth receptors results in vasodilation, i.e., blood flow increases from the body core to the surface (Folk. 1974). The heat is them dissipated to the ambient environment. When this mechanism is inadequate, i.e., at around 37^{o} C, thermal sweating is initiated. Thermal sweating occurs from the eccrine glands in the skin and the sweat consists of a dilute solution of sodium chloride. The rate of sweating is adjusted according to the need for heat dissipation, but moderate dehydration does not alter the rate of sweating. The reflex control of sweating is partly related to the stimulation of peripheral receptors and partly to the temperature of the hypothalamus. Sweating may result in dehydration as well as the depletion of salts from the body, which must be replenished by ingestion of water and salts. Under prolonged exposure to extreme heat conditions, there is a transitory increase in plasma volume. The blood volume increases after several days, as does the consumption of oxygen and food. There is some accompanying dehydration, which may result in an increase in the viscosity of blood and an increase in the heart rate. Consequently, body temperature increases, and vasodilation occurs in two ways: (1) small increase in vasodilation due to the release of vasoconstricted tone, and (2) a larger increase of blood flow through the limbs due to active vasodilation.

Exposure parameters influencing human responses to the thermal environment

Two models, widely used for characterizing relationships between thermal stimuli and human responses, use classic heat transfer theory to describe thermal exchanges between the body and the environment (ASHRAE, 1989). The steady state model, developed by Fanger (1970), assumes that the body is near thermal neutrality, and considers the core and skin of the body as one compartment. The two-node transient energy balance model, developed by Gagge et al. (Referenced in ASHRAE, 1989b) distinguishes between the body core and skin, and states that the rate of heat storage is equal to the net rate of heat gain minus the heat loss.

Heat exchange from the body to the environment occurs through: sensible heat flow from the skin, latent heat flow from the evaporation of sweat and from evaporation of moisture diffused throughout the skin, sensible heat flow through respiration, and latent heat flow due to evaporation of moisture during respiration. It has long been recognized that three principal factors affecting loss of body heat are: temperature, humidity and air motion (Houghton et al., 1923). The temperature of the air and surrounding objects is responsible for heat loss or gain by the body. Increase in relative humidity of the environment decreases heat loss of the body by evaporation. The Effective Temperature index, developed to describe the degree of warmth experienced by a person, is based on the identification of all combinations of temperature and humidity that will result in the same sensation of warmth. Radiant heat transfer from the human body is expressed in terms of the Mean Radiant Temperature (MRT), defined as "...the uniform temperature of an imaginary enclosure in which radiant heat transfer from the human body equals the radiant heat transfer in the actual nonuniform enclosure (ASHRAE, 1989a. p.8.12)." To describe the effects of convection and radiation on heat transfer, a parameter, namely, operative temperature has been defined as "..the average of the mean radiant and ambient air temperature, weighted by their respective heat transfer coefficients (ASHRAE, 1989a. p.8.2)."

In addition to thermal sensation experienced by the body as a whole, local thermal discomfort may also occur. The sensation of draft, defined by Houghten et al. (1938) as "...any local sense of cooling of a portion of the body, caused either by an excessive movement of air of normal temperature, by air having a normal velocity by a lower temperature, by excessive radiation to a cold surface, or any combination of these effects (p.289)." In addition to the factors already discussed, mean air velocity is likely to be an important exposure parameter for this response. Radiant temperature asymmetry is the exposure parameter that can be related to a sensation of local thermal discomfort by occupants of a space. The temperature of floors and vertical air temperature differences are other exposure parameters that may be linked to local thermal discomfort (ASHRAE. 1989b). Finally, carbon dioxide may also be an exposure parameter that influence human responses to the thermal environment. Janssen et al. (1982) report that subjects described the room as fresher, cooler, and having greater air motion at lower CO_2 concentrations.

The exposure parameters that can be hypothesized to influence human responses to the thermal environment therefore include dry bulb temperature, relative humidity, mean air velocity, mean radiant temperature, and levels of CO_2.

5.2.2 Identification of exposure parameters influencing human responses to air quality

Human responses to air quality may be discussed in terms of responses related to odor, and those related to symptoms. Woods (1988) distinguishes between perceived and non-perceived stressors. Physical stressors that stimulate the four basic types of sensory receptors (i.e., thermoreceptors, olfactory receptors, auditory receptors and visual receptors) are referred to as perceived stressors. Responses to odor can be expected to fall in this category with respect to air quality parameters. Stressors that do not affect the sensory receptors or that only affect them at values above those that cause physiological strains are called non-perceived stressors. Responses to non-perceived stressors may include clinical responses in terms of infections, respiratory or neurological disorders, as well as symptoms such as headaches, fatigue, dizziness, drowsiness, nausea, irritation of the eyes, throat, skin and upper and lower respiratory tracts, fever and loss of memory.

Exposure parameters related to odor responses

Olfactory receptors are located in the olfactory cleft, high in the nasal passages. In addition, receptors of the common chemical sense (i.e., free nerve endings) are also present in the surrounding tissue. Thus, the two operate as a single perceptual system (ASHRAE, 1993). However, in order to distinguish between perceived and unperceived stressors, they are discussed separately. Volatile substances having a molecular weight in the range of 15 to 300 are stimuli for odor sensations. Most odorous substances are organic, but not all substances that meet these criteria are odorous (Carlson,1994). In typical non-industrial indoor environments, 50 to 300 volatile organic compounds may be found (VOCs) (Molhave et al., 1992). Olfactory receptors, connected to the olfactory bulb by a nerve fiber, transmit information to various central structures of the brain (ASHRAE, 1993).

Molhave et al. (1992) report on the use of the Total Volatile Organic Compound (TVOC) indicator to assess environmental measures of VOCs. They caution that the use of this indicator has not been standardized in terms of concentrations included and the types of health effects assessed. Usually, the TVOC indicator is an addition of masses of polluting molecules in mg / m^3. This measure has been obtained in some experimental work by the authors through chemical analysis (using an integrating FID detector). Molhave (1991) reports that from a biological perspective, number of molecules per cubic meter may be more relevant. The usefulness of the TVOC indicator has not yet been demonstrated for odor perception, as correlations between indoor VOC concentrations and odor complaints in indoor environments is often reported to be poor (ASHRAE, 1993).

This may be attributed to the fact that the nose is the most sensitive instrument for odor perception (ASHRAE, 1993).

In addition to the concentrations of VOCs in indoor environments, humidity and temperature have also been reported to affect the perception of odor. It is reported that at constant dry bulb temperature, an increase in humidity lowers the intensity level of cigarette smoke odor (Kerka et al., 1956). The authors suggest that this effect may have a physical interpretation; i.e., in air conditioned spaces in which dehumidification takes place, water soluble odorants may be removed along with the condensate on the surface of the coil, effectively resulting in a change in odorant concentrations.

Carbon dioxide has long been used as an indicator of air quality (ASHRAE, 1989a). This is mainly related to comfort (odor) criteria. Carbon dioxide may be the primary contaminant to control in spaces where smoking is not allowed. The primary source of carbon dioxide in the absence of smoking is the occupants in the space.

The exposure parameters that are likely to influence odor response therefore include the concentrations of VOCs, assessed in terms of the TVOC indicator, Carbon dioxide, temperature and relative humidity.

Exposure parameters related to the occurrence of symptoms

Molhave (1990) reports on five categories of symptoms that together constitute the Sick Building Syndrome. These are listed below:

1. Sensory irritation in eyes, nose, and throat (e.g., pain, sensation of dryness,

smarting feeling, stinging irritation, hoarseness and voice problems).

2. Neurologic or general health symptoms (e.g., headache, sluggishness, mental fatigue, reduced memory, reduced capability to concentrate, dizziness, intoxication, nausea, vomiting, and tiredness).
3. Skin irritation (e.g., pain, reddening, smarting or itching sensations, and dry skin)
4. Unspecific hypersensitivity reactions (e.g., running nose and eyes, asthma-like symptoms among non-asthmatics, sounds from the respiratory system)
5. Odor and taste symptoms (e.g., changed sensitivity of olfactory or gustatory sense, and unpleasant olfactory or gustatory perceptions)

Volatile organic compounds may be stimuli for symptoms that can be described as eye, nose and throat irritation (1) , odor and taste symptoms (5), as well as protective reflexes such as unspecific hypersensitivity reactions (4) (Molhave et al., 1992). These authors describe the mechanisms by which the effects of air quality are perceived. The three sensory systems, namely, the olfactory sense, the gustatory sense, and the common chemical sense respond to airborne chemicals. The trigeminal nerve and other non-myelinated nerves in other tissue areas conduct sensory information from the receptors. Activation of the senses results in the symptoms listed above. The exposure parameter that assesses the concentrations of VOCs is the TVOC indicator, as defined above.

Environmental tobacco smoke is another contaminant that is likely to lead to perceptions of odor as well as some of the symptoms listed above. Nicotine may be the appropriate exposure parameter to assess concentrations of ETS, as this is the compound that is specific to ETS (Leaderer et al., 1983). As the most prevalent component of ETS is particulate matter, particulate concentrations may also be important parameters to assess.

Particulate concentrations may also be responsible for some of the symptoms listed above (Woods et al., 1988). Particle sizes less than 2μm are most likely to be retained in the lungs, particles greater than 8 to 10 μm are likely to be retained in the upper respiratory tract, whereas, intermediate sizes are deposited in the conducting airways of the lungs from which they are cleared, swallowed or coughed out (ASHRAE, 1993).

Neurologic or health symptoms may be attributed to other factors in addition to the air quality parameters discussed above. Woods et al. (1988) indicate that symptoms such as headache, dizziness, drowsiness, fatigue and nausea may be caused by thermal, air quality, luminous and acoustic stressors.

Exposure parameters related to occupant reports of symptoms may therefore include VOCs measured in terms of TVOC, particulate counts of three ranges of sizes, carbon dioxide, and nicotine.

5.3 EMPIRICAL EVIDENCE OF LINKS BETWEEN HUMAN RESPONSE DOMAINS AND EXPOSURE PARAMETERS

The evaluation synthesis presented in Chapter 4 also examined the selected field studies with respect to human response - exposure links. Seven of the ten field studies in the sample investigated some correlations between human response domains and exposures. Table 5.1 summarizes the results of this analysis. None of these reported associations between lighting and acoustic parameters and human responses. This may be attributed to the limited number of studies that actually measured both exposures and human responses and / or analyzed the associations between them. Responses

Table 5.1 Evaluation synthesis: Correlations between human response domains and exposure parameters (Ref. Sensharma et al. 1993b)

Study	Human response domains	Relationships between human response domains and exposures										
		Thermal			Air Quality						Lighting	Acoustics
		T_a	RH	SET	CO_2	VOC	F	P	MO	ACH		
Zweers et al., 1990a, 1992	EP	0	0	na	0	na	na	na	na	na	0	0
	PP	0	0	na	x	na	na	na	na	na	0	0
	EA	0	0	na	x	na	na	na	na	na	0	0
Zweers et al., 1990b.; Skov et al., 1987	EP	x	0	na	0	0	0	0	0	0	0	0
	PP	0	0	na	0	0	0	0	0	0	0	0
	EA	x	0	na	0	x	0	0	0	x	0	0
Hedge et al., 1991.	EP	0	0	na	0	na	0	0	na	na	0	na
	PP	x	0	na	0	na	0	0	na	na	0	na
	EA	0	0	na	0	na	0	0	na	na	0	na
Broder et al., 1990.	PP	0	0	na	0	0	na	0	na	na	na	na
	EA	x	0	na	x	0	na	0	na	na	na	na
Wallace et al., 1991.; Nelson et al., 1991.	EP	0	x	na	0	0	0	x	0	na	na	na
	PP	x	0	na	x	x	0	x	x	na	na	na
	EA	0	0	na	0	0	0	0	0	na	na	na
Hodgson et al., 1992	EP	0	0	na	0	0	0	0	na	na	0	0
	PP	0	0	na	0	x	0	x	na	na	0	0
	EA	0	0	na	0	0	0	0	na	na	0	0
Woods et al., 1982	EP	0	0	x	x	na	na	na	na	na	na	na
	PP	0	0	x	x	na	na	na	na	na	na	na
	PA	0	0	0	0	na	na	na	na	na	na	na

Key: X indicates that significant correlations between the relevant domains of human response and categories of exposure factors were found; 0 indicates that no significant correlations between the relevant human response domains and categories of exposures were found or were not assessed; na indicates that these exposures were not assessed.

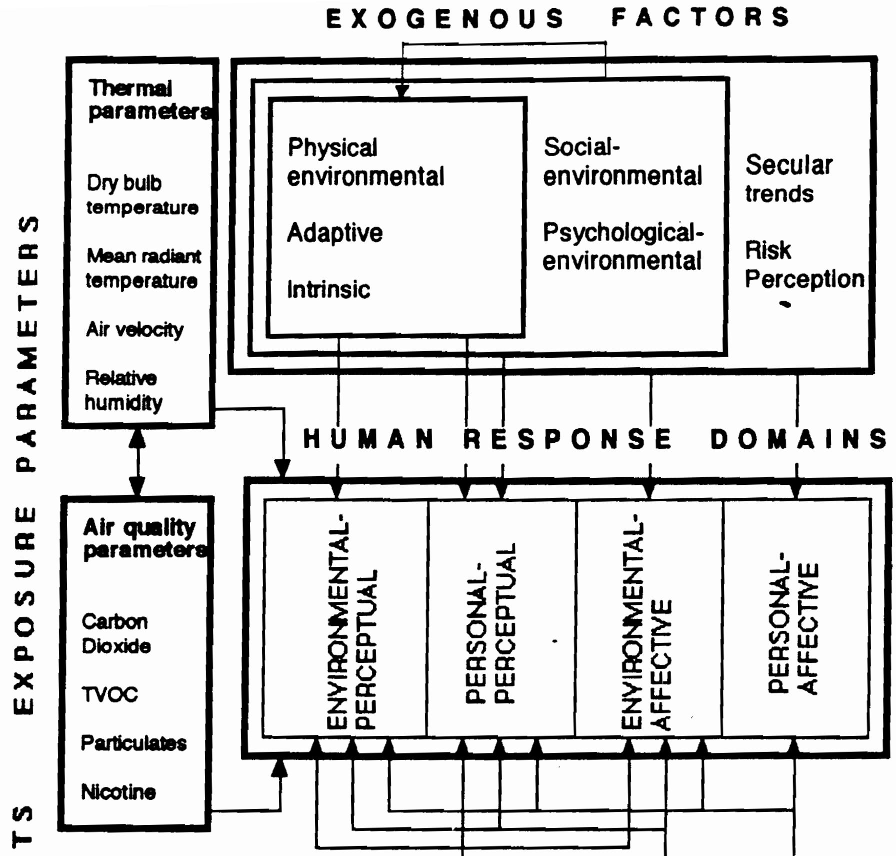
T_a = air temperature; RH = relative humidity; SET = Standard Effective Temperature; CO_2 = Carbon dioxide, VOC = volatile organic compounds; F = Formaldehyde; P = Particulates; MO = microorganisms; ACH = air change per hour.

directed to the environment (both perceptual and affective) were correlated in five studies with thermal and air quality factors. Thus, environmental responses can be appropriately correlated with exposures. However, nonperceived stressors may not be identified in this way. The personal-perceptual response domain is therefore critical for the identification of unperceived stressors. Four studies reported correlations between exposures and personal-perceptual responses. Three of these examined symptoms. At least two of these three included buildings with problems (Wallace et al., 1991; Hodgson et al., 1992.). The fourth (Woods et al., 1982) investigated internal sensory responses (e.g., warmer or cooler hands and feet), which may render the environment unacceptable. It is therefore proposed that both the perceptual domains should be investigated for correlations with exposures to identify perceived and unperceived stressors.

5.4 DEVELOPMENT OF A MODEL LINKING HUMAN RESPONSES TO EXPOSURE PARAMETERS FOR THERMAL AND AIR QUALITY ASSESSMENT

This section integrates the findings from chapters 3, 4, and 5 to develop a conceptual model that describes the combined impacts of exposure parameters, exogenous factors and methodological effects on human response. Figure 5.2 illustrates the model for human responses to thermal and air quality stressors.

Each of the four human response domains are linked to: (a) a set of exogenous factors, (b) methodological effects, and (c) exposure parameters. The model illustrates the broad categories of exogenous factors that influence each domain of human response. Specific human responses within these domains can be associated with different factors within



METHODOLOGIES / METHODOLOGICAL EFFECTS	PANEL	SUBJECT	OCCUPANT
RELIABILITY	High	High	Low
SAMPLE BIAS	High	Moderate	Low
TEST EFFECTS	Moderate	High	Moderate
PREDICTIVE VALIDITY	High	High	Low
GENERALIZABILITY	Low	Low	High

Figure 5.2 Conceptual model linking human responses to the thermal and air quality factors, exogenous factors and methodological effects.

these categories of exogenous factors. Each human response domain is also associated with one or more of the three categories of methodologies. Each methodology is associated with methodological effects. In keeping with the focus of this dissertation, the conceptual model shows parameters related to thermal and air quality, although other exposure parameters such as lighting and acoustics also influence human responses.

A part of the model is tested in the empirical study described in Chapter 6. Methodological effects cannot be compared, as human responses in the empirical study were assessed using only occupant methodology. Each of the four human response domains was represented, but only a few human responses within each human response domains were assessed to reasonably limit the scope of the study. The selection of human response measures for the empirical study was based on those most frequently used and reported in the literature, especially in reports of field investigations.

5.5 CONCLUSION

This chapter identified conceptual links between the four domains of human response and thermal and air quality exposure parameters. It was concluded that human response domains can be associated with specific stressors, nonspecific stressors, or both specific and nonspecific stressors. Based on the physiological responses of human beings to thermal and air quality stressors, specific exposure parameters were identified for human responses to the thermal environment and to indoor air quality. A set of exposure parameters were identified, as it is clear from the existing literature that people react to a combination of exposure parameters rather than to an individual exposure stimulus. Empirical evidence for links between human response domains and exposures was synthesized for ten field studies. It was concluded that responses related to the environment were more likely to be correlated with exposures, but that personal perceptual responses may be critical for the identification of stressors that are not recognized (or unperceived stressors). Finally, the findings of chapters 3,4, and 5 are summarized in the form of a conceptual model that illustrates the net impacts of physical environmental factors or exposure parameters, exogenous factors, and methodological effects on the four human response domains.

CHAPTER 6

THE EMPIRICAL STUDY: METHODOLOGY

6.1 INTRODUCTION

This chapter describes the procedures that were used to empirically assess the conceptual model presented in Chapter 5. That model defines the combined impacts of physical indoor environmental stressors as well as exogenous factors and methodological effects on human responses to the physical indoor environment. The empirical study described herein assessed a part of this model. The scope of the empirical study is specified in section 6.2. Section 6.3 consists of a list of the hypotheses that were addressed by the study to assess the efficacy of the conceptual model in identifying the determinants of human responses to the physical indoor environment. The research design, including the analysis procedure, is described in section 6.4. This section also discusses the rationale for the research design. Independent and dependent variables are identified in Section 6.5. Operational definitions are provided for each of these variables. Section 6.6 includes a list of the criteria used for the selection of the sample of buildings and occupants. Data collection procedures for system data, exposure data and human response data are outlined in Section 6.7.

6.2 SCOPE OF EMPIRICAL STUDY

The conceptual model was assessed for: (1) two types of non-industrial work environments that can be characterized as open plan spaces, and (2) two of the four primary stressors in the indoor environment, namely, thermal and air quality. Further, methodological effects were not assessed in the empirical study, as only one type of methodology was used. It is conceivable that the model can be tested for other types of buildings (e.g., residential), occupants (e.g., children, the elderly), and for other indoor environmental stressors, by appropriate operationalization of the variables specified in the model.

The rationale for the selection of non-industrial work environments, as discussed earlier, is that there are differences in: (1) the levels of stressors typically found in industrial versus non-industrial environments, and (2) the characteristics of the occupants of these environments. Unlike industrial environments, non-industrial environments are characterized by combinations of relatively low levels of stressors, i.e., levels of stressors that do not individually have toxic effects or obvious adverse health impacts. Nevertheless, occupants of these environments may experience symptoms or clinical signs of illness, for which a specific cause often cannot be identified. Also, as non-industrial environments are more likely to include susceptible occupants, the toxicological approach may not be adequate in providing indoor conditions that assure occupant well being. The model developed in chapter 5 is expected to be useful for assessing human responses that are not described as health impacts, but rather, as symptoms, for which clinical assessment may not be possible. The selection of work environments, rather than other non-industrial environments such as residential, was based on the sheer magnitude of people affected by problems such as SBS and BRI in work environments, that are typically not amenable to control by individual occupants.

To adequately test the conceptual model, the scope of the empirical study was determined with the view of increasing the range of variation in levels (or concentrations) of stressors and exogenous variables. Two spaces were selected to increase the probability of variability in indoor environmental conditions as a function of factors such as the type of HVAC systems, sources, and the orientation of indoor spaces. Additionally, the use of two different occupant groups was expected to increase the probability of varying several exogenous factors such as exposure times, mean age, clothing levels, and some social and psycho-environmental factors.

In keeping with the focus of this dissertation, the empirical study assessed two of the four primary stressors, namely, thermal and air quality. This selection was based on the predominance of these stressors in the literature related to the Sick Building Syndrome (SBS). Additionally, these two stressors have been reported in the literature as having interactive impacts on human response.

6.3 HYPOTHESES

The overall objective of the study was to empirically test the hypothesized relationships between exposures and exogenous variables (independent variables) and selected human responses (dependent variables). The hypothesized relationships between human responses and exogenous variables are identified in Table 6.1. As there is increasing evidence in the literature that the human responses being assessed herein are likely to be attributed to a combination of exposure parameters, a *set* of exposure

Table 6.1: Hypothesized relationships between human responses (dependent variable) and exogenous variables (independent variables).

Human responses: Dependent variable	Exogenous variables: Independent variables				
	Other physical	Intrinsic	Adaptive	Social	Risk
E-P Intensity of: Temperature and Humidity *and* **P-P** Intensity of: Temperature and Humidity	Lighting, Personal space	Age, Gender, Smoking status, Physical work, Consumption of tea and coffee, Consumption of alcohol, Health status on test day	Medications, Exposure time, Metabolic rate, Clo-values.		
E-A Acceptability of: Temperature, Humidity, and Thermal conditions	Lighting, Personal space	Age, Gender, Smoking status, Physical work, Consumption of tea and coffee, Consumption of alcohol, Health status on test day	Medications, Exposure time, Metabolic rate, Clo-values.	Social score, Work type	Risk score
P-A Thermal comfort	Lighting, Personal space	Age, Gender, Smoking status, Physical work, Consumption of tea and coffee, Consumption of alcohol, Health status on test day	Medications, Exposure time, Metabolic rate, Clo-values.	Social score, Work type	Risk score
E-P Intensity of odor at workstation	Personal space	Age, Gender, Smoking status, Health status on test day.	Medication, Exposure time		
E-A Acceptability of Odor	Personal space	Age, Gender, Smoking status, Health status on test day.	Medication, Exposure time	Social score, Work type	Risk score

Table 6.1
(continued)

Human response: Dependent variable	Exogenous variables: Independent variables				
	Other physical	Intrinsic	Adaptive	Social	Risk
E-A Acceptability of Air Quality	Lighting, Personal Space	Age, Gender, Smoking status, Health status on test day, Physical work, Alcohol and tea and coffee consumption	Medication, Exposure time, Metabolic rate, Clo-values	Social score, Work type	Risk score
P-P Presence of General symptoms and Local symptoms	Personal space, lighting, acoustics	Age, Gender, Smoking status, Physical work, Consumption of alcohol and tea and coffee, Correction lenses, Health status on test day	Medication, Exposure time, Metabolic rate, Clo-values	Social score, Work type	Risk score
E-A Overall acceptability	Personal space, lighting, acoustics	Age, Gender, Smoking status, Physical work, Consumption of alcohol and tea and coffee, Correction lenses, Health status on test day	Medication, Exposure time, Metabolic rate, Clo-values	Social score, Work type	Risk score
P-A General comfort	Personal space, lighting, acoustics	Age, Gender, Smoking status, Physical work, Consumption of alcohol and tea and coffee, Correction lenses, Health status on test day	Medication, Exposure time, Metabolic rate, Clo-values	Social score, Work type	Risk score

parameters rather than a single exposure parameter have been identified. All six exposure variables assessed in the study (i.e., operative temperature, air velocity, relative humidity, and concentrations of carbon dioxide, TVOC and particulates) were hypothesized to influence each of the human responses, and are therefore not individually listed in table 6.1. The selection of exogenous factors was based on the identification of specific variables that were expected to influence the human response being assessed for each category of exogenous factors in the model. The general form of the null hypothesis being tested for each dependent variable was:

All the hypothesized independent variables (i.e., exposure and exogenous variables) considered together do not explain a significant amount of the variation in the dependent variable (i.e., human response).

Each of the hypothesized relationships in Table 6.1 can be stated is this form. For example, the first set of relationships in Table 6.1 can be expressed in the form of a null hypothesis as follows:

The exogenous factors: lighting, acoustics, age, gender, smoking status, amount of physical activity, consumption of tea, coffee and alcohol, health status on test day, ingestion of medication, clothing level, metabolic rate, and exposure time; and the exposure variables (not shown in Table 6.1): operative temperature, air velocity, relative humidity, carbon dioxide concentrations, Total Volatile Organic Compounds (TVOCs), and total particulate concentrations; together do not explain a significant amount of variation in the dependent variable , i.e.., the human response: 'intensity of temperature' at the workstation.

To permit a more rigorous test of the conceptual model, the hypothesis stated above was also tested by adding the entire set of variables for each dependent variable. As shown in the conceptual model, it was expected that exogenous factors for each human response domain can be arranged in a hierarchy (Chapter 4). Thus, if we consider human responses in each of the four domains related to thermal stressors, it is evident that affective responses are likely to be influenced by the same set of exogenous factors as perceptual responses, but are, in addition, also likely to be influenced by factors described as 'secular trends' and 'risk perception'. As the role of risk perception and social and psychosocial factors has not adequately been established in the existing literature, it was considered important to assesses whether these factors also influence perceptual responses.

To conclude, each of the hypotheses listed above was tested, first, with the hypothesized set of exogenous variables, and then, with the entire set of independent variables. Also, as there is increasing evidence in the literature about the multifactorial impacts of thermal and air quality stressors, all the six exposure variables assessed in the study were used to test each of the hypotheses.

6.4 RESEARCH DESIGN

The empirical study was carried out in a field setting rather than a laboratory setting, to permit the assessment of exogenous factors which could not have been replicated in a laboratory setting. As the independent variables (i.e., exposures and exogenous variables) could not be manipulated or held constant as in a laboratory study, the selection of the sample of buildings and occupants for the study was done with the purpose of maximizing variability in these independent variables. The research design is graphically illustrated in Figure 6.1.

Variability in exogenous factors and exposures: Some exogenous factors such as susceptibilities and the use of correction lenses were expected to vary randomly. However, factors such as the type of work and other social factors were expected to vary between groups. Therefore, it was determined that at least two occupant groups should be identified. As will be discussed in section 6.6, two occupant groups; i.e., office workers and students were selected. The two selected spaces were open plan spaces in: (1) the Information Systems Building (CNS), and (2) one architecture studio space at Cowgill Hall.

The research design also attempted to maximize variability in exposures. Controls in buildings are designed to maintain a specified, homogenous range of conditions within the indoor space, but variability can be expected at different locations based on factors such as the location of windows or external walls, thermostats, and the position of supplies and returns in the ventilation systems. Therefore, large spaces with multiple thermostatic zones were preferred. Exposures were also expected to vary based on the time of day and on seasonal differences in outdoor conditions. Therefore, both human response and exposure data were taken on two days, one during mild outdoor conditions, and one during cold conditions. Additionally, data were taken twice on each of those days. The rationale for two sets of daily data is that concentrations of contaminants can be expected to vary with the period of occupancy. Thus, a total of four sets of human response data were taken for each of the respondents of the spaces, along with four sets of exposure measures at each exposure sampling point.

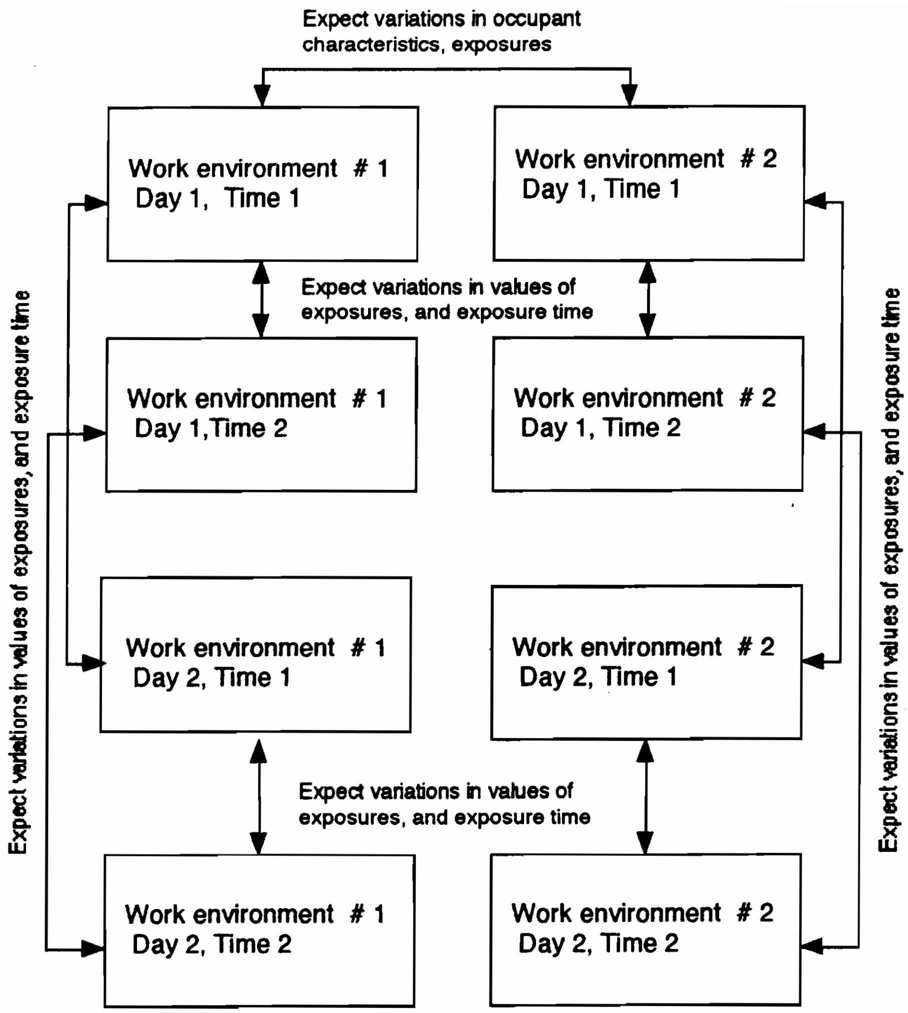


Figure 6.1 Research design

Methodological effects: Methodological effects were not varied for this study. The same methodology was used for all the selected spaces and occupant groups. However, the design of the questionnaires and the administration of questionnaires was done to minimize methodological effects such as recall of questionnaire items. These are discussed more fully in the section on questionnaire design. The following time related threats to internal validity were considered, and it was concluded that these would not be expected to play a major role in human responses:

History	Social factors and secular trends include factors such as changes in management policies, and other events such as media coverage of certain issues that may influence human responses. There were no significant outside influences during the period of the study, as both sets of responses were taken over a relatively short period of time (two and a half months). One social factor that may have influenced human responses in one space (the studio at Cowgill Hall) may be the stress associated with exams and project deadlines during the second set of tests taken in that space.
Maturation	Changes in intrinsic and adaptive factors can be expected to occur over time. However, these were not considered to be major threats to the results of this study as they are not likely to change significantly over a short period of time for an adult population.
Testing	The possibility of the Hawthorne effect was considered and some steps were taken to minimize this effect. The informed consent form was developed to convey to the respondents that the study was not

conducted in response to suspected problems in the building, and the academic nature of the study was emphasized. The time between testing was maximized to the extent possible to minimize the possibility of recall of questionnaire items and responses. Questionnaire design also minimized this threat to some extent. The possibility that respondents may recall their responses on past questionnaires and give different responses, expecting that changes have been made in the indoor environment was considered. Alternatively, they may give consistent results even if environmental conditions have changed (i.e., autocorrelation).

Mortality Systematic trends related to non-responses and respondents dropping out of the study were considered. No systematic trends were expected.

Data analysis

Multiple regression analysis was selected as the method of analysis for the testing of the hypotheses listed above. The purpose of this analysis can be described as follows: "To describe the extent, direction and strength of the relationship between several independent variables and a continuous dependent variable (Kleinbaum et al., 1988,. p.12)." The dependent variables in the empirical study were treated as continuous variables. Evidence to support the use of rating scales for the assessment of human responses as interval level data comes from studies related to the use of the seven point thermal sensation scale used by ASHRAE (McIntyre, 1980). The independent variables are either continuous variables, or have been recoded as dummy variables for the regression analysis.

The initial analysis plan was to combine the data from both the selected spaces, to test the hypotheses. However, several unanticipated events led to the adoption of a different approach. The data from the CNS building were analyzed separately from the Cowgill building. As discussed in section 6.8, there were several non-responses from occupants of the Cowgill studio. This was attributed to the informal nature of the studios. Also, one part of the studio comprised students that were not part of a scheduled studio class, thereby making it very difficult to conduct the test under fully occupied conditions. Additionally, the difference in the testing times on each day had to be reduced in this case, i.e., as the studio met only in the afternoon, the first set of data were taken in the early afternoon, and the second set of data was taken close to 5:00 p.m. Also, during the first test day at the Cowgill studio, a breakdown of one of the exposure instruments made it necessary to abort the test midway through the data collection process. Finally, to complete the four sets of data needed for the study, data had to be collected close to the end of term, making it difficult for the occupants to participate due to the pressure of final project deadlines. Data for the second day of testing for two zones could not be taken as the studio was moved to an adjoining classroom for a lecture session.

The first step in testing the hypotheses listed above was to calculate a correlation matrix for all the variables in the equation. The procedure used for this was 'DESCRIPTIVES CORR' procedure within the 'REGRESSION' procedure. The purpose of this matrix was to identify independent variables that were highly correlated, and to either eliminate one of the variables, or to create interaction variables, as large correlations between independent variables can be expected to substantially affect the results of multiple regression analysis (SPSS Inc.,1990). A correlation coefficient of 0.70 was selected as a cutoff point. Only one set of variables, namely, dry-bulb temperature and mean-radiant temperature were found to be highly correlated (Pearson Correlation Coefficient of 0.88

for the Information Systems Building data). Therefore, these two variables were expressed in terms of the variable 'operative temperature', which is defined as "the average of the mean radiant and ambient air temperature weighted by their respective heat transfer coefficients (ASHRAE, 1989a, p.8.2)." Practically, it is calculated as the average value of the dry bulb temperature and the mean radiant temperature (ASHRAE, 1989b). Also, it was assumed that the requirement for normalcy of error terms for regression analysis was met because of the relatively large number of observations (around 89 for CNS, and around 64 for Cowgill Hall).

The next stage in the analysis was to identify the range of values for each independent variable and to plot frequency graphs for all the variables in the analysis. Additionally, the frequency distribution was examined to identify any significant outliers in the independent variables that would need to be addressed in the interpretation of the results.

The final step in the analysis was to test the hypotheses using regression analysis. The rationale for decisions about the treatment of missing values and the procedures for selecting variables are discussed here. Missing data within each questionnaire that was returned were determined to be random and rare. Cases in which missing values occurred for any of the variables in the analysis were eliminated (i.e., listwise missing-value treatment). The stepwise selection procedure was selected for building the regression model. This procedure is a combination of the forward and backward selection procedure. In this procedure, the first variable selected is the one with the largest positive or negative correlation with the dependent variable. If the F-test rejects the hypothesis that the coefficient of the entered variable is 0, that variable is retained in the model. The entry criterion used in this analysis was a probability of F-to-enter of 0.05. Next, the second variable is selected based on the highest partial correlation. If it passes the entry criteria, it is retained in the model. Then, the first variable is examined to see whether it should be removed from the equation. A probability of F-to-remove of 0.10 is used. Variable selection stops when no more variables meet entry and removal criteria. As described earlier, two sets of independent variables were entered for each dependent variable.

6.5 OPERATIONALIZATION OF VARIABLES

Variables identified in the conceptual model are operationalized in this section. Independent variables include exposure variables as well as exogenous variables. Human response variables are dependent variables.

6.5.1 Independent variables

Exposure variables

These include thermal and air quality parameters expected to impact human responses to thermal and air quality conditions in the indoor environment. The selection of exposure parameters for this study was based on expected relationships between human responses and exposures from the literature, as well as on instrumentation available at the Indoor Environment Program at Virginia Tech to monitor exposures. Thermal parameters include dry bulb temperature, plane radiant temperature, air velocity, and relative humidity. Air quality parameters include CO_2 , particulates, and TVOCs. All the selected exposure variables and parameters can be described as interval level data.

Exogenous variables

Operational definitions for each of the variables included within the categories of exogenous factors described in the conceptual model are given below:

Responses to other physical factors: These were defined as occupant responses to physical factors other than the ones being assessed. In this case, the two other primary stressors, lighting and acoustics, were assessed in terms of acceptability. Additionally, the acceptability of personal space was assessed as an indicator of the spatial attributes of the space. These variables were assessed on a six-point acceptability scale adapted from Rohles et al. (1989), in which 1 = very unacceptable and 6 = very acceptable.

Intrinsic factors: These were defined as 'personal' factors over which individuals have little control, and which cannot readily be changed over a short period of time. For human responses related to thermal and air quality, they included: gender, age, background health status, correction lenses, smoking status, typical amount of physical work, typical consumption of tea or coffee, and alcohol. Some of the variables that require definition include the following:

Background health status This variable was intended to be a measure of susceptibility of each respondent. Respondents were asked to check one or more of ten listed health conditions. These included: headache, rash or other skin condition, chronic eye disease, chronic back pain, respiratory illness, asthma, sinusitis, cardiovascular disease, allergies and other health conditions (e.g., Hedge, 1991). The score for this variable was calculated by adding one point for each health condition checked.

Smoking status This was initially assessed in terms of four categories, namely, current smoker, occasional smoker, former smoker, and never-smoker. In the analysis, this variable was recoded as a dichotomous variable, i.e., as either 'current smoker' (= 1), or 'not a current smoker' (= 0). Hedge (1991) notes that smoking status may influence responses to SBS symptoms and comfort.

Correction lenses There is some evidence for associations between the use of correction lenses and symptoms (Hedge, 1991). This variable was also initially assessed in terms of four categories, namely, none, contact lenses, reading glasses, and other types of glasses. For the analysis, this variable was recoded as a dummy variable, i.e., as either 'none' (= 0) or 'some type of correction lenses used' (=1).

Amount of physical work This variable was intended to serve as an indicator of health condition, and was assessed in terms of respondent's estimate of the number of hours per week that they typically spend doing physical work or exercise. It was expected to influence responses to the thermal environment . This variable can be described as a measure of physical condition; i.e., the higher the amount of physical exercise a person is accustomed to, the better his or her physical condition (Folk, 1974).

Consumption of (1) tea or coffee, and (2) alcohol These variables were assessed in terms of the respondent's estimate of the number of beverages of each of these categories that they consume daily. Ingestion was expected to be a factor in thermal response (Folk, 1974).

Adaptive factors were defined as factors that were amenable to individual control by respondents to 'adapt' to the environment. For the empirical study, the following adaptive factors were assessed: exposure time, metabolic rate, clo-values and medication. These variables are defined as follows:

Exposure time This variable was assessed as the total number of minutes that the respondent reported having spent at his or her workstation until the time that he or she completed the questionnaire. This variable was expected to influence thermal responses as well as symptoms (e.g., Cone, 1991).

Metabolic rate This variable was expected to influence thermal responses (ASHRAE, 1989). It was assessed in terms of the average metabolic heat produced by the body for each respondent for two hours preceding the time that he or she completed the questionnaire. Metabolic activity was measured in terms of 'mets', where 1 met is defined as the metabolic rate of a sedentary person. The values of metabolic heat generation for various activities were taken from ASHRAE (1989a, p.8.8). Activities not listed on the chart provided therein,were matched with similar activities, and metabolic rates estimated based on the metabolic rates of the latter. As several respondents reported their activities for more or less than the two hours requested in the questionnaire, average metabolic rates were calculated for the entire time that was recorded by each respondent.

Clothing insulation This variable was expected to influence thermal responses (ASHRAE, 1989a). It was assessed in terms of clo-values based on values provided for commonly used garments in ASHRAE (1989a, p.8.11). As in the case of metabolic rates, clothing not listed on the chart provided therein was matched with similar garments and clo-values estimated based on the clo-values for the latter.

Medication Respondents were asked to report if they were taking any medication other than vitamins on the day that the test was conducted. This variable is measured as a dummy variable. i.e., as 'yes' or 'no', and was expected to influence thermal responses (Folk, 1974) as well as air quality responses, as some symptoms described as representing SBS may also result from the ingestion of medication.

Social factors These can be defined as factors in the social environment that may influence human responses to the physical indoor environment. Most of these were assessed indirectly, in terms of psycho-social factors as defined later. This approach was thought to be justified because the ultimate objective of this study is to provide guidance to designers of physical environments in terms of exposure parameters. One variable that can be described as a social factor is the type of work. This variable is assessed in terms of four five categories: managerial or administrative, professional or technical, clerical or secretarial, student, and other. This variable was not used in the analysis of the Cowgill data, as all respondents were students. For the CNS analysis, this variable was recoded in terms of four dummy variables; i.e, including all the above categories except the student category.

Psycho-environmental factors These were defined as respondent's assessment of the social environment. Ten aspects of the social environment were assessed in terms of: (1) the perceived importance of each aspect to general satisfaction with work (please see Appendix 1, Questionnaire day 1, time1, page 4 of 9), and (2) perceptions of activities carried out in the space for each aspect (please see Appendix 1, Questionnaire day 1, time 1, page 5 of 9). Each of these were assessed on five point scales and included personal control over work decisions, personal control over the physical work environment, nature of work (varying or repetitive, and boring or stimulating), clarity of job responsibilities, workload, relationship with supervisors and colleagues, opportunity for advancement in job, and the level of work related stress). For the Cowgill study, some of these were modified to better reflect that specific social environment. For instance, 'relationship with supervisors' was modified to 'relationship with instructors', and "opportunity for advancement in job' was modified to 'importance of course with respect to your future career'. These aspects of work were adapted from the questionnaire used in the EPA study (e.g., Nelson et al., 1991). A new variable, namely, social score was computed by summing the weighted scores on each aspect of work. The weights for each aspect listed above consisted of respondent's assessment of the importance of each of these aspects to general satisfaction with work. Thus, the value for the variable 'social score' was calculated by summing the product of (1) and (2) for each aspect of work.

Secular trends and risk perception Secular trends were defined as variables outside the indoor environment that may impact human response, usually consisting of short term events or long term trends. Examples of these include media coverage, scientific and technical literature or anecdotal information related to the awareness of the impacts of indoor environmental hazards on health. As these were not expected to vary over the relatively short duration of the study, they were assessed indirectly in terms of risk perception, i.e, it was expected that secular trends would influence individual perception of risk related to potential hazards in the indoor environment. Seven attributes of risk were identified from Lowrence et al. (1976) and Slovic et al. (1980) including, voluntariness of risk, immediacy of effect, precision of risk known to people exposed to the risk, precision of risk known to science, familiarity of risk, possibility of preventing the consequences of risk, and the extent that the risk affects the respondent personally. In a study conducted by Slovic et al. (1990) 110 respondents including experts, students, League of Women Voters members and business and professional members of the 'Active Club' were asked to rate 30 technologies and activities on nine qualitative characteristics that were identified as being important to judgements about the overall risk of death from each of these technologies and activities. Risk profiles were compiled for each activity or technology and compared with estimates of the risk of dying as a consequence of each. Disaster potential, dread and severity of consequences were most closely related to lay judgements of risk.

In a subsequent extended study, 90 hazards were studied and 18 risk characteristics including the 9 included in the previous study. Factor analysis was carried out to identify three factors: dread (including controllability, dread, catastrophic potential, preventive control, fatal, inequitable risks and benefits, catastrophic, threat to future generations, not easily reduced, involuntary, and affects me personally), familiarity (including not observable, unknown to those exposed, effects immediate, new (or unfamiliar), unknown to science), and number of people exposed.

For the assessment of risk perception in this dissertation, seven of these characteristics were selected based on the nature of indoor environmental hazards in buildings that are not expected to be problematic. As in the original study (Slovic et al., 1990), bipolar scales were used. In the dissertation, it was decided to identify a quantitative risk score rather than a qualitative risk profile. It was also decided that a five point rather than a seven point scale would be adequate. The selected attributes were assessed on a five point scale for mechanical systems (building systems), office equipment (processes), other occupants, and indoor furnishings. A new variable risk score was computed by summing the scores on each of the attributes for the four hazards assessed here (please see Appendix 1, Questionnaire day 1, time 1, pages 6 of 9 and 7 of 9).

6.5.2 Dependent variables

Human responses, characterized in terms of the four domains, environmental-perceptual, personal-perceptual, environmental-affective and personal-affective, constituted the dependent variables in this study. For human responses to thermal and air quality stressors, the following dependent variables were assessed:

Environmental-perceptual (EP) responses: Intensity of temperature, intensity of wetness or dryness, and intensity of odor (at the time that the questionnaire was completed, and when the respondent first entered the space). Each of these were assessed on a seven point scale. Temperature and humidity responses were recoded as 1 = very cold or very dry to 7 = very hot or very humid respectively.

Personal-perceptual (PP) responses: Intensity of temperature, intensity of wetness or dryness, and detection of symptoms. The first two were assessed on a seven point scale (also recoded as for EP responses). For the last variable, two new variables were computed, namely, general symptoms and local symptoms. Local symptoms refer to irritational effects on specific receptors in the body. A list of 24 symptoms was presented to respondents who were requested to check the symptoms that they were experiencing at the time of filling out the questionnaire. The variables were computed by summing the number of symptoms that were checked within each category. The variable 'general symptoms' includes fatigue, dizziness, aching muscles, sluggishness, lack of concentration, headache, difficulty remembering, nausea, wheezing, stuffy nose, shortness of breath, runny nose, sneezing and chest tightness. The variable 'local symptoms' includes sore eyes, tearing eyes, dry eyes, burning eyes, redness in skin, dry skin, hoarseness, coughing, dry throat, and sore throat. The list of symptoms included in the questionnaire (please see Appendix 1, Questionnaire day 1, time 1, page 3 of 9) was adapted from several questionnaires used in building evaluations (e.g., Hedge)

Environmental-affective (EA) responses include acceptability of temperature, humidity, thermal conditions, odor and air quality. Each of these are assessed on a six point scale first developed by Rohles et al (1989) where 1 = very unacceptable and 6 = very acceptable.

Personal-affective (PA) responses include thermal comfort and overall comfort. These are assessed in terms of six point scales, constructed to be similar to the environmental-affective scales used in this study where 1 = very uncomfortable and 6 = very comfortable.

6.6 SAMPLE SELECTION PROCEDURES

Spaces for the empirical study were selected from a pool of six spaces identified in consultation with the Director of Facilities Planning at Virginia Tech. Two sets of selection criteria were developed: (1) selection criteria for spaces, and (2) selection criteria for occupants. These are listed below:

Criteria for the selection of spaces

- *At least two spaces* were required, to maximize the possibility of variation in exposure parameters, based on the type of ventilation systems, orientation of the spaces, and the amount of glazing.
- Only *open plan spaces* were considered, as the nature of the study required a

minimum number of exposure sampling locations, and a large number of human responses. Open plan spaces were expected to have more homogenous conditions, permitting the acquisition of representative exposure data using fewer sampling locations. The rationale for minimizing exposure sampling locations was attributed to the need for simultaneous acquisition of exposure and human response data, and the fact that data acquisition time at each exposure sampling station ranged from 20-30 minutes. To maximize the number of observations, i.e., human responses, a large occupant group was needed.

- *Sealed buildings* (i.e., mechanically ventilated) were sought to minimize uncontrolled variability in indoor conditions resulting from unmonitored opening and closing of windows, as well as fluctuating outdoor conditions. This was determined to be a desired rather than required criterion, as it was not possible to obtain any conclusive evidence about the impacts of operability of windows on human response in the literature.

Criteria for the selection of occupants

- An *occupant population greater than 30* was required, to obtain a large number of observations.
- *At least two populations of building occupants* that were sufficiently different to maximize variability in exogenous factors.

Two buildings identified for the empirical study met the predetermined criteria. The first floor office space in the Information Systems Building (CNS), and a graduate studio space on the fourth floor of the Architecture building (Cowgill Hall) were selected. Both spaces are open plan spaces. The CNS building has 6'-0" tall partitions and individual offices as well as offices serving 2 to 5 persons. The studio space at Cowgill Hall has no partitions.

Each space has a large occupant population (55 in the CNS building, and 76 in the Cowgill studio). The external walls of the CNS buildings are fully glazed, whereas the studio space at Cowgill has a glazed area that covers roughly one third of the exterior. Both buildings are sealed buildings. Finally, occupant groups were different with respect to the type of work, the mean age, and exposure times. Occupants of the Cowgill space were expected to have less rigid breaks and more variations in exposure times as compared to the occupants at the CNS building. Of the other four spaces considered for the study, two were not sealed buildings, one space had very high partitions, and one had a small occupant population (less than 30).

6.7 DATA COLLECTION PROCEDURES

This section describes the procedures used to obtain data related to the mechanical systems in the two spaces (section 6.71), exposure data (section 6.72), and human response data (section 6.73).

6.7.1 System data

Background information related to the mechanical systems was obtained to characterize the systems. The information was used in determining exposure sampling location points as well as in the interpretation of the results of the study. The following information related to the systems was obtained from Physical Plant at Virginia Tech.

Information Systems Building (CNS) This building is served by more than 31 water source heat pumps. For the selected space, positions of thermostats are indicated on the plan in Figure 6.2. Standard panel filters with an efficiency of 30% are used. The return duct is lined. The designed percent of outdoor air was originally designed to be 13%, but actual measurements carried out by Physical Plant indicated that this was 8%. The measured supply and return air flow rates for a sample of supplies and returns and design flow rates are shown in Table 6.2. For supply numbers A to D, design flow rates are higher than measured flow rates in 10 out of 14 cases. For the perimeter supplies, 7 supplies have measured air flow rages greater than design flow rates. Except in one case (P1), measured return rates are much lower than design return rates.

Cowgill Hall The mechanical system is a Constant Air Volume (CAV) System, located centrally in the penthouse, one floor above the studio space used in this study. Locations of supply and return air devices, as well as locations of thermostats are shown in Figure 6.3. Air is first filtered through prefilters, consisting of 45 panels measuring 2'-0" x 2'-0" with 2" pleated type filters. Next, the air is passed through 4500 pounds of Purfil (odoroxidant filter). Finally, the air is passed through bag filters with 90% efficiency for atmospheric dust. The ductwork is unlined except for the rectangular ducts from mixing boxes to registers and diffusers. The outdoor air dampers are set at a position that adjusts to provide a minimum of 15% of outdoor air. The position of the damper changes with outdoor air temperature to provide upto 100% of outdoor air. Flow rates into the space selected for the study were measured using an air velocity sensor on the B&K 1213 - the MM0038 air velocity transducer and are reported in Table 6.3 (Need to determine design flow rates). Design flow rates were not available from supplies H - V and for the returns. Locations of the return and supply air devices indicated in this table are shown in Figure 6.3.

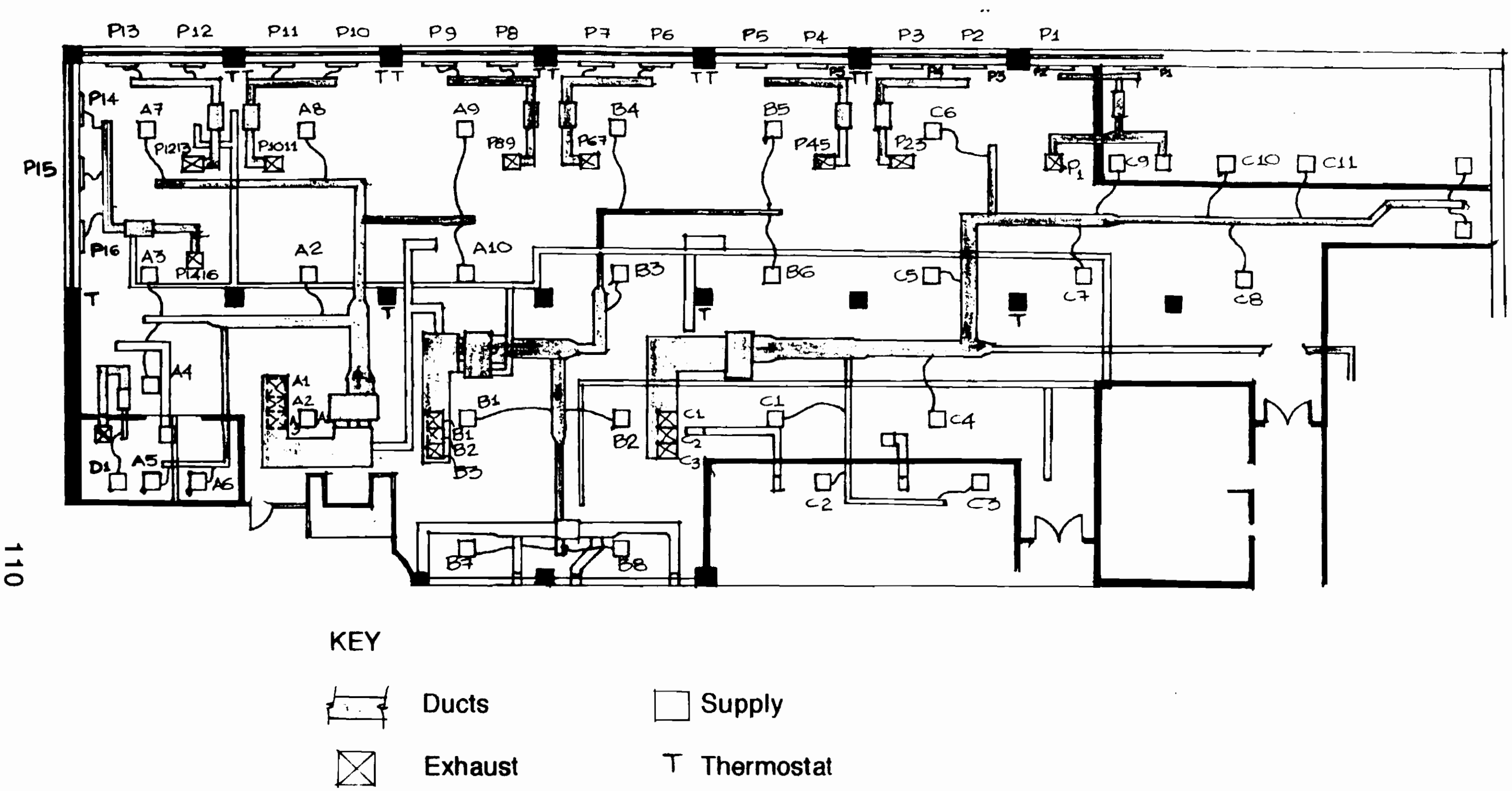


Figure 6.2 **Schematic layout of mechanical system at Information Systems Building**

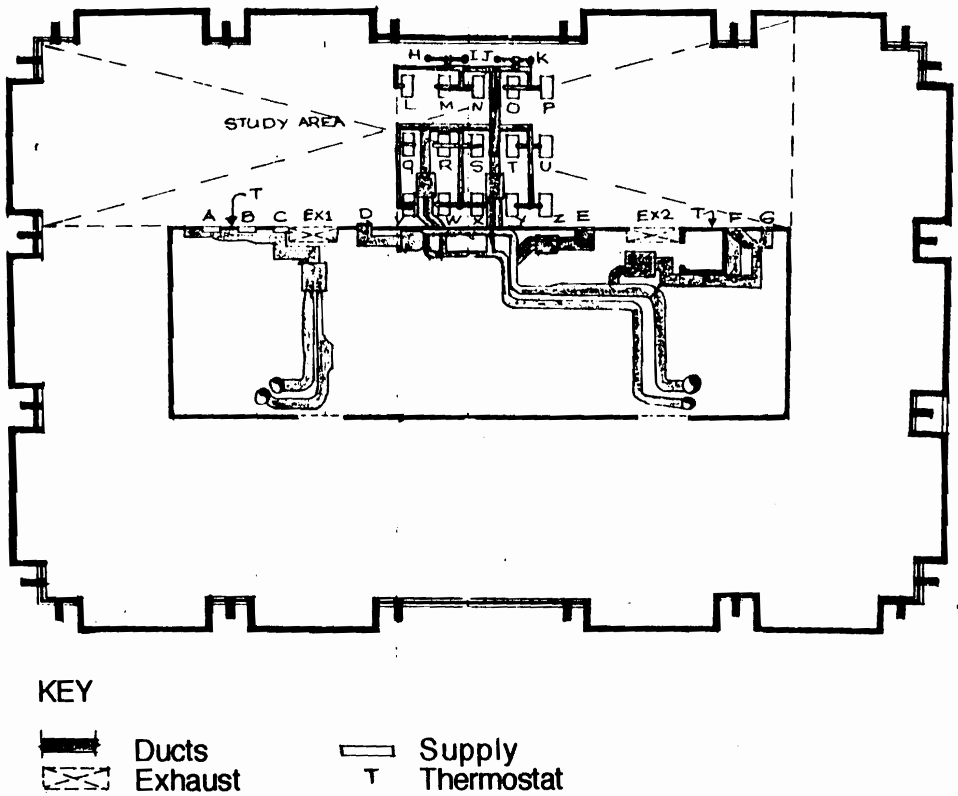


Figure 6.3 Schematic layout of mechanical system at Cowgill Hall

Table 6.2 **Information Systems Building (CNS): Comparison of measured and design air flow rates**

Supplies			Returns		
Supply #*	Air flow rate (cfm)		Return #*	Air flow rate (cfm)	
	measured	design		measured	design
A4	455	470	A1	646	1200
A7	435	470	A2	838	1200
A1	359	470	A3	822	1200
A9	509	470			
A5	113	100			
B2	521	500	B1	349	1200
B5	476	500	B2	260	1200
B4	438	500	B3	129	1200
B7	476	500			
B8	540	500			
C1	404	na	C1	1071	1200
C8	435	500	C2	807	1200
C5	518	500	C3	582	1200
D1	327	400	D1	292	400
P1	216	300	P1	305	200
P2	451	200	P23	464	600
P3	403	200	P45	507	600
P5	325	200	P67	473	600
P7	380	200	P89	558	600
P8	341	200	P1011	490	600
P10	379	200	P1213	418	600
P12	351	200	P1416	544	600
P14	265	300			
P15	247	300			
P16	193	300			

Note: * supply #s are indicated on Figure 6.2, na indicates not available.

Table 6.3 Cowgill Hall: Comparison of measured and design air flow rates

Supplies			Returns		
Supply #*	Air flow rate (cfm)		Return #*	Air flow rate (cfm)	
	measured	design		measured	design
A	378	875	1	3206	na
B	826	875	2	1750	na
C	1151	875			
D	604	875			
E	763	1165			
F	470	1165			
G	572	1165			
H	137	na			
I	176	na			
J	81	na			
K	93	na			
L	44	na			
M	49	na			
O	54	na			
R	67	na			
U	68	na			
V	34	na			

Note: * supply #s are indicated on Figure 6.3; na indicates not available.

6.7.2 Exposure data

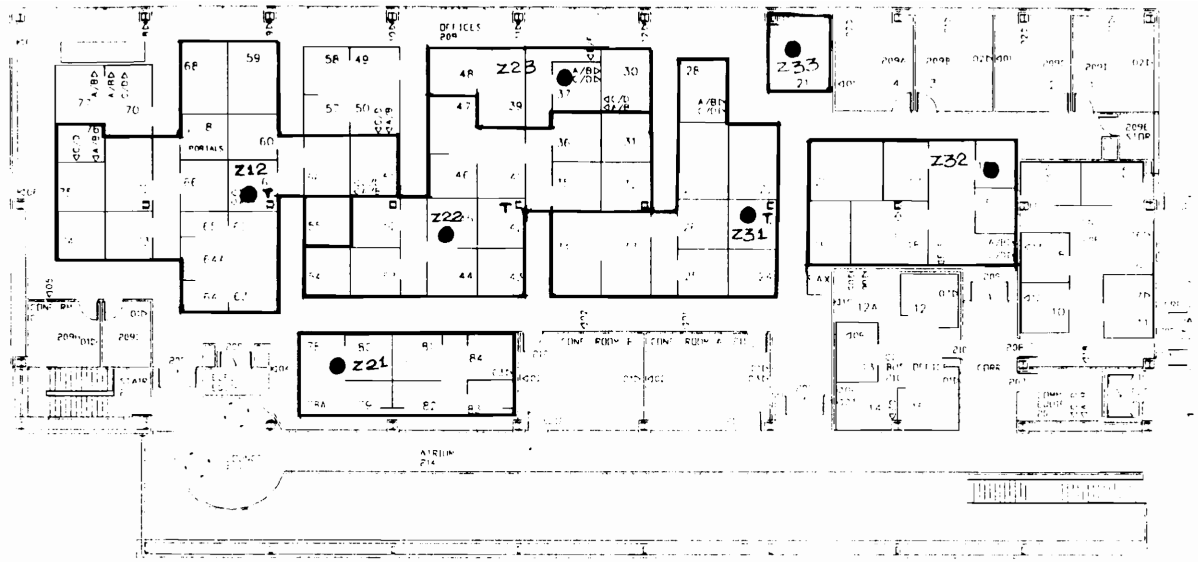
This section describes the procedures used to determine exposure sampling locations, the instrumentation used, and the procedure used to collect the data at each sampling location.

Determining exposure sampling stations

As exposure data could not practically be taken at each respondent location, it was necessary to define zones within the spaces for which representative exposure data could be obtained. Thermostatic zones were first identified, based on the layout of the mechanical systems. Then, these zones were subdivided in terms of the locations of supplies or in terms of the geometry of the space, as discussed for each of the two spaces.

Information Systems Building (CNS)

Three thermostatic zones were identified. Although the periphery of the building was served by independent heat pumps representing separate thermostatic zones, these were not considered in determining sampling locations, as they were not occupied, except in one instance. The three thermostatic zones were then subdivided into two to three subzones, based on the location of supplies and thermostats. One sampling location within each zone was selected to be the nearest occupied space to the thermostat. The other location(s) was selected to be near the supply farthest from the heat pump. The one occupied space that directly faced the perimeter of the building was sampled independently. Exposure sampling locations are shown in Figure 6.4



KEY

boundary of zone

Exposure sampling station

Z11 indicates zone 1 subzone 1

T Thermostat

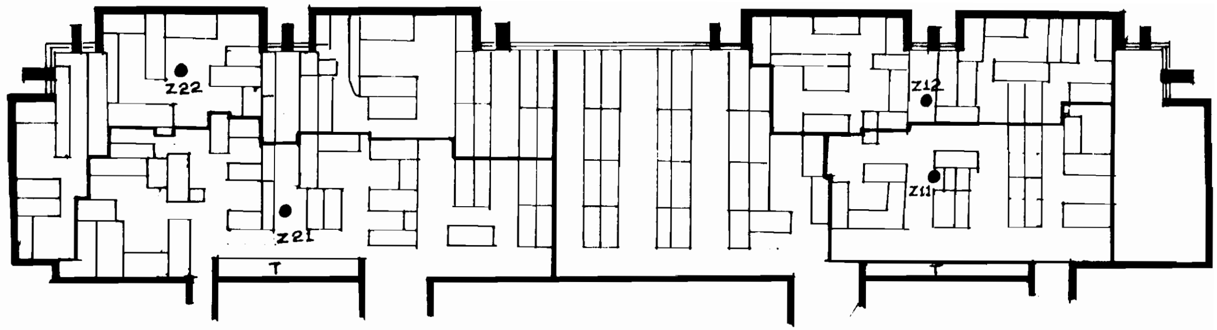
Figure 6.4 Information Systems Building: Exposure sampling zones and sampling stations

Cowgill Hall

The identification of exposure sampling points for the studio space in Cowgill was based on (1) thermostatic zones, and (2) geometry of the space in terms of interior and perimeter locations. As shown in Figure 6.5, The two zones included in the study represent two thermostatic zones. These two thermostatic zones were further subdivided into two subzones; i.e., each zone had two sampling locations. The first sampling location for each of these zones was therefore selected to be in close proximity to the respondent located nearest to the thermostat. The second sampling location for each thermostatic zone was in the portion facing the glazed area of the two zones in a location that would provide the least obstruction to the activities of the occupants. Sampling locations near glazed areas of the studio were expected to represent exposures in the perimeter areas of the studio.

Instrumentation

Instrumentation available at the Indoor Environment Program was used to obtain exposure data for this study. Dry bulb temperature, relative humidity, air velocity, and plane radiant temperature were measured using the Bruel and Kjaer Indoor Climate Analyzer Type 1213. The Air Temperature Transducer, Radiant Temperature Asymmetry Transducer, Air Velocity Transducer, and Humidity Transducer were mounted on a tripod, at a height representing that of the breathing level of a seated person. Carbon dioxide and Total Volatile Organic Compound (TVOC) measures were obtained using the Bruel and Kjaer Gas Analyzer Type 1302. The gas sampling tube was also mounted on the tripod. The data from both these instruments was saved on board a personal computer using the BK-Link Program provided by the manufacturers of the instruments. These files, saved as Text files were then converted to a spreadsheet format using the CONV.EXE



KEY

boundary of zone

Exposure sampling station

z11 indicates zone 1 subzone 1

T Thermostat

Figure 6.5 Cowgill Hall: Exposure sampling zones and sampling stations

program. These files were then imported into EXCEL for calculating average values for each of the parameters listed above. Finally, particulate concentrations were calculated using the Climet particle counter. This instrument was set to give particle concentrations every five minutes, and to compute an average after every three sets of data (i.e., every fifteen minutes). The sampling tube for this instrument was also mounted on the tripod with the other transducers. All the instruments, including the laptop computer were placed on a cart as shown in Figure 6.6. This set up provided the mobility required to transport the instrumentation from one sampling station to another.

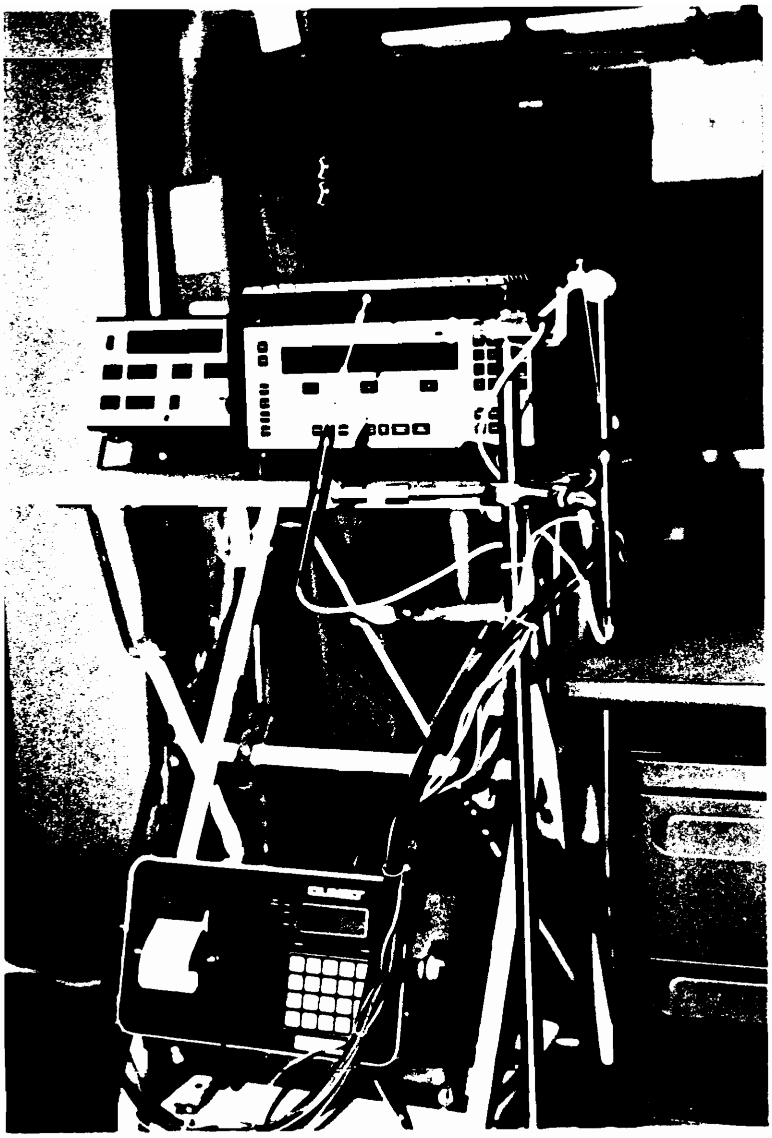


Figure 6.6 Instrumentation for exposure measures

Data acquisition procedure

The instrumentation mounted on the cart and the tripod holding the transducers was stationed at each sampling location for about twenty minutes to half an hour. Mean radiant temperature was calculated from plane radiant temperature readings using a formula prescribed in ASHRAE (1989b, p. 8.12). Mean Radiant Temperature is the temperature of an imaginary enclosure in which radiant heat transfer from the human body equals the radiant heat transfer in the actual nonuniform enclosure (ASHRAE, 1989b, p.8.12). The plane radiant temperature, on the other hand, is the uniform temperature of an enclosure in which the incident radiant flux on one side of a small plane element is the same as that in the actual environment (ASHRAE, 1989b, p.8.13). The mean radiant temperature is preferred over plane radiant temperature, as the former describes the thermal radiation for the human body from all directions. To calculate this parameter, plane temperature readings had to be obtained in three different positions of the transducer. For ease of data collection, plane radiant temperature readings in one position only were obtained at intervals of 30 seconds until four data values were obtained. Then the entire set of exposure data were taken after rotating the plane radiant temperature transducer through 90^{o} . The entire set of parameters were then measured for about 10 minutes at intervals of 10 seconds. Finally, plane temperature readings were taken in the up-down position at 30 second intervals till four values were obtained. The gas analyzer and particle counter were run simultaneously with the Indoor Climate Analyzer. For the particle counter, printed values were obtained at five minute intervals, and an average set of values was obtained at the end of fifteen minutes. For the gas analyzer, data were obtained for intervals of 1.5 minutes for a period of 15 minutes. The actual time for data collection was, thus, limited to 15-20 minutes. After accounting for initial setting-up time and moving between stations, the data collection procedure was designed to take 30 minutes at each station.

Instrumentation was set up at locations that were not likely to disrupt occupants' work. However, respondents whose office spaces were selected as exposure sampling locations were briefed before the actual study about possible intrusions in their work spaces.

6.7.3 Human response data

Human response data were collected from all occupants of the spaces selected for the study, who consented to participate in the study. This section first describes the issues considered in the development of the instrument for assessing human response, namely, the questionnaires. Then, procedures for: (1) obtaining the informed consent of occupants, (2) pretesting of the instrument for data collection (i.e., the questionnaire), and (3) administration of the questionnaires to respondents in the actual study are described.

Questionnaire design

Human responses and exogenous variables were assessed by means of questionnaires administered to participants of the study. As data were taken twice a day on two days, each respondent completed four questionnaires. The four questionnaires used for acquiring human response data at CNS are included in Appendix 1. The primary criteria for the design of the questionnaire included: (1) reducing the possibility of recall of questionnaire items and responses, both within and between questionnaires, (2) minimizing the response time per questionnaire to 10 minutes, and (3) Developing comparable scales for the assessment of perceptual responses, and affective responses.

This section describes the rationale for (1) question order, and (2) the development of rating scales for human response assessment.

Question order

Some questionnaire items were repeated in all four questionnaires (please refer to Appendix 1). These include human responses, expressed in terms of four domains of human response for thermal and air quality conditions in the indoor space, and some exogenous factors. It was expected that responses on questionnaire items would be influenced by preceding items in the same questionnaire as well as by items repeated from earlier questions. To minimize the possibility of recall of questionnaire items and responses, respondents were instructed to complete the items in the order that they were presented to them. The questionnaires were developed to alternate questionnaire items that were expected to be related in the minds of the respondent with other items that were not closely related. For example, as it was expected that response to the item on overall comfort would be influenced by responses to other items, it was the first item in the questionnaire. Affective responses were alternated with less directly related perceptual responses. As it was expected that environmental-perceptual responses would be related to the two personal-perceptual responses: intensity of temperature and humidity, these were separated by a series of items that required respondents to concentrate on a checklist of symptoms. Acceptability responses were requested for a variety of factors, arranged in random order. Finally, the item on thermal comfort was located on a separate page in the questionnaire.

Psycho-social factors were assessed only once in the series of four questionnaires, as were several background questions to reduce response time for each questionnaire. The two sets of questions for assessing psychosocial factors were separated by a questionnaire item and located on two separate sheets, to reduce the possibility of a response set. The questionnaire item on risk perception was included in the first and last questionnaire, as it was expected that the focus on indoor environmental factors was likely to influence risk perception. Some background questions such as medication, health status on test day, correction lenses, and clothing insulation levels were included in one of the two questionnaires administered per test day. Finally, metabolic activity was assessed in each questionnaire.

Development of scales to assess human responses

Numerical rating scales were used to assess human responses. Graphical scales were also considered. However, as there was not enough information in the existing literature, about the influence of different lengths, and visual properties of such scales on the human responses assessed in this study, numerical scales were preferred. Although numerical scales can be constructed without the use of numbers, it is suggested by Guilford (1954) that attaching numbers may have the effect of achieving greater equality of psychological intervals between categories. The number of steps for the scales ranged from 1 to 7 for perceptual scales, and 1 to 6 for affective scales. The use of negative numbers was avoided, as it may have suggested a break in the scale, thus implying non-continuity. Guilford (1945) also suggests that the use of negative numbers may be confusing to some respondents.

The number of steps in a rating scale may vary from three to ten (Oppenheim, 1966). Decisions about the number of steps used in each rating scale were based on Conklin's recommendation (reported in Guilford, 1945), that the maximum number of steps for a bipolar scale should be nine, and on Symond's finding that seven steps is optimal, based on inter-rater correlations (also reported in Guilford, 1945). Additionally, the thermal sensation scale, widely used in studies assessing thermal environments is a seven point scale. A neutral category was considered to be appropriate for perceptual responses (i.e., a person may feel thermally neutral). Hence, an odd number of steps was acceptable. An even number of steps was used for affective responses, to reduce the number of non-committal responses, thereby forcing respondents to respond on either side of the scale.

Human subjects review procedure and informed consent

The protocol for the empirical study was submitted for review by the Institutional Review Board of Virginia Tech. The project was listed as imposing minimal risk to the participants of the study, and was approved for exemption by the Board. Following this approval, informed consent forms were circulated to the occupants of both buildings. One person, assigned as the coordinator for the study, by the director of the office space at the Information Systems Building, accompanied the researcher to each of the individual office spaces. In the Cowgill studio, the instructor for the scheduled studio class, occupying one half of the study space introduced the researcher and encouraged students to participate. For the other half of the studio, occupants were approached individually by the investigator. In all cases, occupants' questions about the study were addressed, and the signed consent forms collected before the study. For those occupants who could not be approached before the study, consent forms were made available on test days, if they wished to participate in the study. The informed consent form used for CNS is included in Appendix 2.

Pretesting questionnaires

The objectives of the pretest were: (1) to determine whether the respondents selected for this study were able to understand and respond to each item in the questionnaire, and (2) to determine the average completion time for the questionnaire.

The first pretest questionnaire (see Appendix 3) consisted of a compilation of items from the four questionnaires developed for the actual study. Additionally, five items on page 11 of the questionnaire asked for pretest respondents' assessment of the questionnaire.

Selection of pretest respondents

The major criteria for selection of pretest respondents were:

(1) Pretest respondents should be representative of respondents in the actual study, and

(2) Actual study respondents should not be included in the pretest, or be able to communicate with pretest respondents.

As the actual study consisted of two sets of respondents, namely, office workers and students working in an architecture studio, the pretest was conducted first on a sample of 8 office workers and 12 students. Changes made to the questionnaire were then pretested on a smaller group of respondents: 2 office workers and 3 students. The initial pretest respondents included office workers from the Sponsored Research Program office at Virginia Tech, and architecture students working in a separate building from the actual study respondents. The pretest respondents for the revised questionnaire included two office workers from the department of Urban Affairs and Planning, and students from the same studio as the initial pretest.

The pretest respondents were expected to be representative of the actual study population. The office workers in the pretest and the actual study engaged in a broad range of activities, and included secretarial and clerical staff as well as professional and administrative personnel. As the actual study respondents were architecture students, the pretests were also conducted on a sample of architecture students. As the focus of this study was on human responses to the physical environment, it was expected that knowledge related to physical environmental stressors would be an important factor in the responses. Care was taken to ensure that pretest respondents did not communicate with actual study respondents. Architecture students for the pretest were located in a separate building from the actual study respondents. Office workers for the pretest and actual study were also vastly different with respect to their location and the departments in which they worked.

Data collection procedures

The initial pretest for office workers was conducted by seeking permission from the Head of the Institutional Review Board at the office of Sponsored Programs to use volunteers from that department for the pretest. Permission could not be obtained to conduct the pretest in another department, initially identified for the pretest. An internal memo was circulated within the Office of Sponsored Programs to identify volunteers for the pretest. The questionnaires were administered to the volunteers. They were given about half an hour to complete the questionnaire. After the questionnaires were collected, they were scanned for unexpected responses and comments on the questionnaires by the respondents. Clarifications were sought, where needed, from the respondents. All respondents were asked one question, namely, "What does the term 'thermal' mean to you?". This question was asked to determine the determinants of thermal comfort (e.g., temperature, humidity and air movement).

The initial pretest questionnaires for students were administered by an instructor for the studio to volunteers. They were collected during the next studio session. The procedure for interviewing each respondent was the same as that described in the preceding paragraph. After the initial questionnaires were analyzed, and modifications made, respondents were approached directly by the researcher. The same procedures as the initial pretest were followed for the second pretest.

Data analysis and results of pretest

This section describes the method of analysis used to address each objective of the pretest and the resulting recommendations for improvement of the questionnaires. Modifications made after the initial pretest were further tested with a smaller sample. It was found in the second stage of the pretest that the revised items in the questionnaire were appropriate for the target respondent group.

Objective 1 To determine whether the respondents selected for this study were able to understand and respond to each item in the questionnaire.

Non-responses to each item in the questionnaire were identified. One student volunteer did not return the questionnaire, and could not be identified. One office worker volunteer did not respond to the questions on 'acceptability' on indoor environmental factors. It was not possible to get a follow-up interview with this respondent.

In addition to non-responses, respondents' evaluations of the questionnaire were examined to identify items that required modification. Respondents' comments are included in Appendix 4. The first two items in the evaluation are summarized as follows:

- Items related to the assessment of work: One person noted that it was necessary to read the instructions for this section twice before responding to them. Two items in this section were identified by one respondent each as being difficult to understand. These included: 'definition of job responsibilities' and 'importance of course with respect to future'. As none of the other respondents reported difficulty with the items, they were retained in the final questionnaire. A further examination of this section revealed the possibility of getting a 'response set' - people consistently rating an item as high or low on two attributes (i.e., importance of item and assessment of item in this case). This item was therefore modified in the second stage of the pretest by splitting it into two items (see corresponding items in the questionnaire for Day 1, Time 1 in Appendix 1).

- The other section that was identified as being difficult to understand and respond to was the section on risk perception.
  - Four persons reported that it was difficult to understand that the risk item on 'other occupants' required a judgement on whether other occupants were a health risk. Three of these respondents, did, however, indicate in their responses that this was a risk. The question was modified in the actual study as "other occupants (e.g., other persons who occupy the space)" to clarify this item.
  - Two respondents expressed a concern that they may not have been qualified to respond to the questions on 'precision' of risk. During the interview, it was suggested that rephrasing the instructions for the item to stress that 'perceptions' rather than factual information was being sought would clarify this item. The item was modified in the second stage of the pretest and retained for the final questionnaire (Appendix 1, questionnaire for Day 1, Time 1).

- One occupant did not respond to each column of the risk perception questions. She indicated that it would help to make the instructions more explicit. In the second stage of the pretest, instructions were modified to include the name of the column that the respondent was expected to address next.

- Two respondents noted that they had difficulty finding appropriate categories to mark with respect to clothing levels. One respondent also indicated this difficulty during the interview. In the actual study, each of the subcategories in this section include an 'other' category. The clo-values were calculated by allocating a value for these items based on judgement.

- Five respondents reported that the section on 'occupancy profile' was confusing. To reduce the complexity of this item, and to reduce recall errors, this item was restructured to ask for occupant activity profiles for two hours preceding the time that they responded to the questionnaires. This item was pretested in the second pretest. Two respondents noted that they had difficulty responding to the question on the total number of hours spent at workstation. This question was revised in the actual study to clarify this item.

Objective 2 To determine the average completion time for the questionnaire.

The average response time for the questionnaire was 19.88 minutes with a standard deviation of 5.71. The mode value was 15 minutes. The highest response time, reported by two respondents, was 30 minutes. One respondent recorded a response time of 10 minutes, the lowest for the sample of pretest respondents. It was concluded that in the actual study, the response time would average about 10 to 15 minutes, as each questionnaire was only a part of the entire pretest questionnaire. This is consistent with the criterion for minimizing response time, used in the development of the questionnaire.

Conclusions

The pretest results demonstrated that the respondents for this study could be expected to understand and respond to each item in the questionnaires. The average completion time determined from the pretest met the goal of minimizing response time for the actual study.

CHAPTER 7

RESULTS AND DISCUSSION

7.1 INTRODUCTION

This chapter presents the results of the empirical study described in chapter 6. First, Section 7.2 reports on the response rates for each of the tests in the two buildings. The possibility of bias in the data is discussed in this section. Section 7.3 describes measured data for human response, exposure, and exogenous variables. The primary objective of this section is to do an overall assessment of the ranges of values for each variable, and to make some inferences about possible building performance, to aid in the interpretation of the results of the regression analysis. Section 7.3.1 is a discussion of the measured data for the Information Systems Building (CNS). Section 7.3.2 is a discussion of the measured data for Cowgill Hall. Section 7.3.3 is a comparison of the two indoor spaces. Section 7.4 reports on the results of the regression analysis. Expected and unexpected results are identified and discussed in sections 7.4.1 for CNS and 7.4.2 for Cowgill Hall. Results for the two spaces are compared in Section 7.4.3. Finally, Section 7.5 consists of overall conclusions reached by the study in terms of the conceptual model.

7.2 RESPONSE RATES AND SAMPLE SIZES FOR EXPOSURES

The office space in the Information Systems Building was occupied by 55 persons. Four of these occupants declined to participate in the study. On each test day, however, it was not possible to get responses from all the occupants. Some of the occupants spent much of their time in the field. Others were, at different times, involved in conferences or meetings away from their desk. Response rates for the four sets of human response data were 64%(35 respondents), 71% (39 respondents), 69% (38 respondents), and 60% (33 respondents). The average response rate was 66%. Except for one section of the office which included field engineers who spent most of the day away from the office, failure to respond was not expected to be attributable to specific occupant characteristics. As a special effort was made in the scheduling of questionnaire administration to accommodate for the inclusion of field engineers in the study, it is concluded that the data obtained from this building is not likely to be biased.

The studio space at Cowgill Hall that was included in the study was occupied by 76 persons. Three persons declined to participate. However, thirteen did not respond to the informed consent; i.e., they could not be contacted. As these occupants could not be contacted on either of the test days as well, it was concluded that they may not have been regular occupants of that space during the time of day during which the tests were conducted. For the first day, the morning and afternoon response rates were 45% (34 respondents) and 42% (32 respondents) respectively. On the second day of testing, only two zones could be assessed, as the occupants of the other two zones were in a lecture room during that time. For the second day, based on an occupancy of 50 persons for two zones, the response rates for the morning and afternoon respectively were: 40% (20 respondents) and 30% (15 respondents). The generally low response rates at Cowgill were attributed to the informal nature of the studios, and varied work schedules of the students. The further drop in response rates for the second test day were attributed to the nearness of exams and project deadlines. It was concluded for this space that it was not possible to assess for bias by comparing occupant characteristics of respondents and non-respondents.

7.3 MEASURED DATA

Measured data obtained in the empirical study is presented in terms of frequency distributions, means and standard deviations for variables assessed in the study. Frequency distributions are presented in Appendix 5 for dependent variables, and exogenous factors. Means, standard deviations and sample size are presented for each of the four sets of data taken in the two buildings (i.e., morning and afternoon on two days in each of the two buildings). Table 7.1 describes the data obtained at the Information Systems Building and Table 7.2 describes the data for Cowgill Hall. The purpose of taking four sets of data, as described in section 6.4, was to increase variability in the independent variables. The means and standard deviations in the Tables 7.1 and 7.2 provide some indication of the variability in the independent variables for the four data sets in each building. This information is used in the interpretation of the results of the regression analysis presented in Section 7.4. The measured data for exposure variables are also examined with respect to the standards to assess if criteria specified in the standards were being met.

7.3.1 Frequency distributions: Information Systems Building

Because of the large sample size of the data, percent frequency distributions were plotted to assess the reasonableness of the data for the selected environment and occupant group. Frequency distributions for dependent variables and exogenous variables that were not dichotomous were plotted for the data obtained at the Information Systems Building (please see Appendix 5). Frequency distributions for exposures were not done because the ranges of values and sample sizes were small. The distributions for the dependent variables were approximately normal for temperature (E-P and P-P), humidity (E-P and P-P), acceptability (temperature, humidity, air quality, overall conditions, thermal comfort, and general comfort). Distributions of the perceptual responses for temperature and humidity are reasonable because the range of temperature in the space was expected to yield a human response close to the central portion of the scale (i.e., neutral). Also, the scales are bipolar; i.e., the sensory receptors can sense warm as well as cool conditions, and dry as well as wet conditions. Conditions in the space were not expected to deviate substantially from acceptable limits in a building such as this, without known problems. Some skewness towards the higher portion of the range reflects the forced bias introduced in the acceptability scale (Rohles et al., 1971). Some skewness is seen in the distributions of odor intensity, general and local symptoms, and acceptability of odor. The distribution of the responses to odor intensity were skewed as expected to the lower part of the range (i.e., little or no odor), as there was no obvious odor in the space. In a building which is not expected to be problematic, odor can be expected to exist below threshold. Consequently, more normal distributions could be expected in a problematic buildings in which occupants complaint of odors. As a result of the perceptual response for odor, odor acceptability was also skewed towards the high end of the scale. The low number of symptoms reported is also expected in buildings such as this one that are not suspected to be problematic. Conversely, an exceptionally poor environment can be expected to yield a more normal distribution of symptom score.

Distributions for the exogenous variables (independent variables) are approximately normal for the variables: other physical factors (acoustics, lighting, and personal space), clothing insulation values, metabolic rates and age. As in the case of the acceptability responses described above, acceptability of lighting, acoustics and personal space can also be reasonably expected to follow roughly normal distributions, with slight biases toward the higher end of the scales in environments without known problems. Clothing insulation values and metabolic rates reported most frequently compare well with the values defined in the standards as representing typical clothing levels (0.6 CLO) and metabolic rates (1.2 MET) for office workers (ASHRAE, 1992). Skewness is seen in the distributions of the following variables: physical work, tea and coffee consumption, exposure time, health status, social score, and risk score. Skewness in the variables 'physical work', 'health status', and 'tea and coffee consumption' may be attributed to similarity in occupant characteristics for this group of occupants. Skewness for the variable 'exposure time' is a function of the design of the study; more respondents were present at the beginning of the day. The distribution of the variable 'social score' is skewed to the left, as expected in a building without known problems. The distribution of the variable 'risk score' shows a flat profile and indicates wide variation in the perception of risk by the occupants.

7.3.2 Means and standard deviations: Information Systems Building

Exposure variables

As seen in Table 7.1, operative temperature in the Information Systems Building (CNS) was fairly uniform for all four sets of data. Based on ASHRAE standard 55 (1981R), the range of acceptable operative temperature in winter conditions is 20^{o} to 23^{o} C. The mean temperatures deviated slightly from this range, but were within the range for summer conditions (23^{o} to 26^{o} C). However, the Clo-values for the data in this empirical study were in the range of 0.37 to 0.95, whereas typical winter clo-rates assumed in prescribing operative temperatures for winter conditions are 0.8 to 1.2 Clo (ASHRAE, 1991). Therefore the measured temperature may be considered to be within the recommended range.

Relative humidity for all four sets of data was in the lower part of the range . The lowest value was 21% which is below the minimum prescribed level, and the highest values was 41.98% which is within the specified range, but at the lower bounds of this range. On the first day, the mean values for the morning and afternoon data were below the lower range of 30% as indicated in the standards (ASHRAE 55-1981R and ASHRAE 62-1989).

Air velocity was below the upper limit of 0.8 m/s as specified in ASHRAE 55 (1981R). Carbon dioxide levels were also within the acceptable range (i.e., not greater than 1800 mg/m^3 as specified in ASHRAE 62-1989). However, the mean values obtained in the afternoons were greater than those obtained in the morning on both days. This is expected, as carbon dioxide is generated by occupants in the space (ASHRAE, 1989a).

Table 7.1 Measured data for four tests: Information Systems Building

7.1a Independent variables: Exposure variables

Exposure variables	**Means, standard deviations, and sample size for exposure variables**			
	Day 1, Time 1	**Day 1, Time 2**	**Day 2, Time 1**	**Day 2, Time 2**
Operative temperature (ºC)	23.39 ± 0.78* 8	24.05 ±0.76 8	23.65 ± 0.71 8	23.85 ± 0.68 8
Relative humidity (%)	25.13 ± 3.18 8	27.34 ± 0.98 8	39.45 ± 1.81 8	38.78 ± 1.60 8
Air velocity (m/s)	0.11 ± 0.03 8	0.10 ± 0.03 8	0.11 ± 0.02 8	0.10 ± 0.02 8
Carbon dioxide (mg/m^3)	1082 ± 75. 8	1415 ± 74 8	1186 ± 151 8	1425 ± 73 8
TVOC (mg/m^3)	3.66± 0.67 8	4.16 ± 0.66 8	3.49 ± 0.90 8	4.05 ± 0.91 8
Particulates** (μg/m^3)	0.021 ± 0.006 8	0.023 ± 0.011 8	0.017 ± 0.005 8	0.024± 0.015 8

Note: * The values indicated represent: mean value ± standard deviation
Sample size
** The accuracy of these measures may be questionable, but the precision is expected to be valid

7.1b Independent variables: Exogenous variables

Exogenous variables	Means and standard deviations, or percentages			
	Day 1, Time 1	Day 1, Time 2	Day 2, Time 1	Day 2, Time 2
Other physical				
Accept Acoustics (scale)	3.79 ± 1.15 34	4.00 ± 1.08 39	3.71 ± 1.16 38	3.91 ± 1.07 33
Accept Lighting (scale)	4.14 ± 1.03 35	4.10 ± 1.07 39	3.95 ± 1.16 38	4.27 ± 0.98 33
Accept Personal space (scale)	4.06 ± 1.24 35	4.13 ± 1.03 39	4.08 ± 1.24 38	4.27 ± 1.07 33
Intrinsic				
Age (years)	36.92 ± 7.92 37	39.95 ± 8.92 38	36.38 ± 9.22 37	36.38 ± 9.05 32
Gender (male) ***	73% 37	74% 38	70% 37	75% 32
Smoking status (smoker)***	8% 37	8% 38	8% 37	10% 32
Physical work (hours per week)	12.71 ± 13.57 35	11.17 ± 11.93 36	10.75 ± 11.79 36	11.50 ± 12.29 32
Alcohol (daily consumption)***	26% 35	25% 36	20% 35	19% 31
Tea, coffee (# of bevs. per day)	2.75 ± 4.15 36	2.65 ± 4.12 37	2.50 ± 4.16 36	2.75 ± 4.36 32
Correction lenses (some type of lenses)***	24% 37	26% 38	24% 38	22% 32
Health status (# of health conditions)	1.24 ± 1.16 37	1.21 ± 1.17 38	1.03 ± 0.89 38	1.06 ± 0.95 32
Adaptive				
Medication ('yes')***	24% 37	26% 38	42% 36	40% 30
Exposure time (minutes)	62.66 ± 63.28 35	281.62 ± 124.47 37	75.89 ± 46.93 37	222.33 ± 118.02 33
Metabolic rate (mets)	1.25 ± 0.34 36	1.19 ± 0.23 36	1.22 ± 0.35 36	1.20 ± 0.37 33
Clothing insulation (Clo)	0.58 ± 0.12 33	0.59 ± 0.13 38	0.63 ± 0.14 37	0.63 ± 0.15 32

Table 7.1b
(continued)

Exogenous variables	Means, standard deviations, and sample size			
	Day 1, Time 1	Day 1, Time 2	Day 2, Time 1	Day 2, Time 2
Social				
Social score (score)	143.40 ± 28.55 30	143.45 ± 28.17 31	146.65 ± 31.63 31	142.78 ± 30.93 27
Administrative work***	27% 37	24% 38	27% 37	28% 32
Professional work***	49% 37	53% 38	54% 37	54% 32
Secretarial work***	19% 37	16% 38	16% 37	16% 32
Other work***	5% 37	5% 38	3% 37	3% 32
Risk perception				
Risk score (score)	45.41 ± 29.78 34	43.56 ± 29.40 36	35.10 ± 28.55 30	33.97 ± 28.77 31

Notes: *** For dummy variables, percentage of respondents rather than means and standard deviations are presented

Table 7.1c Dependent variables: Human response

Human responses	Means, standard deviations, and sample size			
	Day 1, Time 1	Day 1, Time 2	Day 2, Time 1	Day 2, Time 2
Environmental-Perceptual				
Intensity of temperature ****	4.31 ± 0.86 36	4.46 ± 0.97 39	4.40 ± 0.92 38	4.61 ± 0.75 33
Intensity of humidity	3.00 ± 0.86 36	3.15 ± 0.93 39	2.90 ± 0.95 38	3.03 ± 0.92 33
Intensity of odor (present)	1.56 ± 1.11 36	1.67 ± 1.03 39	1.47 ± 0.69 38	1.58 ± 0.90 33
Intensity of odor (on entry)	1.50 ± 1.08 36	1.68 ± 1.17 38	1.58 ± 0.92 38	1.52 ± 0.87 33
Personal-Perceptual				
Intensity of temperature	4.33 ±0.79 36	4.51 ± 1.00 39	4.40 ± 0.89 38	4.58 ± 0.79 33
Intensity of humidity	3.28 ± 0.78 36	3.31 ± 0.92 39	3.26 ± 1.18 38	3.12 ± 0.96 33
General symptoms (# of symptoms)	1.33 ± 1.64 36	1.59 ± 2.04 39	1.50 ± 1.80 38	1.21 ± 1.39 33
Local symptoms (# of symptoms)	1.11 ± 1.30 36	1.62 ± 1.27 39	1.34 ± 1.24 38	1.46 ± 1.23 33
Environmental-affective				
Acceptability of temperature	4.31 ± 1.05 35	3.69 ± 1.15 39	4.11 ± 1.13 38	4.12 ± 1.08 33
Acceptability of humidity	3.94 ± 1.21 35	3.85 ± 1.31 39	3.42 ± 1.24 38	3.76 ± 1.00 33
Acceptability of thermal conditions	4.29 ± 0.89 35	3.87 ± 1.07 38	3.90 ± 1.11 38	4.12 ± 1.14 33
Acceptability of odor	4.86 ± 0.77 35	4.80 ± 0.83 39	4.63 ± 1.03 38	4.61 ± 0.79 33
Acceptability of air quality	3.83 ± 1.10 35	3.77 ± 1.18 39	3.61 ± 1.26 38	3.91 ± 1.07 33
Acceptability of overall conditions	3.97 ± 1.07 35	3.90 ± 0.98 38	3.68 ± 1.09 38	4.03 ± 0.85 33

Table 7.1c
continued

Human responses	**Means, standard deviations, and sample size for human response variables**			
	Day 1, Time 1	**Day 1, Time 2**	**Day 2, Time 1**	**Day 2, Time 2**
Personal-affective				
Thermal comfort	4.06 ± 0.98 36	3.72 ± 0.94 39	4.11 ± 1.11 38	4.03 ± 1.01 33
General comfort	4.19 ± 1.28 36	3.80 ± 1.08 39	3.95 ± 1.21 38	3.91 ± 0.96 32

Notes: **** where units are not specified, they are rating scales: seven point scales for perceptual responses, and six point scales for affective responses.

The mean concentrations of volatile organic compounds, measured in terms of TVOCs exceeded the 3 mg/m^3 value which is described by Molhave (1991) as the range of discomfort. As the range of discomfort is from 3 to 25 mg/m^3, concentrations obtained in this study can be described as being marginally in the discomfort range. As in the case of carbon dioxide, TVOC concentrations were also observed to have increased during the latter part of the day. Finally, concentrations of particulates were also well within the acceptable range. The maximum allowable concentration of particulates is 50 μg/m^3. However, it is suspected that there may have been an accuracy error in the particulate data resulting from instrument error. Even so, for the purpose of regression analysis, the values are considered to be acceptable, as it is variation between values that is considered rather than absolute values. Concentrations of particulates were also observed to have increased during the latter part of the day.

Exogenous variables

Differences in mean values for exogenous variables were observed for some variables. Acceptability of acoustics was observed to be higher in the afternoons. This may be explained by the possibility that conversations between occupants are more likely to occur during the morning, when occupants first enter the space. More occupants reported taking medication on the second day. Mean clothing insulation values were also higher on the second day. This may be attributed to cooler outdoor temperatures on that day. Risk perception scores were lower on the second day. Risk perception was assessed twice, once in the first questionnaire, and once in the fourth questionnaire. It is possible that the process of testing resulted in altering the occupant's perception of risk related to the indoor environment. As the standard deviation of the risk score was large compared to the mean (e.g., a coefficient of variation of 0.66 = standard deviation / mean), it is also concluded that there was a large variation in the perception of risk among the occupants. The social score variable, however, had a smaller standard deviation compared to the mean (e.g., coefficient of variation = 0.20), suggesting that the social environment was perceived fairly uniformly by occupants of the space. Other observations about the exogenous variables include the low proportion of smokers in the occupant population in this building compared to the national estimate of the proportion of smokers in the US population (26%) in 1990 (CDC, 1992). Additionally, the majority of building occupants were men.

Dependent variables

The dependent variables in this study, i.e., human responses were fairly constant over the four data sets. The intensity of humidity variables (E-P and P-P) did not vary in spite of the variation in relative humidity between the two days. It is possible that the range of variation may not have been physiologically significant. Alternatively, other factors such as clothing may have modified the influence of relative humidity on these responses. The number of symptoms described as local symptoms were observed to have increased during the latter part of the day on each of the test days. Both local symptoms and general symptoms had large standard deviations compared to the mean (e.g., coefficient of variation = 1.23 for general symptoms, and 1.17 for local symptoms), indicating large variation among the number of symptoms experienced by occupants.

7.3.3 Means and standard deviations: Cowgill Hall

Exposure variables

As seen in Table 7.2, operative temperatures were fairly constant over the four sets of data, and were marginally lower than values obtained at CNS. Mean values for air velocity and carbon dioxide were also fairly stable. Relative humidity on the second day was lower than that on the first day. Concentrations of TVOCs increased marginally during the latter part of the day on both test days. Particulate concentrations were higher on the first test day. The smaller range of variation in concentrations as compared to the CNS data may be attributed to the small interval of time between exposure measurements on each test day.

Exogenous variables

Observations of the data obtained at Cowgill Hall were fairly consistent with observations made about the data obtained at the CNS building. Acceptability of acoustics appeared to be higher for the second set of data on each day. As described earlier, the two sets of data on a single day were taken within 1:00 pm. to 5:00 pm. The proportion of occupants taking some medication is higher on the second day. The standard deviation for the variable 'social score' was fairly low compared to the mean (e.g., coefficient of variation = 0.14), as in the case of CNS, indicating that there was homogeneity among the occupants with respect to their perception of the social environment. Also, like the CNS data, the standard deviation for the variable 'risk score' was observed to be high compared to the mean (e.g., coefficient of variation = 0.88), indicating large variation in occupant

Table 7.2 Measured data for four tests: Cowgill Hall

7.2a Independent variables: Exposure variables

Exposure variables	Means, standard deviations, and sample size for exposure variables			
	Day 1, Time 1	Day 1, Time 2	Day 2, Time 1	Day 2, Time 2
Operative temperature (ºC)	23.64 ± 0.35* 4	23.68±0.32 4	22.88 ± 0.29 2	23.13 ± 0.09 2
Relative humidity (%)	38.93 ± 0.12 4	37.28 ± 0.91 4	16.40 ± 0.92 2	14.50 ± 0.71 2
Air velocity (m/s)	0.11 ± 0.01 4	0.12 ± 0.02 4	0.12 ± 0.04 2	0.12 ± 0.04 2
Carbon dioxide (mg/m^3)	985 ± 95 4	998 ± 66 4	932 ± 17 2	888 ± 9 2
TVOC (mg/m^3)	0.25± 0.79 4	1.93 ± 0.30 4	0.23 ± 0.46 2	0.50 ± 0.30 2
Particulates** ($\mu g/m^3$)	0.10 ± 0.04 4	0.14 ± 0.12 4	0.03 ± 0.01 2	0.019 ± 0.003 2

Note: * The values indicated represent: mean value ± standard deviation
Sample size

** The accuracy of these measures may be questionable, but the precision is expected to be valid.

7.2b Independent variables: Exogenous variables

Exogenous variables	Means and standard deviations or percentages			
	Day 1, Time 1	Day 1, Time 2	Day 2, Time 1	Day 2, Time 2
Other physical				
Accept Acoustics (scale)	3.15 ± 1.06 33	3.44 ± 1.08 32	3.40 ± 1.14 20	3.73 ± 0.70 15
Accept Lighting (scale)	3.94 ± 0.93 33	3.63 ± 1.24 32	4.35 ± 0.75 20	4.27 ± 0.88 15
Accept Personal space (scale)	3.91 ± 1.31 33	3.84 ± 1.44 32	4.00 ± 1.08 20	3.87 ± 1.00 15
Intrinsic				
Age (years)	27.31 ± 4.91 32	27.28 ± 5.20 29	28.53 ± 5.39 19	28.07 ± 4.98 14
Gender (male)***	66% 32	66% 29	58% 19	57% 14
Smoking status (smoker)***	10% 32	14% 29	10% 19	14% 14
Physical work (hours per week)	5.56 ± 3.06 32	5.97 ± 3.18 29	5.42 ± 3.66 19	5.71 ± 3.73 14
Alcohol per day (daily alcohol)***	16% 32	17% 29	32% 19	29% 14
Tea, coffee (# of bevs. per day)	1.18 ± 1.47 32	1.31 ± 1.54 29	1.53 ± 1.71 19	1.43 ± 1.83 14
Correction lenses (some type of lenses)***	44% 32	50% 28	45% 20	60% 15
Health status (# of conditions)	0.79 ± 0.98 34	0.82 ± 1.04 27	0.85 ± 0.81 20	0.73 ± 0.80 15
Adaptive				
Medication (Yes to medic)***	6% 34	4% 27	15% 20	13% 15
Exposure time (minutes)	153.41 ± 115.34 34	232.16 ± 109.94 32	179.75 ± 156.20 20	240.00 ± 119.34 14
Metabolic rate (mets)	1.14 ± 0.19 36	1.12 ± 0.12 32	1.17 ± 0.23 20	1.11 ± 0.11 15
Clothing insulation (Clo)	0.79 ± 0.18 28	0.77 ± 0.17 27	0.78 ± 0.15 20	0.77 ± 0.17 15

Table 7.2b
continued

Exogenous variables	Means, standard deviations, and sample size			
	Day 1, Time 1	Day 1, Time 2	Day 2, Time 1	Day 2, Time 2
Social Social score (score)	156.70± 21.28 27	161.67 ± 20.69 24	157.12 ± 30.45 17	162.69 ± 29.38 13
Risk perception Risk score (score)	36.74 ± 32.16 31	33.76 ± 30.98 29	26.07 ± 25.00 14	26.07 ± 25.00 14

Notes: *** For dummy variables, percentage, rather than means and standard deviations are presented.

Table 7.2c Dependent variables: Human response

Human responses	Means, standard deviations, and sample size			
	Day 1, Time 1	Day 1, Time 2	Day 2, Time 1	Day 2, Time 2
Environmental-Perceptual				
Intensity of temperature *****	4.21 ± 0.69 34	4.50 ± 0.80 32	4.35 ± 0.67 20	4.07 ± 0.88 15
Intensity of humidity	3.71 ± 0.80 34	3.59 ± 0.98 32	3.40 ± 0.82 20	3.53 ± 0.74 15
Intensity of odor (present)	1.91 ± 1.08 34	1.75 ± 1.02 32	2.05 ± 1.10 20	1.67 ± 0.98 15
Intensity of odor (on entry)	2.03 ± 1.14 34	1.78 ± 1.07 32	2.05 ± 1.36 20	2.00 ± 1.31 15
Personal-Perceptual				
Intensity of temperature	4.24 ±0.71 33	4.66 ± 0.97 32	4.30 ± 0.80 20	4.07 ± 0.70 15
Intensity of humidity	3.73 ± 0.80 33	3.53 ± 1.16 32	3.50 ± 0.76 20	3.40 ± 0.83 15
General symptoms (# of symptoms)	1.15 ± 1.23 34	0.78 ± 0.87 32	1.55 ± 1.32 20	1.00 ± 1.31 15
Local symptoms (# of symptoms)	0.88 ± 1.12 34	0.84 ± 1.14 32	1.45 ± 1.50 20	1.00 ± 1.41 15
Environmental-affective				
Acceptability of temperature	4.33 ± 0.692 33	4.03 ± 1.26 32	4.40 ± 0.68 20	4.33 ± 0.82 15
Acceptability of humidity	4.15 ± 0.97 33	4.09 ± 1.06 32	4.30 ± 1.13 20	4.27 ± 0.88 15
Acceptability of thermal conditions	4.24 ± 0.75 33	4.13 ± 1.21 32	4.25 ± 0.79 20	4.33 ± 0.62 15
Acceptability of odor	4.79 ± 0.60 33	4.69 ± 0.90 32	4.65 ± 0.75 20	4.73 ± 0.46 15
Acceptability of air quality	3.70 ± 1.08 33	3.84 ± 1.11 32	3.95 ± 1.05 20	4.00 ± 0.93 15
Acceptability of overall conditions	3.82 ± 0.77 33	3.81 ± 1.06 32	4.00 ± 0.65 20	4.36 ± 0.50 14

Table 7.2c
Continued

Human responses	Means, standard deviations, and sample size			
	Day 1, Time 1	Day 1, Time 2	Day 2, Time 1	Day 2, Time 2
Personal-affective				
Thermal comfort	4.35 ± 0.73 34	4.13 ± 0.85 31	4.00 ± 0.65 20	4.27 ± 0.70 15
General comfort	4.35 ± 0.77 34	4.07 ± 1.18 31	4.00 ± 1.12 20	4.43 ± 0.94 14

Notes: "*" where units are not specified, they are rating scales: seven point scales for perceptual responses, and six point scales for affective responses.

perceptions of risks associated with the indoor environment. As in the case of CNS, risk perception scores were lower on the second day, suggesting that a 'test effect' probably occurred.

Dependent variables

Human responses for the four sets of data were fairly constant over the four sets of data. As in the case of the CNS data, the standard deviations for general and local symptoms were high compared to their means (e.g., coefficients of variability = 1.07 and 1.27 respectively), indicating large variability in the presence of symptoms in the occupant population. Unlike CNS, the total number of local symptoms was observed to have decreased slightly in the case of 'time 2' data for each day. As in the case of the other variables, limited time between measurements on each test day are expected to have resulted in low variability between measures taken on each test day.

7.3.4 Comparison of data for the two indoor spaces

It is observed that with respect to exposures, the lowest value for relative humidity for Cowgill (14%) was much lower than that for CNS (21%). Also, the mean value of TVOCs in Cowgill Hall (0.81) was lower than that for CNS (3.78). The mean age of the occupants of the CNS building (36.66) was higher than that for Cowgill (27.66). Both environments included a majority of men in the occupant population (73% and 63% for CNS and Cowgill Hall respectively). The proportion of smokers in Cowgill Hall (12%) was slightly higher than that for CNS (8%), but both were below the estimated national proportion of smokers (26%). There were large variations in both populations with respect to respondent's physical activity as indicated by the large standard deviations. The number of cups of tea and coffee consumed daily by occupants for CNS (2.67) was larger than that for Cowgill (1.33). However, one respondent in the former group indicated a daily consumption of 24 cups of coffee. This may have resulted in a higher mean value for this variable.

7.4 REGRESSION ANALYSIS

Tables 7.3 and 7.4 depict the results obtained for the regression analysis for the data taken at the Information Systems Building, and Cowgill Hall respectively. The values reported in the tables are: (1) adjusted R^2: the corrected coefficient of determination (R^2) , which corrects R^2 to more closely reflect the goodness of fit of the model in the population (SPSS,Inc. 1990), (2) significance level: i.e., the p-value resulting from the F-test (Kleinbaum et al. 1988), (3) Partial Regression Coefficients (B) which are used in the regression equation, and (4) Beta coefficients (i.e., "the coefficients of the independent variables when all variables are expressed in standardized (z score) form (SPSS, Inc., 1990.")). Beta coefficients provide some indication of the relative importance of variables.

As the regression analysis was done separately for the data taken from the Information systems Building (Section 7.4.1), and Cowgill Hall (Section 7.4.2), individual results are discussed first. This discussion first identifies variables that are included in the hypotheses presented earlier. Then, variables that were hypothesized to influence human response, but did not enter the final regression equation are examined. Last, unexpected variables that entered the equation are examined. In Section 7.4.3, the two

Table 7.3 Information Systems Building: Results of regression analysis

HYPOTHESIZED VARIABLES				ALL VARIABLES			
Dependent	Independent	B	Beta	Dependent	Independent	B	Beta
E-P:	Teacof	-0.07	-0.42	*E-P*	Teacof	-0.72	-0.43
temperature	cloval	+1.72	+0.30	*temperature*	cloval	+1.57	+0.28
R^2 adj. 0.18		+3.68		R^2 adj. 0.21	risksc	+0.01	+0.21
Sign. 0.0001				Sign. 0.00		+3.44	
E-P:	medic	-0.49	-0.27	*P P*	wsec	-0.69	-0.28
humidity	smoke	+1.03	+0.40	*humidity*	lens	+0.56	+0.28
R^2 adj. 0.35	bhealth	-0.23	-0.29	R^2 adj. 0.54	bhealth	-0.26	-0.33
Sign. 0.00	cloval	-1.70	-0.28	Sign. 0.00	acacoustics	+0.24	+0.32
	particulates	-20.11	-0.30		physwk	-0.02	-0.17
	CO_2	+0.001	+0.21		cloval	-1.65	-0.28
		3.64			smoke	+0.92	+0.36
					wother	-1.04	-0.27
					optemp	-0.14	-0.17
						14.44	
P-P:	teacof	-0.07	-0.41	*P-P:*	Teacof	-0.07	-0.41
temperature	cloval	+1.74	+0.31	*temperature*	cloval	+1.59	+0.28
R^2 adj. 0.17		+3.56		R^2 adj. 0.20	risksc	+0.01	+0.20
Sign. 0.0001				Sign. 0.0001		+3.42	
P-P:	medic	-0.78	-0.41	*P-P:*	Medic	-0.33	-0.17
humidity	evel	+9.56	+0.21	*humidity*	wother	-1.53	-0.39
R^2 adj. 0.18		+2.59		R^2 adj. 0.42	wsecretarial	-0.61	-0.24
Sign. 0.00				Sign. 0.00	acacstcs	+0.41	+0.52
					aclight	-0.30	-0.36
					evel	10.77	+0.24
					cloval	-1.37	-0.22
						3.05	
Accept	Social score	+0.02	+0.48	Accept	Social score	+0.02	+0.48
temperature	gender	+1.25	+0.57	temperature	gender	+1.25	+0.57
R^2 adj. 0.38	wprofessional	-0.93	-0.46	R^2 adj. 0.38	wprofessional	-0.93	-0.46
Sign. 0.00	alcohol	+0.86	+0.28	Sign. 0.00	alcohol	+0.86	+0.28
	op.temp.	-0.22	-0.24		op.temp.	-0.22	-0.24
	Medic	+0.44	+0.21		Medic	+0.44	+0.21
		17.96				17.96	

Table 7.3
(continued)

HYPOTHESIZED VARIABLES				ALL VARIABLES			
Dependent	Independent	B	Beta	Dependent	Independent	B	Beta
Accept humidity R^2 adj. 0.47 Sign. 0.00	Smoke risk score social score ac.pers.sp. Bhealth rel.humidity	+1.49 -0.02 +0.02 +0.41 -0.31 -0.04 +2.09	+0.43 -0.43 +0.40 +0.38 -0.30 -0.22	Accept humidity R^2 adj. 0.46 Sign. 0.00	Ac. Acoustics wsecreterial risk score bhealth	+0.59 -0.86 -0.01 -0.23 +2.44	0.57 -0.26 -0.23 -0.22
Accept thermal R^2 adj. 0.35 Sign. 0.00	Ac. Light social score bhealth	+0.39 +0.01 -0.19 +0.81	+0.43 +0.38 -0.21	Accept thermal R^2 adj. 0.35 Sign. 0.00	Ac. Light social score bhealth	+0.39 +0.01 -0.19 +0.81	+0.43 +0.38 -0.21
Thermal comfort R^2 adj. 0.27 Sign. 0.00	Ac. Light air velocity alcohol risk score social score	+0.21 -11.63 +0.82 -0.01 +0.01 +3.50	+0.25 -0.25 +0.30 -0.29 +0.25	Thermal comfort R^2 adj. 0.27 Sign. 0.00	Ac. Light air velocity alcohol risk score social score	+0.21 -11.63 +0.82 -0.01 +0.01 +3.50	+0.25 -0.25 +0.30 -0.29 +0.25
Workstation: odor now R^2 adj. 0.08 Sign. 0.0096	Air velocity Ac. Pers.sp.	13.18 -0.20 +1.06	+0.27 -0.22	Workstation: odor now R^2 adj. 0.30 Sign. 0.00	Tea -coffee wprofessional alcohol air velocity ac.pers.sp.	+0.09 +0.44 -0.80 +11.48 -0.19 +0.78	+0.44 +0.22 -0.27 +0.23 -0.21
Workstation: odor on entry R^2 adj. 0.21 Sign. 0.00	gender smoke	-0.85 +1.03 +2.03	-0.35 +0.32	Workstation: odor on entry R^2 adj. 0.36 Sign. 0.00	Tea-coffee smoke wadmin. Gender	+0.07 +1.04 -0.72 -0.55 +1.77	+0.30 +0.32 -0.27 -0.22
Accept odor R^2 adj. 0.18 Sign. 0.00	Wadmin. Gender	+0.68 +0.57 +4.22	+0.32 +0.30	Accept odor R^2 adj. 0.31 Sign. 0.00	Tea-coffee ac.pers.sp. Wadmin. alcohol	-0.07 +0.19 +0.47 +0.52 +3.99	-0.43 +0.23 +0.22 +0.20

Table 7.3
(continued)

HYPOTHESIZED VARIABLES				ALL VARIABLES			
Dependent	Independent	B	Beta	Dependent	Independent	B	Beta
Accept air quality R^2 adj. 0.45 Sign. 0.00	Ac.light Bhealth. Ac.pers.sp. Tea-coffee Risk score	+0.46 -0.26 +0.37 -0.04 -0.01 +0.99	+0.42 -0.25 +0.34 -0.18 -0.16	Accept air quality R^2 adj. 0.45 Sign. 0.00	Ac.light Bhealth. Ac.pers.sp. Tea-coffee Risk score	+0.46 -0.26 +0.37 -0.04 -0.01 +0.99	+0.42 -0.25 +0.34 -0.18 -0.16
				General symptoms R^2 adj. 0.45 Sign. 0.00	Bhealth smoke wprofessional social score	+0.87 +2.20 +0.98 +0.01 -2.13	+0.49 +0.38 +0.24 +0.20
				Local symptoms R^2 adj. 0.43 Sign. 0.00	Bhealth Medication Smoke Acacoustics Exp.time	+0.52 +0.44 +1.26 -0.35 0.002 +1.38	+0.43 +0.16 +0.32 -0.30 +0.22
				Accept. Overall R^2 adj. 0.81 Sign. 0.00	Ac.light ac.acoustics gender ac.pers.sp. Lens medication	+0.32 +0.38 +0.65 +0.21 -0.37 -0.34 -0.004	+0.35 +0.43 +0.29 +0.22 -0.17 -0.16
				General comfort R^2 adj. 0.32 Sign. 0.00	Gender smoke wadmin. Ac.light	+0.71 +1.22 +0.71 +0.24 +2.47	+0.29 -0.38 +0.26 +0.24

sets of results are compared and interpreted in terms of differences in the two spaces and occupant characteristics.

7.4.1 Information Systems Building.

Thermal responses

The environmental-perceptual response 'temperature at workstation' and the personal-perceptual response 'temperature of the personal state' were found to be influenced by daily consumption of tea or coffee and the insulation value of the clothing, as hypothesized. As the variables that influenced thermal sensation with respect to the environment and the personal state were the same, it can be concluded that these two dependent factors are closely related. This finding provides support for Fanger's finding that people perceive their own personal state, not that of the environment, and that after a period of adaptation, the two are nearly the same (Fanger. 1970). Typical tea and coffee consumption is negatively related to intensity of temperature for both the variables. This is unexpected, as ingestion of a meal leads to increased metabolic activity, thereby resulting in an increase in body temperature. It is possible, however, that a high consumption of tea and coffee may indicate low consumption of food, which may reduce the basic metabolic rate of the body.

When all independent variables were included in the analysis, the total risk score, representing the perception of risk of the occupants with respect to sources in the environment is a factor in explaining both the dependent variables. The role of risk perception has not been adequately addressed in the literature on human responses to the indoor environment. It is possible that people who perceive that the environment presents a risk to their health are more sensitive to deviations in temperature. Also, as physical plant had responded to previous complaints of inadequate thermal control in the space by collecting some data, it is possible that respondents may have expected that this study was also concerned with the investigation of a problem, even though they had been informed that this was a purely academic study. In this case, therefore, risk perception could have played a role in respondent's perception of temperature. The unexpected role of risk perception on these perceptual responses may also be explained in terms of the possibility that increased perception of risk may result in emotional responses (increased heart beat resulting in increased metabolic rate) that may result in increased skin temperature. Carlson (1994) reports on the impacts of simulated expressions on autonomic responses such as increases or decreases in heart rate and skin temperature, An autonomic responses of this nature is therefore possible for people who feel that the environment is a risk to their health.

The goodness of fit for all these variables is low, although the addition of risk perception increases the value of the adjusted R^2 to 0.21. This may be attributed to the relatively low range of variation in exposure parameters. Thus, for these variables, exogenous factors can be expected to be better determinants of human response than exposure factors at the range of exposure parameters present in this space.

The perception of humidity at the workstation (E-P) is negatively related to the ingestion of medication, as well as to the score on health status (a higher score indicates greater susceptibility), clothing insulation, and particulate mass. It is positively related to smoking status and carbon dioxide concentrations. The beta value for smoking status, is higher than the other variables, indicating that this variable is relatively more important in explaining variation in the dependent variable. The range of values of relative humidity in the space is 21.00% to 41.98% with a mean value of 32.15%. As the relative humidity is in the low range, it is possible that better health, absence of medication, lower amount of clothing, and lower concentrations of particulate mass may have served to make respondents more tolerant of the low humidity levels or dryness in the air. The adjusted R^2 for this dependent variable is 0.35. The exposure variables 'particulate mass' and 'carbon dioxide concentration' also explained some of the variation in this dependent variable; i.e., the higher the concentration of carbon dioxide in the environment, the higher the level of perceived humidity.

When all variables were added however, this value increased to 0.54. The unexpected variables that entered the equation are: the type of work: 'secretarial' or 'other', i.e., persons engaged in work described as secretarial, clerical or other were more likely to rate the environment as being drier. Work type has been reported to be an important exogenous factor in many studies. In this case, as the physical work environment was not likely to be very different for different types of work, it is less likely that physical work environments rather than the type of work may have an influence on this human response. It is possible, however, that persons engaged in secretarial work may work at their workstations more than professionals or administrators, as the latter are likely to be away from their desks to attend conferences and meetings during the typical work day. In addition, persons wearing lenses are less likely to vote that the relative humidity was low for the measured values of relative humidity. The acceptability of acoustical conditions is also positively related to the perceived intensity of humidity at the workstation. The mean value of acceptability scores on this variable is 3.8, i.e., neither acceptable nor unacceptable. Thus, it is possible that respondents who found the acoustical conditions to be more acceptable, are also less likely to indicate the environment was dry.

Operative temperature is one of the variables that explained perception of the humidity at the workstation. This supports the contention that thermal and air quality exposure parameters must be considered as a *set* when examining their impacts on human responses.

The value of R^2 is greater for the E-P response (0.35) related to the intensity of humidity as compared to the R^2 for the corresponding P-P response (0.18). Air velocity is positively related to perceived intensity of humidity for the personal state, and enters the equation even in the presence of the entire set of variables. At the given relative humidity, lower air velocity will increase the boundary layer of air resulting in the finding that respondents tend to perceive the dryness of the air to a greater extent. The addition of all variables results in a higher adjusted R^2 (0.42) including the variables work type: secretarial and other, acceptability of acoustics and light, and clothing insulation. The acceptability of acoustics is positively related to the E-P and P-P responses for intensity of humidity; i.e., if respondents judged the environment to be less acceptable in terms of acoustics, they are more likely to notice the dryness of the environment. The same explanation may apply to the relationship between 'acceptability of lighting' and the P-P response for humidity.

Thirty-eight percent of the variation in the acceptability of temperature of the workstation was explained by a combination of the factors: social score, gender, worktype (professional), alcohol consumption, operative temperature, and medication. This is consistent with the hypothesis. It is important to note that the exposure variable 'operative temperature' is a factor in this equation, although it did not enter the regression equation for temperature sensation. Professionals in the space are less likely to rate the temperature as 'acceptable'. Marans et al (1985) suggest that previous work experience may play a role in the criteria by which people make judgements of acceptability. This factor was not, however, assessed in this study.

For the hypothesized set of variables, 47% of the acceptability of humidity in the space was explained by smoking status, risk score and social score, acceptability of personal space, susceptibility, and the exposure variable relative humidity. This is consistent with the hypothesis. The higher the social score, the higher is the respondent's satisfaction with the social environment. Also, as expected, the variable relative humidity was an independent variable for this response. When all variables were entered into the equation, however, acceptability of acoustics was an important factor, as in the case of the other responses related to humidity. This relationship needs further examination. It is possible that methodological effects may account for the inclusion of this variable, as all acceptability responses were included on the same page in the questionnaire; i.e., the probability of a response set must be considered. Also, work described as secretarial or clerical was likely to be negatively impact the acceptability of humidity, as in the case of the other responses related to humidity.

Acceptability of the overall thermal environment had a lower value of adjusted R^2 as compared to the acceptability of the individual thermal parameters, temperature and humidity. The acceptability of lighting, social score and susceptibilities explained 35% of the variation in the dependent variable. The variable 'bhealth' consists of the number of health conditions reported by the occupants, and is negatively related to 'acceptability of the thermal environment'. Thus, occupants in poorer health are more likely to vote that the thermal environment in unacceptable. Finally, 27% of the variation in thermal comfort (personal-affective response) is explained by acceptability of lighting, air velocity, alcohol consumption, risk score and social score. The exposure parameter, air velocity is negatively correlated with thermal comfort. High air velocities may result in the detection of draft, making respondents less comfortable thermally. The mean air velocity in the space was 0.10 m/s. However, at the highest velocity (maximum value: 0.18 m/s), respondents may have detected the presence of draft, leading to a lower level of thermal comfort.

Air quality and general responses

The difference in results of the regression analysis for two environmental-perceptual responses: (1) odor at workstation at the time that respondents were completing the questionnaire ($R^2 = 0.08$), and (2) their perception of the odor when they first entered the space ($R^2 = 0.21$) can be explained by the phenomenon of adaptation to odors. Air velocity was a factor in the perception of odor at the time of response. It is possible that odors from other areas may be dissipated through air movement, thereby causing people to detect odors from other areas in the space. Acceptability of personal space, an indicator of crowding, is also associated with odor perception. This relationship is supported by evidence that CO_2 control is linked to the control of occupancy odors (ASHRAE, 1989a). Intrinsic factors 'smoking status', and 'gender' entered into the regression equation for odor perception on entry into the space. When all independent variables were entered, daily consumption of tea or coffee, and work type (professional), and alcohol consumption also entered the equation for odor perception at the time of response. The role of ingestion on odor perception needs to be further examined. For the variable 'odor perception on entry', tea and coffee consumption, and work type (administrative)are additional independent variables for this dependent variable. Persons who are administrators or have managerial responsibilities are less likely to detect an odor. The regression model for 'acceptability of odor', for the set of hypothesized variables is consistent with the results of the E-P response to odor intensity on entry, in that work type (administrative or managerial), and gender are independent variables in both models. For the entire set of variables, however, consumption of tea or coffee, consumption of alcohol, acceptability of personal space and work type (administrative) are important predictors.

Acceptability of air quality is predicted by acceptability of light, acceptability of personal space, susceptibilities, consumption of tea and coffee, and risk score. Methodological effects (i.e., the probability of a response set) may account for the higher value of R^2 obtained for this equation, as acceptability responses explain some of the variation in the dependent variable.

The detection of general symptoms, assessed in terms of the number of conditions checked by the respondent are predicted by susceptibilities, smoking status, work type, and social score. The relationship of the latter two variables with the dependent variable is consistent with the findings of the evaluation synthesis that job factors were likely to play a role in the experience of general symptoms (e.g., Hodgson et al. 1992., Zweers et al. 1992). Local symptoms (i.e., symptoms that can be described in terms of irritation of specific receptors) are found to be predicted by susceptibilities, medication, smoking status, acceptability of acoustics and exposure time. The first three variables in the equation are consistent with expectation; i.e., people in poorer health may be more likely to experience symptoms. Consequently, it is not possible to conclude that these are a result of the physical environment. Acceptability of acoustics is also a factor; i.e., a less acceptable acoustical environment may exacerbate some symptoms. Exposure time has been implicated in the literature as a factor for this human response; symptoms related to SBS usually worsen through the day.

Variations in respondents' ratings of acceptability of the overall environment are explained by their rating of the acceptability of lighting, acoustics, personal space, gender, correction lenses, and medication. This is as expected, however, no exposure variables enter the equation. For ratings of general comfort, gender, smoking status, worktype (administrative), and acceptability of light are important factors.

Table 7.4 Cowgill Hall: Results of regression analysis

HYPOTHESIZED VARIABLES				ALL VARIABLES			
Dependent	Independent	B	Beta	Dependent	Independent	B	Beta
Work station: temperature R^2 adj. 0.08 Sign. 0.0117	Gender	-0.42 +4.57	-0.31	*E-P: temperature* R^2 adj. 0.08 Sign. 0.0117	Gender	-0.42 +4.57	-0.31
Work station: humidity R^2 adj. 0.29 Sign. 0.0000	Ac.light gender Op. Temp.	-0.44 +0.53 -0.27 25.29	-0.56 +0.33 -0.25	*E-P humidity* R^2 adj. 0.29 Sign. 0.0000	Ac.light gender Op. Temp.	-0.44 +0.53 -0.27 25.29	-0.56 +0.33 -0.25
P-P: temperature R^2 adj. 0.26 Sign. 0.000	Gender CO_2	-0.77 0.004 +0.88	-0.46 +0.34	*P-P: temperature* R^2 adj. 0.26 Sign. 0.000	Gender CO_2	-0.77 0.004 +0.88	-0.46 +0.34
P-P: humidity R^2 adj. 0.13 Sign. 0.0015	ac.light	-0.33 4.99	-0.39	*P-P: humidity* R^2 adj. 0.13 Sign. 0.0015	ac.light	-0.33 4.99	-0.39
Accept temperature R^2 adj. 0.19 Sign. 0.0006	Ac.pers.sp. Ac.light	+0.21 +0.23 +2.61	+0.31 +0.28	Accept temperature R^2 adj. 0.19 Sign. 0.0006	Ac.pers.sp. Ac.light	+0.21 +0.23 +2.61	+0.31 +0.28
Accept humidity R^2 adj. 0.06 Sign. 0.0239	Ac.light	+0.27 +3.19	+0.28	Accept humidity R^2 adj. 0.20 Sign. 0.0004	Ac.acoustics social score	+0.37 +0.01 +1.38	+0.39 +0.24
Accept thermal R^2 adj. 0.21 Sign. 0.0002	Ac.light ac.pers.sp.	+0.28 +0.19 +2.40	+0.34 +0.28	Accept thermal R^2 adj. 0.22 Sign. 0.0002	Ac.acoustics Alcohol	+0.35 +0.46 +2.88	+0.43 +0.24
Thermal comfort R^2 adj. 0.27 Sign. 0.0000	Ac.light Met.rate smoke	+0.29 +0.29 +0.61 +1.54	+0.39 +0.29 +0.28	Thermal comfort R^2 adj. 0.27 Sign. 0.0000	Ac.light Met.rate smoke	+0.29 +0.29 +0.61 +1.54	+0.39 +0.29 +0.28
Workstation: odor now R^2 adj. 0.16 Sign. 0.0031	Bhealth Age Smoke	-0.26 +0.05 -0.67 +0.56	-0.31 +0.26 -0.26	Workstation: odor now R^2 adj. 0.12 Sign. 0.0025	Social score	-0.01 +3.74	-0.37

Table 7.4
(continued)

HYPOTHESIZED VARIABLES				ALL VARIABLES			
Dependent	Independent	B	Beta	Dependent	Independent	B	Beta
Workstation: odor on entry R^2 adj. 0.26 Sign. 0.0002	Age Bhealth Smoke Exp.time	+0.05 -0.33 -1.28 0.002 +0.12	+0.27 -0.36 -0.47 +0.35	Workstation: odor on entry R^2 adj. 0.18 Sign. 0.0002	Social score	-0.02 +4.42	-0.44
Accept odor R^2 adj. Sign.	No variables entered the equation			Accept odor R^2 adj. Sign.	No variables entered the equation		
Accept air quality R^2 adj. 0.16 Sign. 0.0017	Risk score Met.rate	-0.01 +1.66 +2.44	-0.32 +0.29	Accept air quality R^2 adj. 0.16 Sign. 0.0017	Risk score Met.rate	-0.01 +1.66 +2.44	-0.32 +0.29
				General symptoms R^2 adj. 0.25 Sign. 0.0001	Bhealth Gender	+0.32 -0.60 +1.07	+0.34 -0.30
				Local symptoms R^2 adj. 0.29 Sign. 0.00	Bhealth ac.light	+0.44 -0.37 +1.96	+0.39 -0.33
				Accept. Overall R^2 adj. 0.68 Sign. 0.00	Ac.acoustics ac.pers.sp. Ac.light social score	+0.22 +0.27 +0.29 -0.01 +2.40	+0.30 +0.45 +0.40 -0.18
				General comfort R^2 adj. 0.24 Sign. 0.0002	Ac.light risk score Exp.time	+0.39 +0.01 -0.002 +2.77	+0.38 +0.30 -0.27

7.4.2 Cowgill Hall

Thermal responses

Gender was the first variable to enter the regression equations for E-P and P-P responses related to the intensity of temperature. Women were found to be more likely to rate the temperature as being higher. The close relationship between these two responses is consistent with the CNS results. The regression equation for the dependent variable: environmental perceptual response for humidity included the independent variables: acceptability of lighting, gender, and operative temperature. These were all hypothesized values. For the P-P response, carbon dioxide concentrations also explained some of the variation in the dependent variable. The R^2 for the P-P response is much higher (0.26) compared to the corresponding R^2 for the E-P response (0.08). For the CNS data, the R^2s for these two responses were nearly equal.

The variable 'acceptability of lighting' was also the only independent variable that explained variation in the dependent variable: personal perceptual response for humidity. The R^2 (0.21) for the E-P response is higher than that for the corresponding P-P response (0.13).

The variable 'acceptability of humidity' (E-A) can be predicted by acceptability of lighting if hypothesized variables only are used in developing the regression model. Thus, the P-P response for humidity is similar to the E-A response. However, the R^2 is very low (0.06). Acceptability of acoustics and social score are the independent variables if all variables are used in developing the model. The adjusted R^2 in this case increases to 0.20.

Acceptability of temperature is predicted by the acceptability of personal space and the acceptability of lighting, as predicated. Intrinsic and adaptive factors, as well as social factors and risk perception did not enter the equation. Acceptability of thermal conditions was also explained by the two variables listed above. Thus, acceptability of temperature and thermal conditions are closely related in this case. However, when all variables were used to develop the regression model, acceptability of acoustics , acceptability of lighting, and gender were the independent variables. Finally, thermal comfort can be predicted using the independent variables: acceptability of lighting, metabolic rate, and smoking status.

Air quality

Odor at the workstation at the time of response is explained by susceptibility, age, and smoking status, as hypothesized. When all variables were entered, however, social score was the only independent variable that entered the equation. The R^2 for the former was higher, however. Odor on entry at the workstation is predicted by the independent variables age, susceptibilities, smoking status and exposure time. As in the previous case, 'social score' was the only variable to enter the equation when all independent variables were entered. 'Social score' was not hypothesized as being a factor for the perceptual responses. It is possible that occupants may have been aware of indoor environmental problems in this building several years before the study, and this awareness may have influenced their perceptual responses.

Acceptability of odor could not be significantly explained by variation in any of the independent variables assessed in this study. Sixteen percent of the variation in 'acceptability of air quality' was explained by the independent variables: metabolic rate and risk score. The predominance of the variable 'risk score' in air quality judgements may be linked to the awareness of past environmental problems by the occupants.

Susceptibility and gender explained some of the variation in the dependent variable 'general symptoms'. Susceptibility was also a factor in the regression equation for local symptoms. For this dependent variable, acceptability of lighting was also negatively related. This is consistent with the expectation that poor lighting may result in eye strain resulting in irritation.

Acceptability with the overall environment was explained by variations in the acceptability of acoustics, lighting, and personal space, and social score. As in the case of CNS, the high values of the adjusted R^2 for this equation may be attributed, in part, to the possibility of a response set for the 'acceptability' variables. Finally, general comfort is predicted by the independent variables acceptability of lighting, risk score and exposure time.

7.4.3 Comparison of regression results for the two spaces

The regression equations for the E-P and P-P responses related to the intensity of temperature were closely related in both sets of data. This provides support for the contention that after a period of adaptation, thermal sensation for the environment and the body are almost equal (ISO, 1975). The exposure parameter 'operative temperature' entered the regression equations for the E-P response related to the intensity of humidity for both sets of data. Thus, at higher temperature, the air may be perceived as being drier for the same level of humidity. Also, 'acceptability of acoustics' entered the regression equation for the dependent variable 'acceptability of humidity' in both data sets. This provides support for the notion that people respond to multiple stressors in the environment. The variables for the regression equations for 'acceptability of temperature' and 'acceptability of thermal conditions' were identical in the case of Cowgill Hall. However, this similarity was not observed in the case of the CNS data. These two dependent variables need further examination. Interviews during the pretests indicated that the two were not identical.

Risk score was a factor in the regression equation for the dependent variable 'acceptability of air quality'. The role of risk perception in affective responses needs further examination. Media coverage of risks related to the air in indoor environments may account for the influence of this variable on judgements related to air quality. It is expected that risk communication occurs in a variety of ways. Plough et al. (1990) define risk communication as any public or private communication that informs individuals about the existence, nature, form, severity or acceptability of risks. This factor can be included in the broad category of secular trends in the framework of the conceptual model presented in this dissertation. Finally, susceptibility was a factor in the regression equations for general and local symptoms for both sets of data. Thus, respondents who experience more chronic health conditions may be more susceptible to relatively minor deviations in environmental conditions.

7.5 CONCLUSIONS

Tables 7.5 and 7.6 summarize the implications of the results of the regression analysis on the conceptual model proposed earlier for the Information Systems Building and Cowgill Hall respectively. It is observed that in both cases, exogenous factors explained more of the variation in the dependent variables as compared to exposure parameters. In both spaces, exposures were well within the limits prescribed in the standards, except for relative humidity and TVOCs. Relative humidity entered the equation for the dependent variable 'acceptability of humidity' for the CNS data, but did not explain variations in other dependent variable for any of the two sets of data. Operative temperature, air velocity, carbon dioxide and particulate mass explained some of the variation in some other dependent variables. Thus, these parameters may have an influence on human response when relative humidity is low, even though they do not fall outside the range of the prescribed standards. The variable 'TVOC' did not explain the variation in any of the dependent variables, although it was found to be outside the recommended limits. However, the values were only marginally in the discomfort range.

Other physical factors, intrinsic and adaptive factors explained some of the variation in most of the dependent variables. Based on the results, however, additional research is needed to identify specific parameters within these categories of exogenous factors for specific human responses. Social factors explained some of the variation in perceptual responses for the CNS data. However, these were all worktype related variables, i.e., the type of work explained some of the variation in these dependent variables. As discussed earlier, these independent variables may include some dimension of adaptive factors, as when work type determines the amount of time spent at the individual workstation. Risk score entered the equation for E-P and P-P responses related to temperature. As the range of temperature in the space did not strictly meet the criteria for winter conditions, it is possible to infer that people who perceive a greater risk related to the indoor environment are more sensitive to deviations in temperature or other exposure

Table 7.5 Independent variables explaining variation in 16 dependent variables: Information Systems Building.

Dependent variables	Independent variables					
	Exposure	Other physical	Intrinsic	Adaptive	Social factors	Risk percep-tion
EP temperature			•	•		•
EP humidity	•	•	•	•	•	
EP odor now	•	•	•		•	
EP odorant.			•		•	
PP temperature			•	•		•
PP humidity		•		•	•	
PP gen.symp.			•		•	
PP local symp.		•	•	•		
EA temperature	•		•	•	•	
EA humidity		•	•		•	•
EA thermal		•	•		•	
EA odor		•	•		•	
EA air quality		•	•			•
EA all		•	•	•		
PA thermal	•	•			•	•
PA all		•	•		•	

Note: • indicates that one or more variables within this category of independent variables explained some variation in the dependent variable.

Table 7.6 Independent variables explaining variation in the 16 dependent variables: Cowgill Hall.

Dependent variables	Independent variables					
	Exposure	Other physical	Intrinsic	Adaptive	Social factors	Risk perception
EP temperature				•		
EP humidity	•	•	•			
EP odor now					•	
EP odorant.					•	
PP temperature	•		•			
PP humidity		•				
PP gen.symp.			•			
PP local symp.		•	•			
EA temperature		•				
EA humidity		•			•	
EA thermal		•	•			
EA odor						
EA air quality				•		•
EA all		•			•	
PA thermal		•	•	•		
PA all		•		•		•

Note: • indicates that one or more variables within this category of independent variables explained some variation in the dependent variable.

parameters. Social score also explained some of the variation in the dependent variables intensity of odor at present and on entry for the Cowgill data. Persons who were more satisfied with the social environment tended to perceive odor less. This, as discussed above, may be attributed to the history of the building with respect to indoor environmental problems.

The possibility of a response set needs to be further examined for the acceptability responses. An alternate rephrasing of the questionnaire items or question order could reduce this effect. Also, as several exogenous factors were assessed only in one of the four questionnaires to reduce response time, the effects of testing on these factors cannot be examined. In the effort to standardize instrumentation to assess human response, methodological effects should be further examined and minimized.

The results of this study demonstrate the need to consider the impact of exposures and exogenous factors simultaneously on human response. The solution to problems related to indoor environmental problems will consequently require multiple actions, i.e., the physical and social environment, as well as lifestyle factors may need to be modified to obtain a desired level of human response. Interaction effects between the independent variables were not assessed in this analysis. It is possible that exposure variables may interact with other exposure variables or with other exogenous variables. This aspect needs to be further examined. Also, analysis of the distributions of the error terms (residuals) can be expected to improve prediction of the dependent variables by validating the normalcy assumption. If the assumption is not met for certain variables, remedial actions such as transformations to logarithms or exponentials may be required to improve the normalcy of errors for those variables. Residual analysis was not conducted for this dissertation. Chapter 8 summarizes the implications of the study with respect to the objectives of this dissertation.

CHAPTER 8

CONCLUSIONS

8.1 INTRODUCTION

The objective of this dissertation was to define human response criteria and measures that can be used in the evaluation of building environments, and to identify links between these human response criteria and exposure parameters, exogenous factors, and methodological effects. A characterization of human response (Section 3.2), consisting of four human response domains was used as a framework for identifying human response criteria that can be used to evaluate buildings at different levels of building performance (Section 3.3). Through a literature review and an evaluation synthesis, a hierarchy of exogenous factors related to the four human response domains was presented (Section 4.2, 4.3). Then, three types of methodologies were defined and linked to one or more human response domains. Methodological factors likely to influence the results obtained by using each of these broad categories of methodologies were discussed (Section 4.4). Then links were identified between the four human response domains and thermal and air quality exposure parameters (Section 5.2, 5.3). A conceptual model synthesizing the information described above was then presented (Section 5.4). Then, an empirical study was conducted in two open-plan, non industrial work environments to test a part of the conceptual model. Selected measures of human response were assessed, but methodological effects were not explicitly assessed, as only one type of methodology was used.

This chapter provides as assessment of the extent to which each of the objectives of this dissertation (defined in chapter 1) were met. Section 8.2 provides conclusions with respect to the first objective, namely, the definition of human response criteria. Section 8.3 is a discussion of conclusions reached with respect to each of the tasks related to the development of the conceptual model (objective two). Finally, section 8.4 provides conclusions from the findings of the empirical study with respect to the hypothesized model (objective three). Following from these conclusions, Section 8.5 consists of recommendations for the development of criteria for the practice of evaluating building performance, and identifies avenues where further research is needed to refine the conceptual model and apply it to the practice of building evaluation.

8.2 CONCLUSIONS: DEFINING HUMAN RESPONSE CRITERIA

Objective one	*To define human response criteria for the purpose of evaluating the performance of actual and virtual buildings.*

The concept of the four domains of human response was developed to define human response criteria for evaluating building performance (Section 3.22). Based on the definitions of three building performance categories, critical human response domains were identified for specifying criteria for each building performance category (Section 3.3). Support for the use of the concept of four human response domains comes from findings of the empirical study. From the available data (Appendix 5), cumulative frequency analyses of the data on affective responses indicates that less than 50% of the respondents in each building rated thermal, air quality, lighting and acoustic conditions individually and collectively as acceptable or very acceptable on the 6-point scale. As the human response criteria for healthy buildings has been defined in section 3.3 as at least 80%, this finding precludes characterizing either of these two buildings as healthy. Based on available data, it is not possible to conclude with certainty which of the other two categories (marginal or problematic) are applicable to the two spaces in this study. As results also indicated that less than 20% of the respondents reported more than two symptoms, it is likely that the buildings could be classified as marginal. However, as clinical signs were not assessed, it is not possible to conclusively exclude the problematic category. *Consequently, it is concluded that the concept of four human response domains is useful in specifying criteria for a hierarchy of building conditions.*

8.3 CONCLUSIONS: DEVELOPMENT OF A CONCEPTUAL MODEL

Objective two — *To develop a conceptual model that assesses the impacts of thermal and air quality stressors in the indoor environment, as well as exogenous factors and methodological effects on human response.*

This objective was addressed in three stages: (1) exogenous factors and methodological factors were identified for each human response domain, (2) a set of exposure factors was identified for human responses related to thermal and air quality, and (3) the information from (1) and (2) was synthesized to develop the conceptual model.

Section 4.2 hypothesized, based on a literature review, that each of the four human response domains can be associated with a set of exogenous factors, and further, that these exogenous factors can be arranged in a hierarchy. These relationships were assessed in section 4.3 by conducting an evaluation synthesis involving ten reported field studies. As hypothesized, the evaluation synthesis suggested that social and psychological-environmental factors may be causal factors for personal-perceptual responses in all buildings, while in problematic buildings, social and psychological-environmental factors may influence environmental-perceptual responses. The impact of secular trends and risk perception on affective responses could not be assessed based on the available empirical evidence. *It is concluded that the evaluation synthesis provided preliminary support for the hypothesized relationships between human response domains and exogenous factors.*

The categorization of methodologies into three categories: subject, panel and occupant, permitted a comparison of the possible methodological effects that can be expected from the use of each type of methodology. The discussion on methodological effects in section 4.4 linked the four domains of human response to one or more categories of methodologies. It is therefore necessary to select methodologies based on the human response domain being assessed. Test procedures used for the selected methodology can consequently be developed to minimize methodological effects that are expected to influence human responses for the selected methodology. The assessment of environmental-affective (criterion for healthy buildings) responses requires the consideration of the social environment, whereas the assessment of symptoms (criterion for problematic buildings) requires more than a transient period of occupancy. For the same reasons, subject and panel methodologies may be inadequate for the assessment of affective responses, necessary for assessing healthy buildings. *It is therefore concluded that for evaluation of problematic or healthy buildings, occupant methodologies are most suitable. However, once a building has been identified as a healthy building, panel methodologies can be used for periodic evaluations to monitor building condition* *using environmental and personal-perceptual responses.*

Exposure parameters influencing human responses related to thermal and air quality were identified from a literature review. *Based on the literature, it is possible to conclude that human responses are linked to a* ***set*** *of stressors, rather than to individual stressors.* As in the case of exogenous factors, links between human response domains and exposure parameters were assessed by means of the evaluation synthesis (Sensharma et al., 1993b). That study concluded that environmental responses may be linked to perceived stressors, whereas personal responses may be linked to unperceived stressors, especially in the case of buildings with problems.

The findings discussed above were synthesized in the development of a conceptual model that explained the hypothesized net impacts of exogenous factors, methodological effects and exposures on the four domains of human response. Section 8.4 is an assessment of the extent to which this conceptual model was validated by the empirical study.

8.4 CONCLUSIONS: THE EMPIRICAL STUDY

Objective three *To conduct an empirical study to test a selected portion of the conceptual model developed as part of objective two.*

Conclusions from the findings of the empirical study with respect to the conceptual model are stated in terms of three primary issues. First, the usefulness of the concept of four human response domains for the practice of building evaluation is assessed. Second, the role of exogenous factors on the four human response domains is assessed. Third, links between human response measures and exposures are discussed. Fourth, one exogenous factor, namely, risk perception is discussed, as it has not hitherto been adequately addressed in the current literature on building evaluation.

Is the concept of four human response domains useful for the practice of building evaluation?

The results of the empirical study provide support for the use of the concept of four domains of human response in defining criteria for the evaluation of building performance. First, the study illustrates that corresponding measures within each of the four domains of human response are *not* identical. The sets of variables that explain variation in corresponding measures of human response in each of the four domains were found to be different, except that E-P and P-P responses for temperature were found to be similar. For instance, environmental-perceptual (E-P) responses and personal-perceptual (P-P) responses for humidity were not explained by the same set of independent variables. Similarity in the sets of independent variables that entered the regression equations for E-P and P-P responses for temperature is supported by existing literature. This finding reinforces the importance of operationalizing human response measures to reflect the goals of indoor environmental control. *Thus, it is concluded that the use of perceptual response measures as a criteria for building evaluation does not assure acceptability (Environmental-affective response) of indoor environmental conditions.*

Second, the empirical study provided support for the premise of the conceptual model (chapter 5) that a unique set of exogenous factors influence each human response domain. For instance, the variable 'social score' was one of the independent variables that explained some of the variation in affective responses and symptoms, as hypothesized, and did not enter the regression equations for perceptual responses. *It is therefore concluded from the empirical study that a hierarchy of exogenous factors is linked to the four human response domains as hypothesized. However, additional work is needed to further operationalize these exogenous factors.*

The impact of exogenous factors on human responses

While the conceptual model (shown in Figure 5.2) describes the net impacts of exposures, exogenous variables, and methodological effects on human response, the empirical study demonstrates the predominance of the effects of exogenous factors on human response for indoor environments in which exposure parameters are within the criteria prescribed in existing standards. Exogenous variables explained more of the variation in the dependent variables than did exposure parameters representing thermal and air quality for both buildings. This finding is consistent with current literature that reports on lack of consistent human response-exposure links, especially in Sick Buildings.

As indicated by the conceptual model and demonstrated by the empirical study, perception of the social environment (operationalized as 'social score' in the empirical study) explains variation in affective responses (criteria for healthy buildings) and variation in the prevalence of symptoms (P-P responses). Additionally, the two physical factors: acoustics and lighting, that were exogenous to the empirical study also explained some of the variation in several of the dependent factors. *It is therefore concluded that control of the exogenous physical environment, social environment, adaptive factors, and* *risk assessment, may all be needed to achieve healthy buildings and to resolve problems associated with SBS.*

Intrinsic factors such as smoking status, gender, age, health status, etc. were found in the empirical study to influence human responses to indoor environments. The results of the regression analysis demonstrate that intrinsic factors and exposure factors are both linked to human responses. *It is therefore concluded that occupant characteristics must be considered in developing appropriate exposure criteria.*

The impact of exposure parameters on human responses

The empirical study validates the contention made in the development of the conceptual model that exposure parameters must be considered as a ***set*** in assessing their impacts on human responses. Past studies have reported on the lack of correlations between exposure variables and human responses. Moreover, the regression analysis of the data from this empirical study demonstrated that for both indoor spaces: (1) operative temperature explained some of the variation in the E-P response for humidity, (2) relative humidity was a factor only for the dependent variable 'acceptability of humidity' for the CNS data, (3) carbon dioxide explained some of the variation in the P-P response for temperature at Cowgill Hall, and for the E-P response for humidity for the case where only the hypothesized set of variables was entered in the regression equation for CNS, (4) particulate mass and air velocity entered the regression equations for other perceptual responses related to the thermal environment, (5) in some cases, acceptability of other environmental stressors, namely, acoustics and lighting also explained some of the variation in other perceptual responses. *It is concluded, therefore, that for levels of* *exposures typically found in indoor environments, it is necessary to consider the multifactorial nature of impacts of exposures on human responses, rather than the impacts of individual stressors.*

The impact of risk assessment on affective responses

The importance of the variable 'risk score' with respect to the acceptability of air quality in both spaces indicates that this factor may influence the criteria by which people judge the acceptability of responses. The variable 'risk score' also explained some of the variations in the 'acceptability of humidity' and 'thermal comfort' for CNS; and in 'general comfort' for Cowgill Hall. Current literature on indoor environmental evaluation has not adequately addressed the role of risk perception on human responses to indoor environments. *Based on the results of the empirical study, it is concluded that risk perception influences affective responses but not perceptual responses, and should therefore be considered in the assessment of affective responses.*

Finally, this dissertation demonstrates that the use of the characterization of human response for the development of criteria for building evaluation can be expected to lead to a better identification of problems where they exist, i.e., to minimize false negative errors in building diagnostics, without necessarily accepting more false positives.

8.5 RECOMMENDATIONS AND IMPLICATIONS FOR FURTHER RESEARCH

The concept of the four domains of human response provides a useful framework for the definition of criteria for evaluating building performance. However, standardized measures of human response need to be developed. For instance, this empirical study used the sum of symptoms experienced by respondents as a measure for assessing symptoms related to SBS (grouped as local or general symptoms). Other ways of grouping the symptoms are possible, as are measures such as the intensity of symptoms. *It is recommended that a comparative assessment of the use of different measures of human responses be conducted to aid in the standardization of instruments to assess human response.* Measures of social score and risk perception are not adequately assessed in the literature. *It is therefore recommended that the development and comparison of multiple indices be conducted to permit the selection of indices that are most closely related to sets of exposures and exogenous variables.*

Based on the findings of this dissertation, it was concluded that different criteria are needed for different building conditions to permit explicit fault detection for existing building (discussed in Section 8.2) and for the design of new buildings. Human response domains appropriate for three building performance categories have been identified. One useful avenue for further research would be the identification of correlations between the four human response domains. If it is possible, for example, to predict affective responses from perceptual responses after accounting for relevant exogenous factors, an instrument could be developed to assess human responses using a minimum amount of response time. *It is therefore recommended that studies be conducted to identify correlations between human response domains.*

This dissertation assesses human responses using only one methodology, namely, occupant methodology. As discussed in this dissertation, three types of methodologies commonly used in research and building evaluation practice have been identified, each associated with specific methodological effects. As only two of these methodologies, namely, panel and occupant methodologies are available for evaluation in the field, only these two methodologies are discussed here. The empirical study for this dissertation did not explicitly assess methodological effects. However, one current standard (ASHRAE, 1989a) specifies the use of panel methodologies for the subjective assessment of air quality. *It is recommended that results obtained by using alternate methodologies be compared.* However, as occupant well being is the ultimate objective of indoor environmental control, it is necessary to assess whether results obtained using panel methodologies can be generalized to occupants. It is expected that this may be possible for perceptual responses, as it may be possible to match panels and occupants with respect to adaptive and intrinsic factors.

It is possible that there may be differences in the set of exogenous factors influencing human response in problematic versus healthy buildings. This observation is made from the results of the evaluation synthesis, as well as some evidence from the empirical study that suggests that knowledge of prior building condition may influence human responses. *It is recommended that a study be conducted to compare the determinants of human responses for known problematic and healthy buildings.* This type of study can be expected to lead to a better understanding and refinement of the conceptual model. Also, a comparative study will permit the identification of ranges of exposures that are likely to result in discomfort when other stressors interact. This is similar to the approach used by Molhave (1992) in determining the effects of different levels of TVOCs on human response.

The empirical study attempted to minimize the problem of internal invalidity as discussed in the research design. Internal invalidity refers to " the possibility that the conclusions drawn from experimental results may not accurately reflect what has gone on in the experiment itself (Babbie, 1989)". For instance, consideration of the probable impacts of history, maturation, testing and mortality were discussed in section 6.4. In the development of the questionnaires, instrumentation effects were sought to be minimized. It is possible, therefore, to 'generalize' the findings of this study to the spaces and occupant included in the empirical study. *It is recommended that the issue of generalizability to other types of environments and occupant groups be addressed in subsequent work.* An empirical study including a broad spectrum of work environments would be needed to generalize findings to work environments in general.

Finally, the findings of this dissertation have provided an approach to the assessment of human responses to indoor environments, that can be used to improve the reliability and validity of human response methodologies. This dissertation has also identified several issues that future research must address to develop standardized methodologies and instruments to assess human responses to indoor environments, and to develop exposure criteria for the design and construction of buildings.

CHAPTER 9

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APPENDIX 1

QUESTIONNAIRES

DAY 1 TIME 1

WORK ENVIRONMENT SURVEY

THANK YOU FOR YOUR PARTICIPATION IN THIS STUDY.

Please complete the consent form before you respond to the attached questionnaire. If you have not yet received the consent form along with information about the study, please contact the investigator.

PLEASE READ THE FOLLOWING INSTRUCTIONS BEFORE YOU START RESPONDING TO THIS QUESTIONNAIRE...

- Please complete the questionnaire within half an hour after you receive it. While you complete the questionnaire, several physical measurements of the environment will be taken to characterize the indoor space.
- Please do not discuss the contents of this questionnaire or your responses with any other persons.
- Please complete the entire questionnaire without skipping any questions.
- Please complete the items in the questionnaire in the order that they are presented to you.
- Please do not write your name on this questionnaire.

Please do not write in this space

Identification number: 1060 Sampling Zone

NOW, PLEASE COMPLETE THE FOLLOWING QUESTIONNAIRE......

Please enter a number from the following scale that best describes how you feel at this time

At this time, I am, generally, ____________

1 very uncomfortable
2 uncomfortable
3 somewhat uncomfortable
4 somewhat comfortable
5 comfortable
6 very comfortable

Right now, the time is ________

DESCRIPTION OF YOUR WORKSTATION

Please enter a number from the following scales that best describes <u>your work station</u> <u>at this time</u>

The temperature at my workstation at this time can be described as______

1 very hot
2 hot
3 warm
4 neutral
5 cool
6 cold
7 very cold

The humidity at my work station at this time can be described as ________

1 very wet
2 wet
3 moist
4 neutral
5 slightly dry
6 dry
7 very dry

The odor at my work station at this time can be described as __________

1 no odor
2 very slight odor
3 slight odor
4 moderate odor
5 strong odor
6 very strong odor
7 overpowering odor

The odor at my workstation <u>when I first entered this space</u> can be described as ________________

1 no odor
2 very slight odor
3 slight odor
4 moderate odor
5 strong odor
6 very strong odor
7 overpowering odor

ASSESSMENT OF HOW YOU FEEL

Please check one or more of the following categories that describe how you feel at this time

At this time, I am experiencing the following:

[ ]	sore or strained eyes	[ ]	dry throat	[ ]	headache
[ ]	tearing eyes	[ ]	dry or itchy skin	[ ]	burning eyes
[ ]	hoarseness	[ ]	sluggishness	[ ]	runny nose
[ ]	reddening of skin	[ ]	dry or itching eyes	[ ]	sore throat
[ ]	unusual fatigue or tiredness	[ ]	stuffy nose or sinus congestion	[ ]	difficulty remembering
[ ]	wheezing or whistling in chest	[ ]	difficulty concentrating	[ ]	sneezing
[ ]	dizziness or lightheadedness	[ ]	cough	[ ]	nausea or vomiting
[ ]	aching muscles or joints	[ ]	shortness of breath	[ ]	chest tightness

Please enter a number from the following scales that best describes how you feel at this time

At this time I feel __________

1 very hot
2 hot
3 warm
4 neutral
5 cool
6 cold
7 very cold

At this time I feel __________

1 very wet
2 wet
3 moist
4 neutral
5 slightly dry
6 dry
7 very dry

ASSESSMENT OF THE ENVIRONMENT AT YOUR WORKSTATION

Please enter a number from the following scale that best describes your assessment of each of the following aspects of the environment at your workstation at this time.

1 very unacceptable
2 unacceptable
3 somewhat unacceptable
4 somewhat acceptable
5 acceptable
6 very acceptable

_____	Loudness of sounds	_____	Humidity
_____	Glare	_____	Brightness of lighting
_____	Odor	_____	Temperature
_____	Pitch of sounds	_____	Air movement
_____	Shadows	_____	Number of noisy distractions
_____	Personal space	_____	Thermal conditions
_____	Air quality	_____	Lighting conditions
_____	Acoustics	_____	Overall environmental conditions

DETERMINANTS OF WORK SATISFACTION

Please circle the number on the following scale that best describes the importance of the following to your general satisfaction with your work.

Personal control over work decisions	1 not important	2	3	4	5 very important
Personal control over physical work environment	1	2	3	4	5
Nature of work - whether varying or repetitive	1	2	3	4	5
Nature of work - whether stimulating or boring	1	2	3	4	5
Clarity of job responsibilities	1	2	3	4	5
Workload	1	2	3	4	5
Relationship with supervisors	1	2	3	4	5
Relationship with colleagues	1	2	3	4	5
Opportunity for advancement in job	1	2	3	4	5
Level of work related stress	1	2	3	4	5

Please enter a number from the following scale that best describes how you feel <u>at this time</u>.

At this time, I am, thermally, ______________

1 very uncomfortable
2 uncomfortable
3 somewhat uncomfortable
4 somewhat comfortable
5 comfortable
6 very comfortable

ASSESSMENT OF YOUR WORK

The following information will help us determine occupant perceptions of activities carried out in this space. Please circle the number that best represents your assessment of the following aspects of your work:

Personal control over work decisions	1 low	2	3	4	5 high
Personal control over physical work environment	1 low	2	3	4	5 high
Nature of work	1 repetitive	2	3	4	5 boring
Nature of work	1 boring	2	3	4	5 stimulating
Clarity of job responsibilities	1 poor	2	3	4	5 excellent
Workload	1 inappropriate	2	3	4	5 appropriate
Relationship with supervisors	1 poor	2	3	4	5 excellent
Relationship with colleagues	1 poor	2	3	4	5 excellent
Opportunity for advancement in job	1 poor	2	3	4	5 excellent
Level of work related stress	1 very stressful	2	3	4	5 not stressful

PERCEPTION OF ACTIVITIES AND TECHNOLOGIES USED IN INDOOR SPACES

This section asks for your perceptions about the nature of risk to the health of occupants in this space resulting from the following: building mechanical systems, office equipment, other occupants and indoor furnishings. Please circle the number that best describes your assessment of each of their following aspects.

Building mechanical systems (i.e., lighting, heating, ventilation and air conditioning (HVAC) systems).

Do you feel that this is a health risk to the occupants?
[ ] yes [ ] no

If 'yes', please continue. If 'no', please skip to the next column (office equipment) ☛

How does this risk occur?
1 2 3 4 5
voluntarily ... not voluntarily

When does the consequence of risk occur?
1 2 3 4 5
delayed ... immediate

To what precision is the risk known to the persons exposed to it?
1 2 3 4 5
known ... unknown

To what precision is the risk known to science?
1 2 3 4 5
known ... unknown

How familiar is this risk to you?
1 2 3 4 5
familiar ... unfamiliar

To what extent can the consequences of this risk be prevented?
1 2 3 4 5
completely ... not at all

To what extent does this risk affect you personally?
1 2 3 4 5
directly ... not at all

Continue in the next column, please (office equipment) ☛

Office equipment (e.g., computers, copiers) or chemicals (e.g., adhesives, glues)

Do you feel that this is a health risk to the occupants?
[ ] yes [ ] no

If 'yes', please continue. If 'no', please skip to the following page (other occupants) ☛

How does this risk occur?
1 2 3 4 5
voluntarily ... not voluntarily

When does the consequence of risk occur?
1 2 3 4 5
delayed ... immediate

To what precision is the risk known to the persons exposed to it?
1 2 3 4 5
known ... unknown

To what precision is the risk known to science?
1 2 3 4 5
known ... unknown

How familiar is this risk to you?
1 2 3 4 5
familiar ... unfamiliar

To what extent can the consequences of this risk be prevented?
1 2 3 4 5
completely ... not at all

To what extent does this risk affect you personally?
1 2 3 4 5
directly ... not at all

Turn page over, please (other occupants) ☛

Please continue...

Other occupants (e.g., other persons who occupy the space)

Do you feel that this is a <u>health risk</u> to the occupants?
[ ] yes [ ] no

If 'yes', please continue. If 'no', please skip to the next column (indoor furnishings) ☛

How does this risk occur?
1 2 3 4 5
voluntarily — not voluntarily

When does the consequence of risk occur?
1 2 3 4 5
delayed — immediate

To what precision is the risk known to the persons exposed to it?
1 2 3 4 5
known — unknown

To what precision is the risk known to science?
1 2 3 4 5
known — unknown

How familiar is this risk to you?
1 2 3 4 5
familiar — unfamiliar

To what extent can the consequences of this risk be prevented?
1 2 3 4 5
completely — not at all

To what extent does this risk affect you personally?
1 2 3 4 5
directly — not at all

Continue in the next column, please (Indoor furnishings) ☛

Indoor furnishings (e.g., carpets, drapes)

Do you feel that this is a <u>health risk</u> to the occupants?
[ ] yes [ ] no

If 'yes', please continue. If 'no', please skip to the next page ☛

How does this risk occur?
1 2 3 4 5
voluntarily — not voluntarily

When does the consequence of risk occur?
1 2 3 4 5
delayed — immediate

To what precision is the risk known to the persons exposed to it?
1 2 3 4 5
known — unknown

To what precision is the risk known to science?
1 2 3 4 5
known — unknown

How familiar is this risk to you?
1 2 3 4 5
familiar — unfamiliar

To what extent can the consequences of this risk be prevented?
1 2 3 4 5
completely — not at all

To what extent does this risk affect you personally?
1 2 3 4 5
directly — not at all

BACKGROUND INFORMATION

The following information will help us determine the general characteristics of the occupants of this space.

- What is your age? ________________ years

- What is your gender? [ ] male [ ] female

- Please indicate the type of correction lenses you are presently wearing:
  [ ] none [ ] reading glasses
  [ ] contact lenses [ ] other glasses (eg., bifocals)

- Please indicate if you are currently experiencing any of the following health conditions (check all that apply):
  [ ] headache [ ] asthma
  [ ] rash or other skin condition [ ] sinusitis
  [ ] chronic eye disease [ ] cardiovascular disease
  [ ] chronic back pain [ ] allergies
  [ ] respiratory illness [ ] other health conditions.
  Please specify.
  ____

- Please indicate your current smoking status:
  [ ] current smoker [ ] occasional smoker
  [ ] former smoker [ ] never-smoker

- If current or occasional smoker, please estimate the amount of cigarettes, cigars or pipes smoked daily:

Number of cigarettes	[ ] less than one	[ ] one to five	[ ] six to ten
	[ ] eleven to twenty	[ ] more than twenty	
Number of cigars	[ ] less than one	[ ] one to five	[ ] more than five
Pipefuls	[ ] less than one	[ ] one to five	[ ] more than five

- Please indicate if you are currently taking any medication (except vitamins).
  [ ] No [ ] Yes. Please specify ____________________

- Please estimate the total number of hours per week that you spend doing physical work or exercise. ____________________ hours per week.

- Please estimate the number of beverages that you consume daily.
  coffee or tea ____________ cups
  alcohol ____________ glasses

- Which of the following categories best describes the type of work that you do in this space
  [ ] managerial or administrative [ ] professional or technical
  [ ] clerical or secretarial [ ] student
  [ ] other. Please specify ______________________________

OCCUPANCY PROFILE

The following information will be used to characterize occupancy patterns and typical activity levels in this space.

- Please estimate the total number of hours that you spent today at your workstation until this time.

  ________________ hours ____________ minutes

- In column 2, please estimate the time that you spent doing the following activities in the two hours preceding the present time today. In column 3, please check the category or categories that indicate the location (s) at which you engaged in these activities.

Column 1 ACTIVITIES	Column 2 DURATION	Column 3 LOCATION	
		At workstation	Not at workstation
Reading, seated	hours min.		
Writing or drawing	hours min.		
Typing or keyboarding	hours min.		
Filing, seated	hours min.		
Filing, standing	hours min.		
Walking about	hours min.		
Lifting or packing	hours min.		
Other. Please specify			
1.	hours min.		
2.	hours min.		
3.	hours min.		

DAY 1 TIME 2

WORK ENVIRONMENT SURVEY

THANK YOU FOR YOUR PARTICIPATION IN THIS STUDY.

Please complete the consent form before you respond to the attached questionnaire. If you have not yet received the consent form along with information about the study, please contact the investigator.

PLEASE READ THE FOLLOWING INSTRUCTIONS BEFORE YOU START RESPONDING TO THIS QUESTIONNAIRE...

- Please complete the questionnaire within half an hour after you receive it. While you complete the questionnaire, several physical measurements of the environment will be taken to characterize the indoor space.
- Please do not discuss the contents of this questionnaire or your responses with any other persons.
- Please complete the entire questionnaire without skipping any questions.
- Please complete the items in the questionnaire in the order that they are presented to you.
- Please do not write your name on this questionnaire.

Please do not write in this space	
Identification number	Sampling Zone

NOW, PLEASE COMPLETE THE FOLLOWING QUESTIONNAIRE......

Please enter a number from the following scale that best describes how you feel at this time

At this time, I am, generally, ___________

1 very uncomfortable
2 uncomfortable
3 somewhat uncomfortable
4 somewhat comfortable
5 comfortable
6 very comfortable

Right now, the time is _________

DESCRIPTION OF YOUR WORKSTATION

Please enter a number from the following scales that best describes your work station at this time

The temperature at my workstation at this time can be described as_______

1 very hot
2 hot
3 warm
4 neutral
5 cool
6 cold
7 very cold

The humidity at my work station at this time can be described as ________

1 very wet
2 wet
3 moist
4 neutral
5 slightly dry
6 dry
7 very dry

The odor at my work station at this time can be described as __________

1 no odor
2 very slight odor
3 slight odor
4 moderate odor
5 strong odor
6 very strong odor
7 overpowering odor

The odor at my workstation when I first entered this space can be described as ________________

1 no odor
2 very slight odor
3 slight odor
4 moderate odor
5 strong odor
6 very strong odor
7 overpowering odor

ASSESSMENT OF HOW YOU FEEL

Please check one or more of the following categories that describe how <u>you feel</u> <u>at this time</u>

At this time, I am experiencing the following:

[ ]	sore or strained eyes	[ ]	dry throat	[ ]	headache
[ ]	tearing eyes	[ ]	dry or itchy skin	[ ]	burning eyes
[ ]	hoarseness	[ ]	sluggishness	[ ]	runny nose
[ ]	reddening of skin	[ ]	dry or itching eyes	[ ]	sore throat
[ ]	unusual fatigue or tiredness	[ ]	stuffy nose or sinus congestion	[ ]	difficulty remembering
[ ]	wheezing or whistling in chest	[ ]	difficulty concentrating	[ ]	sneezing
[ ]	dizziness or lightheadedness	[ ]	cough	[ ]	nausea or vomiting
[ ]	aching muscles or joints	[ ]	shortness of breath	[ ]	chest tightness

Please enter a number from the following scales that best describes how you feel <u>at this time</u>

At this time I feel __________

1 very hot
2 hot
3 warm
4 neutral
5 cool
6 cold
7 very cold

At this time I feel __________

1 very wet
2 wet
3 moist
4 neutral
5 slightly dry
6 dry
7 very dry

ASSESSMENT OF THE ENVIRONMENT AT YOUR WORKSTATION

Please enter a number from the following scale that best describes your assessment of each of the following aspects of the environment at your workstation <u>at this time</u>.

1 very unacceptable
2 unacceptable
3 somewhat unacceptable
4 somewhat acceptable
5 acceptable
6 very acceptable

_____ Loudness of sounds

_____ Glare

_____ Odor

_____ Pitch of sounds

_____ Shadows

_____ Personal space

_____ Air quality

_____ Acoustics

_____ Humidity

_____ Brightness of lighting

_____ Temperature

_____ Air movement

_____ Number of noisy distractions

_____ Thermal conditions

_____ Lighting conditions

_____ Overall environmental conditions

Please enter a number from the following scale that best describes how you feel at this time.

At this time, I am, thermally, ________________

1 very uncomfortable
2 uncomfortable
3 somewhat uncomfortable
4 somewhat comfortable
5 comfortable
6 very comfortable

OCCUPANCY PROFILE

The following information will be used to characterize occupancy patterns and typical activity levels in this space.

- Please estimate the total number of hours that you spent today at your workstation until this time.

  ________________ hours ____________ minutes

- In column 2, please estimate the time that you spent doing the following activities in the two hours preceding the present time today. In column 3, please check the category or categories that indicate the location (s) at which you engaged in these activities.

Column 1 ACTIVITIES	Column 2 DURATION	Column 3 LOCATION	
		At workstation	Not at workstation
Reading, seated	hours min.		
Writing or drawing	hours min.		
Typing or keyboarding	hours min.		
Filing, seated	hours min.		
Filing, standing	hours min.		
Walking about	hours min.		
Lifting or packing	hours min.		
Other. Please specify			
1.	hours min.		
2.	hours min.		
3.	hours min.		

CLOTHING LEVELS

Please check the items that describe the clothing that you are presently wearing. Please do not write in the shaded areas.

Underwear		
Men's briefs		04
Panties		03
Bra		01
T-shirt		08
Full slip		16
Half slip		14
Long underwear top		20
Long underwear bottoms		15
Other. Please specify		
Footwear		
Ankle-length socks		02
Calf-length socks		03
Knee socks (thick)		06
Panty hose stockings		02
Sandals / thongs		02
Boots		10
Other. Please specify		
Shirts and Blouses		
Sleeveless, scoop-neck blouse		12
Short-sleeve, dress shirt		19
Long-sleeve, dress shirt		25
Long-sleeve, flannel shirt		34
Short-sleeve, knit sport shirt		17
Long-sleeve, sweat shirt		34
Other. Please specify		
Lined Suit jackets & vests		
Single-breasted (thin)		36
Single-breasted (thick)		44
Double-breasted (thin)		42
Double-breasted (thick)		48
Sleeveless vest (thin)		10
Sleeveless vest (thick)		17
Other. Please specify		
Trousers and Coveralls		
Short shorts		06
Walking shorts		08
Straight trousers (thin)		15
Straight trousers (thick)		24
Sweat pants		28
Overalls		30
Coveralls		49
Other. Please specify		
Dresses and skirts		
Skirt (thin)		14
Skirt (thick)		23
Long-sleeve shirt dress (thin)		33
Long-sleeve shirt dress (thick)		47
Short-sleeve shirt dress (thin)		29
Sleeveless, scoop neck (thin)		23
Sleeveless, scoop neck (thick)		27
Other. Please specify		
Sweaters		
Sleeveless vest (thin)		13
Sleeveless vest (thick)		22
Long-sleeve (thin)		25
Long sleeve (thick)		36
Other. Please specify		
TOTAL CLO VALUE		

WORK ENVIRONMENT SURVEY

THANK YOU FOR YOUR PARTICIPATION IN THIS STUDY.

Please complete the consent form before you respond to the attached questionnaire. If you have not yet received the consent form along with information about the study, please contact the investigator.

PLEASE READ THE FOLLOWING INSTRUCTIONS BEFORE YOU START RESPONDING TO THIS QUESTIONNAIRE...

- Please complete the questionnaire within half an hour after you receive it. While you complete the questionnaire, several physical measurements of the environment will be taken to characterize the indoor space.
- Please do not discuss the contents of this questionnaire or your responses with any other persons.
- Please complete the entire questionnaire without skipping any questions.
- Please complete the items in the questionnaire in the order that they are presented to you.
- Please do not write your name on this questionnaire.

Please do not write in this space

Identification number Sampling Zone

NOW, PLEASE COMPLETE THE FOLLOWING QUESTIONNAIRE......

Turn page over. please ☛

Right now, the time is ________

Please enter a number from the following scale that best describes how you feel at this time

At this time, I am, generally, __________

1 very uncomfortable
2 uncomfortable
3 somewhat uncomfortable
4 somewhat comfortable
5 comfortable
6 very comfortable

BACKGROUND INFORMATION

The following information will help us determine the general characterisitics of the occupants of this space today.

- Please indicate the type of correction lenses you are presently wearing:

  [ ] none [ ] reading glasses
  [ ] contact lenses [ ] other glasses (eg., bifocals)

- Please indicate if you are currently experiencing any of the following health conditions (check all that apply):

  [ ] headache
  [ ] rash or other skin condition
  [ ] chronic eye disease
  [ ] chronic back pain
  [ ] respiratory illness
  [ ] asthma
  [ ] sinusitis
  [ ] cardiovascular disease
  [ ] allergies
  [ ] other health conditions. Please specify.
  ____

- Please indicate if you are currently taking any medication (except vitamins).

  [ ] No [ ] Yes. Please specify ________________

DESCRIPTION OF YOUR WORKSTATION

Please enter a number from the following scales that best describes <u>your work station</u> <u>at this time</u>

The temperature at my workstation at this time can be described as_______

1 very hot
2 hot
3 warm
4 neutral
5 cool
6 cold
7 very cold

The humidity at my work station at this time can be described as ________

1 very wet
2 wet
3 moist
4 neutral
5 slightly dry
6 dry
7 very dry

The odor at my work station at this time can be described as ___________

1 no odor
2 very slight odor
3 slight odor
4 moderate odor
5 strong odor
6 very strong odor
7 overpowering odor

The odor at my workstation <u>when I first entered this space</u> can be described as _________________

1 no odor
2 very slight odor
3 slight odor
4 moderate odor
5 strong odor
6 very strong odor
7 overpowering odor

ASSESSMENT OF HOW YOU FEEL

Please check one or more of the following categories that describe how <u>you feel</u> <u>at this time</u>

At this time, I am experiencing the following:

[ ]	sore or strained eyes	[ ]	dry throat	[ ]	headache
[ ]	tearing eyes	[ ]	dry or itchy skin	[ ]	burning eyes
[ ]	hoarseness	[ ]	sluggishness	[ ]	runny nose
[ ]	reddening of skin	[ ]	dry or itching eyes	[ ]	sore throat
[ ]	unusual fatigue or tiredness	[ ]	stuffy nose or sinus congestion	[ ]	difficulty remembering
[ ]	wheezing or whistling in chest	[ ]	difficulty concentrating	[ ]	sneezing
[ ]	dizziness or lightheadedness	[ ]	cough	[ ]	nausea or vomiting
[ ]	aching muscles or joints	[ ]	shortness of breath	[ ]	chest tightness

Please enter a number from the following scales that best describes how you feel <u>at this time</u>

At this time I feel ________

1 very hot
2 hot
3 warm
4 neutral
5 cool
6 cold
7 very cold

At this time I feel ________

1 very wet
2 wet
3 moist
4 neutral
5 slightly dry
6 dry
7 very dry

ASSESSMENT OF THE ENVIRONMENT AT YOUR WORKSTATION

Please enter a number from the following scale that best describes your assessment of each of the following aspects of the environment at your workstation <u>at this time</u>.

1 very unacceptable
2 unacceptable
3 somewhat unacceptable
4 somewhat acceptable
5 acceptable
6 very acceptable

_____	Loudness of sounds	_____	Humidity
_____	Glare	_____	Brightness of lighting
_____	Odor	_____	Temperature
_____	Pitch of sounds	_____	Air movement
_____	Shadows	_____	Number of noisy distractions
_____	Personal space	_____	Thermal conditions
_____	Air quality	_____	Lighting conditions
_____	Acoustics	_____	Overall environmental conditions

Please enter a number from the following scale that best describes how you feel at this time.

At this time, I am, thermally, ______________

1 very uncomfortable
2 uncomfortable
3 somewhat uncomfortable
4 somewhat comfortable
5 comfortable
6 very comfortable

OCCUPANCY PROFILE

The following information will be used to characterize occupancy patterns and typical activity levels in this space.

- Please estimate the total number of hours that you spent today at your workstation until this time.

  ______________ hours ____________ minutes

- In column 2, please estimate the time that you spent doing the following activities in the **two hours preceding the present time today**. In column 3, please check the category or categories that indicate the location(s) at which you engaged in these activities.

Column 1 ACTIVITIES	Column 2 DURATION	Column 3 LOCATION	
		At workstation	Not at workstation
Reading, seated	hours min.		
Writing or drawing	hours min.		
Typing or keyboarding	hours min.		
Filing, seated	hours min.		
Filing, standing	hours min.		
Walking about	hours min.		
Lifting or packing	hours min.		
Other. Please specify			
1.	hours min.		
2.	hours min.		
3.	hours min.		

CLOTHING LEVELS

Please check the items that describe the clothing that you are presently wearing. Please do not write in the shaded areas.

Underwear			Double-breasted (thick)		48
Men's briefs		04	Sleeveless vest (thin)		10
Panties		03	Sleeveless vest (thick)		17
Bra		01	Other. Please specify		
T-shirt		08	**Trousers and Coveralls**		
Full slip		16	Short shorts		06
Half slip		14	Walking shorts		08
Long underwear top		20	Straight trousers (thin)		15
Long underwear bottoms		15	Straight trousers (thick)		24
Other. Please specify			Sweat pants		28
Footwear			Overalls		30
Ankle-length socks		02	Coveralls		49
Calf-length socks		03	Other. Please specify		
Knee socks (thick)		06	**Dresses and skirts**		
Panty hose stockings		02	Skirt (thin)		14
Sandals / thongs		02	Skirt (thick)		23
Boots		10	Long-sleeve shirt dress (thin)		33
Other. Please specify			Long-sleeve shirt dress (thick)		47
Shirts and Blouses			Short-sleeve shirt dress (thin)		29
Sleeveless, scoop-neck blouse		12	Sleeveless, scoop neck (thin)		23
Short-sleeve, dress shirt		19	Sleeveless, scoop neck (thick)		27
Long-sleeve, dress shirt		25	Other. Please specify		
Long-sleeve, flannel shirt		34	**Sweaters**		
Short-sleeve, knit sport shirt		17	Sleeveless vest (thin)		13
Long-sleeve, sweat shirt		34	Sleeveless vest (thick)		22
Other. Please specify			Long-sleeve (thin)		25
Lined Suit jackets & vests			Long sleeve (thick)		36
Single-breasted (thin)		36	Other. Please specify		
Single-breasted (thick)		44	**TOTAL CLO VALUE**		
Double-breasted (thin)		42			

DAY 2 TIME 2

WORK ENVIRONMENT SURVEY

THANK YOU FOR YOUR PARTICIPATION IN THIS STUDY.

Please complete the consent form before you respond to the attached questionnaire. If you have not yet received the consent form along with information about the study, please contact the investigator.

PLEASE READ THE FOLLOWING INSTRUCTIONS BEFORE YOU START RESPONDING TO THIS QUESTIONNAIRE...

- Please complete the questionnaire within half an hour after you receive it. While you complete the questionnaire, several physical measurements of the environment will be taken to characterize the indoor space.
- Please do not discuss the contents of this questionnaire or your responses with any other persons.
- Please complete the entire questionnaire without skipping any questions.
- Please complete the items in the questionnaire in the order that they are presented to you.
- Please do not write your name on this questionnaire.

Please do not write in this space

Identification number **Sampling Zone**

NOW, PLEASE COMPLETE THE FOLLOWING QUESTIONNAIRE......

Please enter a number from the following scale that best describes how you feel at this time

At this time, I am, generally, ____________

1 very uncomfortable
2 uncomfortable
3 somewhat uncomfortable
4 somewhat comfortable
5 comfortable
6 very comfortable

Right now, the time is __________

DESCRIPTION OF YOUR WORKSTATION

Please enter a number from the following scales that best describes <u>your work station</u> <u>at this time</u>

The temperature at my workstation at this time can be described as_______

1 very hot
2 hot
3 warm
4 neutral
5 cool
6 cold
7 very cold

The humidity at my work station at this time can be described as ________

1 very wet
2 wet
3 moist
4 neutral
5 slightly dry
6 dry
7 very dry

The odor at my work station at this time can be described as ___________

1 no odor
2 very slight odor
3 slight odor
4 moderate odor
5 strong odor
6 very strong odor
7 overpowering odor

The odor at my workstation <u>when I first entered this space</u> can be described as _________________

1 no odor
2 very slight odor
3 slight odor
4 moderate odor
5 strong odor
6 very strong odor
7 overpowering odor

ASSESSMENT OF HOW YOU FEEL

Please check one or more of the following categories that describe how <u>you feel</u> <u>at this time</u>

At this time, I am experiencing the following:

[ ]	sore or strained eyes	[ ]	dry throat	[ ]	headache
[ ]	tearing eyes	[ ]	dry or itchy skin	[ ]	burning eyes
[ ]	hoarseness	[ ]	sluggishness	[ ]	runny nose
[ ]	reddening of skin	[ ]	dry or itching eyes	[ ]	sore throat
[ ]	unusual fatigue or tiredness	[ ]	stuffy nose or sinus congestion	[ ]	difficulty remembering
[ ]	wheezing or whistling in chest	[ ]	difficulty concentrating	[ ]	sneezing
[ ]	dizziness or lightheadedness	[ ]	cough	[ ]	nausea or vomiting
[ ]	aching muscles or joints	[ ]	shortness of breath	[ ]	chest tightness

Please enter a number from the following scales that best describes how you feel <u>at this time</u>

At this time I feel ________

1 very hot
2 hot
3 warm
4 neutral
5 cool
6 cold
7 very cold

At this time I feel ________

1 very wet
2 wet
3 moist
4 neutral
5 slightly dry
6 dry
7 very dry

ASSESSMENT OF THE ENVIRONMENT AT YOUR WORKSTATION

Please enter a number from the following scale that best describes your assessment of each of the following aspects of the environment at your workstation at this time.

1 very unacceptable
2 unacceptable
3 somewhat unacceptable
4 somewhat acceptable
5 acceptable
6 very acceptable

_____ Loudness of sounds

_____ Glare

_____ Odor

_____ Pitch of sounds

_____ Shadows

_____ Personal space

_____ Air quality

_____ Acoustics

_____ Humidity

_____ Brightness of lighting

_____ Temperature

_____ Air movement

_____ Number of noisy distractions

_____ Thermal conditions

_____ Lighting conditions

_____ Overall environmental conditions

Please enter a number from the following scale that best describes how you feel at this time.

At this time, I am, thermally, ________________

1 very uncomfortable
2 uncomfortable
3 somewhat uncomfortable
4 somewhat comfortable
5 comfortable
6 very comfortable

OCCUPANCY PROFILE

The following information will be used to characterize occupancy patterns and typical activity levels in this space.

- Please estimate the total number of hours that you spent today at your workstation until this time.

  ________________ hours ____________ minutes

- In column 2, please estimate the time that you spent doing the following activities in the **two hours preceding the present time today**. In column 3, please check the category or categories that indicate the location(s) at which you engaged in these activities.

Column 1 ACTIVITIES	Column 2 DURATION		Column 3 LOCATION	
			At workstation	Not at workstation
Reading, seated	hours	min.		
Writing or drawing	hours	min.		
Typing or keyboarding	hours	min.		
Filing, seated	hours	min.		
Filing, standing	hours	min.		
Walking about	hours	min.		
Lifting or packing	hours	min.		
Other. Please specify				
1.	hours	min.		
2.	hours	min.		
3.	hours	min.		

PERCEPTION OF ACTIVITIES AND TECHNOLOGIES USED IN INDOOR SPACES

This section asks for your perceptions about the nature of risk to the health of occupants in this space resulting from the following: building mechanical systems, office equipment, other occupants and indoor furnishings. Please circle the number that best describes your assessment of each of their following aspects.

Building mechanical systems (i.e., lighting, heating, ventilation and air conditioning (HVAC) systems).

Do you feel that this is a health risk to the occupants?
[ ] yes [ ] no

If 'yes', please continue. If 'no', please skip to the next column (office equipment) ☛

How does this risk occur?
1 2 3 4 5
voluntarily — not voluntarily

When does the consequence of risk occur?
1 2 3 4 5
delayed — immediate

To what precision is the risk known to the persons exposed to it?
1 2 3 4 5
known — unknown

To what precision is the risk known to science?
1 2 3 4 5
known — unknown

How familiar is this risk to you?
1 2 3 4 5
familiar — unfamiliar

To what extent can the consequences of this risk be prevented?
1 2 3 4 5
completely — not at all

To what extent does this risk affect you personally?
1 2 3 4 5
directly — not at all

Continue in the next column, please (office equipment) ☛

Office equipment (e.g., computers, copiers) or chemicals (e.g., adhesives, glues)

Do you feel that this is a health risk to the occupants?
[ ] yes [ ] no

If 'yes', please continue. If 'no', please skip to the following page (other occupants) ☛

How does this risk occur?
1 2 3 4 5
voluntarily — not voluntarily

When does the consequence of risk occur?
1 2 3 4 5
delayed — immediate

To what precision is the risk known to the persons exposed to it?
1 2 3 4 5
known — unknown

To what precision is the risk known to science?
1 2 3 4 5
known — unknown

How familiar is this risk to you?
1 2 3 4 5
familiar — unfamiliar

To what extent can the consequences of this risk be prevented?
1 2 3 4 5
completely — not at all

To what extent does this risk affect you personally?
1 2 3 4 5
directly — not at all

Turn page over, please (other occupants) ☛

Please continue...

Other occupants (e.g., other persons who occupy the space)

Do you feel that this is a health risk to the occupants?
[ ] yes [ ] no

If 'yes', please continue. If 'no', please skip to the next column (indoor furnishings) ☛

How does this risk occur?
1 2 3 4 5
voluntarily — not voluntarily

When does the consequence of risk occur?
1 2 3 4 5
delayed — immediate

To what precision is the risk known to the persons exposed to it?
1 2 3 4 5
known — unknown

To what precision is the risk known to science?
1 2 3 4 5
known — unknown

How familiar is this risk to you?
1 2 3 4 5
familiar — unfamiliar

To what extent can the consequences of this risk be prevented?
1 2 3 4 5
completely — not at all

To what extent does this risk affect you personally?
1 2 3 4 5
directly — not at all

Continue in the next column , please (Indoor furnishings) ☛

Indoor furnishings (e.g., carpets, drapes)

Do you feel that this is a health risk to the occupants?
[ ] yes [ ] no

If 'yes', please continue. If 'no', please skip to the next page ☛

How does this risk occur?
1 2 3 4 5
voluntarily — not voluntarily

When does the consequence of risk occur?
1 2 3 4 5
delayed — immediate

To what precision is the risk known to the persons exposed to it?
1 2 3 4 5
known — unknown

To what precision is the risk known to science?
1 2 3 4 5
known — unknown

How familiar is this risk to you?
1 2 3 4 5
familiar — unfamiliar

To what extent can the consequences of this risk be prevented?
1 2 3 4 5
completely — not at all

To what extent does this risk affect you personally?
1 2 3 4 5
directly — not at all

APPENDIX 2

INFORMED CONSENT

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of project	**DEVELOPING HUMAN RESPONSE AND EXPOSURE CRITERIA FOR ASSESSING INDOOR ENVIRONMENTS**
Principal Investigator	**Nisha Patet Sensharma**

I THE PURPOSE OF THIS RESEARCH PROJECT

You are invited to participate in a study that is being conducted to empirically test some theoretical concepts related to occupant assessments of indoor environments. The purpose of this study is to examine how your assessments of your work environment relate to several physical measures of the work space. This space has been selected, as it represents a typical open plan work space. This study is also being conducted in another building on the Virginia Tech Campus.

II PROCEDURES

As participants in this study, you will be requested to complete two questionnaires, one soon after you enter this indoor space, and another just before you leave. While you complete the questionnaire, several physical measurements of the indoor environment will be taken to characterize the space. This procedure will be repeated twice, once in November, and once in December or January.

Your are requested to follow the instructions listed below:

a. Please do not discuss the contents of this questionnaire or your responses with any other persons. This is important, as the questionnaire will be completed at different times by different occupants of this space, and it is important for this research to assure that the data accurately reflect the perceptions of every individual occupant of this space.

b. Please complete the entire questionnaire without skipping any questions, and in the order in which they are presented to you. Missing information may render the data unusable.

It is anticipated that there is no risk to you as a participant in this project. All responses will be confidential.

III BENEFITS OF THIS PROJECT

Although the objective of this study is not to assess the quality of your work space, the data may (a) provide some indication of whether healthy and comfortable conditions are being provided in the space, or (b) detect problems, if these are present. The findings of this study are expected to contribute to the current effort by the building industry to develop methodologies to accurately assess and improve the quality of indoor environments. The findings of this study will be made available to Judy Lilly. Please contact her if you would like to receive information about the findings of this study.

IV EXTENT OF ANONYMITY OR CONFIDENTIALITY

All individual responses on the questionnaires will remain strictly confidential. Only aggregate data for all occupants in the space will be included in written reports of this research. The questionnaires will not include the names of the respondents. Identification numbers will be provided to mark the locations at which measurements are taken.

V COMPENSATION

There will be no monetary compensation or extra course credits for participating in this research.

VI FREEDOM TO WITHDRAW

You are free to withdraw from this study at any time without penalty.

VII APPROVAL OF RESEARCH

This research project has been approved, as required by the Institutional Review Board for projects involving human subjects at Virginia Polytechnic Institute and State University.

VIII SUBJECT'S RESPONSIBILITIES

Name ________________________________

Identification Number

I know of no reason I cannot participate in this study.

____
signature

Please detach and keep this page for your reference

IX SUBJECT'S PERMISSION

I have read and understand the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

Should I have any questions about this research or its conduct, I will contact:

Nisha Patet Sensharma (Investigator)	231-7338 (phone)
Patricia k. Edwards (Faculty advisor)	231-6416 (phone)
James E. Woods (Faculty advisor)	231-3282 (phone)
Ernest R. Stout (Chair, IRB Research Division)	231-9359 (phone)

Please complete this form if you do not wish to participate in this study....

I decline to participate in this study

Name ________________________________

Identification Number

Reason for not participating (optional)

____

____

____

APPENDIX 3

PRETEST INFORMED CONSENT AND QUESTIONNAIRE

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed consent for participants of investigative projects

Title of project	**DEVELOPING HUMAN RESPONSE AND EXPOSURE CRITERIA FOR ASSESSING INDOOR ENVIRONMENTS**
Principal Investigator	**Nisha Patet Sensharma**

I THE PURPOSE OF THIS RESEARCH PROJECT

You are invited to participate in the pretesting of a questionnaire that has been developed to empirically test some theoretical concepts related to occupant assessments of indoor environments. The purpose of this study is to examine how your assessments of your work environment relate to several physical measures of the work space. This study will be conducted in two buildings on the Virginia Tech Campus. The purpose of this pretest is to assess the efficacy of the questionnaire developed for this study in obtaining the required information.

II PROCEDURES

As participants of this pretest, you will be requested to complete the attached questionnaire. In addition, you will be requested to complete an evaluation form that asks for your assessments about the questionnaire.

Your are requested to follow the instructions listed below:

a. Please do not discuss the contents of this questionnaire or your responses with any other persons. This is important, as the questionnaire will be completed at different times by different occupants of this space, and it is important for this research to assure that the data accurately reflect the perceptions of every individual occupant of this space.

b. Please complete the entire questionnaire without skipping any questions, and in the order that they are presented to you. Missing information may render the data unusable.

It is anticipated that there is no risk to you as a participant in this project. All responses will be confidential.

III BENEFITS OF THIS PROJECT

The findings of this study are expected to contribute to the current effort by the building industry to develop methodologies to accurately assess and improve the quality of indoor environments. Your assessments of the questionnaire will be useful in improving confidence in the information obtained using the questionnaire that has been developed.

IV EXTENT OF ANONYMITY OR CONFIDENTIALITY

All individual responses on the questionnaires will remain strictly confidential. Only aggregate data for all respondents will be included in written reports of this research. The questionnaires will not include the names of the respondents.

V COMPENSATION

There will be no monetary compensation or extra course credits for participating in this research.

VI FREEDOM TO WITHDRAW

You are free to withdraw from this study at any time without penalty.

VII APPROVAL OF RESEARCH

This research project has been approved, as required by the Institutional Review Board for projects involving human subjects at Virginia Polytechnic Institute and State University.

VIII SUBJECT'S RESPONSIBILITIES

Name ______________________________

Identification Number

I know of no reason I cannot participate in this study.

____
signature

IX SUBJECT'S PERMISSION

I have read and understand the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

Should I have any questions about this research or its conduct, I will contact:

Nisha Patet Sensharma (Investigator)	231-7338 (phone)
Patricia k. Edwards (Faculty advisor)	231-6416 (phone)
James E. Woods (Faculty advisor)	231-3282 (phone)
Ernest R. Stout (Chair, IRB Research Division)	231-9359 (phone)

WORK ENVIRONMENT SURVEY

PRETEST

THANK YOU FOR YOUR PARTICIPATION IN THIS STUDY.

Please complete the consent form before you respond to the attached questionnaire. If you have not yet received the consent form along with information about the study, please contact the investigator.

PLEASE READ THE FOLLOWING INSTRUCTIONS BEFORE YOU START RESPONDING TO THIS QUESTIONNAIRE...

- Please complete the questionnaire within half an hour after you receive it. While you complete the questionnaire, several physical measurements of the environment will be taken to characterize the indoor space.
- Please do not discuss the contents of this questionnaire or your responses with any other persons.
- Please complete the entire questionnaire without skipping any questions.
- Please complete the items in the questionnaire in the order that they are presented to you.
- Please do not write your name on this questionnaire.

Please do not write in this space	
Identification number	Sampling Zone

NOW, PLEASE COMPLETE THE FOLLOWING QUESTIONNAIRE......

Please enter a number from the following scale that best describes how you feel at this time

At this time, I am, generally, ___________

1 very uncomfortable
2 uncomfortable
3 somewhat uncomfortable
4 somewhat comfortable
5 comfortable
6 very comfortable

Right now, the time is ________ am / pm

DESCRIPTION OF YOUR WORKSTATION

Please enter a number from the following scales that best describes your work station at this time

The temperature at my workstation at this time can be described as______

1 very hot
2 hot
3 warm
4 neutral
5 cool
6 cold
7 very cold

The humidity at my work station at this time can be described as _______

1 very wet
2 wet
3 moist
4 neutral
5 slightly dry
6 dry
7 very dry

The odor at my work station at this time can be described as __________

1 no odor
2 very slight odor
3 slight odor
4 moderate odor
5 strong odor
6 very strong odor
7 overpowering odor

The odor at my workstation when I first entered this space can be described as ________________

1 no odor
2 very slight odor
3 slight odor
4 moderate odor
5 strong odor
6 very strong odor
7 overpowering odor

ASSESSMENT OF HOW YOU FEEL

Please check one or more of the following categories that describe how <u>you feel</u> <u>at this time</u>

At this time, I am experiencing the following:

[ ]	sore or strained eyes	[ ]	dry throat	[ ]	headache
[ ]	tearing eyes	[ ]	dry or itchy skin	[ ]	burning eyes
[ ]	hoarseness	[ ]	sluggishness	[ ]	runny nose
[ ]	reddening of skin	[ ]	dry or itching eyes	[ ]	sore throat
[ ]	unusual fatigue or tiredness	[ ]	stuffy nose or sinus congestion	[ ]	difficulty remembering
[ ]	wheezing or whistling in chest	[ ]	difficulty concentrating	[ ]	sneezing
[ ]	dizziness or lightheadedness	[ ]	cough	[ ]	nausea or vomiting
[ ]	aching muscles or joints	[ ]	shortness of breath	[ ]	chest tightness

Please enter a number from the following scales that best describes how you feel <u>at this time</u>

At this time I feel __________

1 very hot
2 hot
3 warm
4 neutral
5 cool
6 cold
7 very cold

At this time I feel __________

1 very wet
2 wet
3 moist
4 neutral
5 slightly dry
6 dry
7 very dry

ASSESSMENT OF THE ENVIRONMENT AT YOUR WORKSTATION

Please enter a number from the following scale that best describes your assessment of the environment at your workstation <u>at this time</u>.

1 very unacceptable
2 unacceptable
3 somewhat unacceptable
4 somewhat acceptable
5 acceptable
6 very acceptable

_____	Loudness of sounds	_____	Humidity
_____	Glare	_____	Brightness of lighting
_____	Odor	_____	Temperature
_____	Pitch of sounds	_____	Air movement
_____	Shadows	_____	Number of noisy distractions
_____	Personal space	_____	Thermal conditions
_____	Air quality	_____	Lighting conditions
_____	Acoustics	_____	Overall environmental conditions

Please enter a number from the following scale that best describes how you feel at this time.

At this time, I am, thermally, ________________

1 very uncomfortable
2 uncomfortable
3 somewhat uncomfortable
4 somewhat comfortable
5 comfortable
6 very comfortable

ASSESSMENT OF YOUR WORK

The following information will help us determine occupant perceptions of activities carried out in this space. In column 2, please circle the number that best describes nine aspects of your work as listed in column 1. In column 3, please circle the number that best describes the importance of each of these to your satisfaction with your work.

Column 1 Aspects of work	Column 2 Assessment of work	Column 3 Importance
Personal control over work decisions	1 2 3 4 5 high ... low	1 2 3 4 5 not at all important ... very important
Personal control over physical environment at work	1 2 3 4 5 high ... low	1 2 3 4 5 not at all important ... very important
Nature of work	1 2 3 4 5 varied ... repititive	1 2 3 4 5 not at all important ... very important
Nature of work	1 2 3 4 5 stimulating ... boring	1 2 3 4 5 not at all important ... very important
Definition of job responsibilities	1 2 3 4 5 yes ... not at all	1 2 3 4 5 not at all important ... very important
Workload	1 2 3 4 5 appropriate ... inapp-propriate	1 2 3 4 5 not at all important ... very important
Relationship with supervisors	1 2 3 4 5 excellent ... poor	1 2 3 4 5 not at all important ... very important
Relationship with colleagues	1 2 3 4 5 excellent ... poor	1 2 3 4 5 not at all important ... very important
Opportunity for advancement in job	1 2 3 4 5 good ... bad	1 2 3 4 5 not at all important ... very important
Level of work related stress	1 2 3 4 5 not at all stressful ... very stressful	1 2 3 4 5 not at all important ... very important

ASSESSMENT OF ACTIVITIES AND TECHNOLOGIES USED IN THIS SPACE

Based on your current knowledge, this section asks for your assessment of the nature of risk to the health of occupants in this space resulting from the following activities and technologies. Please circle the number that best describes your assessment of the following aspects of each activity or technology.

Building mechanical systems (i.e., lighting, heating, ventilation and air conditioning (HVAC) systems).

Do you feel that this is a health risk to the occupants?
[ ] yes [ ] no

If you answered 'yes', please continue. Else, skip to the next item ☛

How does this risk occur?
1 2 3 4 5
voluntarily — not voluntarily

When does the consequence of risk occur?
1 2 3 4 5
delayed — immediate

To what precision is the risk known to the persons exposed to it?
1 2 3 4 5
known — unknown

To what precision is the risk known to science?
1 2 3 4 5
known — unknown

How familiar is this risk to you?
1 2 3 4 5
familiar — unfamiliar

To what extent can the consequences of this risk be prevented?
1 2 3 4 5
completely — not at all

To what extent does this risk affect you personally?
1 2 3 4 5
directly — not at all

continue in the next column ☛

Office equipment (e.g., computers, copiers) or chemicals (e.g., adhesives, glues)

Do you feel that this is a health risk to the occupants?
[ ] yes [ ] no

If you answered 'yes', please continue. Else, skip to the next item on the following page ☛

How does this risk occur?
1 2 3 4 5
voluntarily — not voluntarily

When does the consequence of risk occur?
1 2 3 4 5
delayed — immediate

To what precision is the risk known to the persons exposed to it?
1 2 3 4 5
known — unknown

To what precision is the risk known to science?
1 2 3 4 5
known — unknown

How familiar is this risk to you?
1 2 3 4 5
familiar — unfamiliar

To what extent can the consequences of this risk be prevented?
1 2 3 4 5
completely — not at all

To what extent does this risk affect you personally?
1 2 3 4 5
directly — not at all

Turn page over, please ☛

Please continue...

Other occupants

Do you feel that this is a health risk to the occupants?
[ ] yes [ ] no

If you answered 'yes', please continue. Else, skip to the next item ☛

How does this risk occur?
1 2 3 4 5
voluntarily — not voluntarily

When does the consequence of risk occur?
1 2 3 4 5
delayed — immediate

To what precision is the risk known to the persons exposed to it?
1 2 3 4 5
known — unknown

To what precision is the risk known to science?
1 2 3 4 5
known — unknown

How familiar is this risk to you?
1 2 3 4 5
familiar — unfamiliar

To what extent can the consequences of this risk be prevented?
1 2 3 4 5
completely — not at all

To what extent does this risk affect you personally?
1 2 3 4 5
directly — not at all

Indoor furnishings (e.g., carpets, drapes)

Do you feel that this is a health risk to the occupants?
[ ] yes [ ] no

If you answered 'yes', please continue. Else, stop.

How does this risk occur?
1 2 3 4 5
voluntarily — not voluntarily

When does the consequence of risk occur?
1 2 3 4 5
delayed — immediate

To what precision is the risk known to the persons exposed to it?
1 2 3 4 5
known — unknown

To what precision is the risk known to science?
1 2 3 4 5
known — unknown

How familiar is this risk to you?
1 2 3 4 5
familiar — unfamiliar

To what extent can the consequences of this risk be prevented?
1 2 3 4 5
completely — not at all

To what extent does this risk affect you personally?
1 2 3 4 5
directly — not at all

BACKGROUND INFORMATION

The following information will help us determine the general characteristics of the occupants of this space.

- What is your age? ________________ years

- What is your gender? [ ] male [ ] female

- Please indicate the type of correction lenses you are presently wearing:
  [ ] none [ ] reading glasses
  [ ] contact lenses [ ] other glasses (eg., bifocals)

- Please indicate if you are currently experiencing any of the following health conditions (check all that apply):
  [ ] headache [ ] asthma
  [ ] rash or other skin condition [ ] sinusitis
  [ ] chronic eye disease [ ] cardiovascular disease
  [ ] chronic back pain [ ] allergies
  [ ] respiratory illness [ ] other health conditions. Please specify. ________________

- Please indicate your current smoking status:
  [ ] current smoker [ ] occasional smoker
  [ ] former smoker [ ] never-smoker

- If current or occasional smoker, please estimate the amount of cigarettes, cigars or pipes smoked daily:

  Number of cigarettes [ ] less than one [ ] one to five [ ] six to ten
  [ ] eleven to twenty [ ] more than twenty
  Number of cigars [ ] less than one [ ] one to five [ ] more than five
  Pipefuls [ ] less than one [ ] one to five [ ] more than five

- Please indicate if you are currently taking any medication (except vitamins).
  [ ] No [ ] Yes. Please specify ________________

- Please estimate the total number of hours per week that you spend doing physical work or exercise. ________________ hours per week.

- Please estimate the number of beverages that you consume daily.
  coffee or tea ____________ cups
  alcohol ____________ glasses

- Which of the following categories best describes the type of work that you do in this space?
  [ ] managerial or administrative [ ] professional or technical
  [ ] clerical or secretarial [ ] other. Please specify ________________

CLOTHING LEVELS

Please check the items that describe the clothing that you are presently wearing. Please do not write in the shaded areas.

Underwear		
Men's briefs		04
Panties		03
Bra		01
T-shirt		08
Full slip		16
Half slip		14
Long underwear top		20
Long underwear bottoms		15
Footwear		
Ankle-length socks		02
Calf-length socks		03
Knee socks (thick)		06
Panty hose stockings		02
Sandals / thongs		02
Boots		10
Shirts and Blouses		
Sleeveless, scoop-neck blouse		12
Short-sleeve, dress shirt		19
Long-sleeve, dress shirt		25
Long-sleeve, flannel shirt		34
Short-sleeve, knit sport shirt		17
Long-sleeve, sweat shirt		34
Lined Suit Jackets & vests		
Single-breasted (thin)		36
Single-breasted (thick)		44
Double-breasted (thin)		42
Double-breasted (thick)		48
Sleeveless vest (thin)		10
Sleeveless vest (thick)		17

Trousers and Coveralls		
Short shorts		06
Walking shorts		08
Straight trousers (thin)		15
Straight trousers (thick)		24
Sweat pants		28
Overalls		30
Coveralls		49
Dresses and skirts		
Skirt (thin)		14
Skirt (thick)		23
Long-sleeve shirt dress (thin)		33
Long-sleeve shirt dress (thick)		47
Short-sleeve shirt dress (thin)		29
Sleeveless, scoop neck (thin)		23
Sleeveless, scoop neck (thick)		27
Sweaters		
Sleeveless vest (thin)		13
Sleeveless vest (thick)		22
Long-sleeve (thin)		25
Long sleeve (thick)		36
TOTAL CLO VALUE		

OCCUPANCY PROFILE

The following information will be used to characterize occupancy patterns and typical activity levels in this space. Please check the column that best describes your occupancy for each half hour today, until this time. In the column marked 'Description of activity', please enter the number from the categories listed below that best describes your activities for each of the indicated times.

> 1= reading, seated, 2 = writing or drawing, 3 = typing or keyboarding, 4 = filing, seated, 5 = filing, standing, 6 = walking about, 7 = lifting or packing, 8 = other (please specify).

Please do not write in the shaded portions.

Time categories	**Location**				**Description of activity**
	at work station	**within office space**	**within the building**	**outside the building**	
8.00 am to 8:30 am					
8:30 am to 9:00 am					
9:00 am to 9:30 am					
9:30 am to 10:00 am					
10:00 am to 10:30 am					
10:30 am to 11:00 am					
11:00 am to 11:30 am					
11:30 am to 12:00 (noon)					
12:00 (noon) to 12:30 pm					
12:30 pm to 1:00 pm					
1:00 pm to 1:30 pm					
1:30 pm to 2:00 pm					
2:00 pm to 2:30 pm					
2:30 pm to 3:00 pm					
3:00 pm to 3:30 pm					
3:30 pm to 4:00 pm					
4:00 pm to 4:30 pm					
4:30 pm to 5:00 pm					
TOTAL EXPOSURE	AM PM	MEAN ACTIVITY LEVELS			AM PM

YOUR ASSESSMENT OF THE QUESTIONNAIRE

The following information will help to improve the quality of information acquired from the questionnaire.

- How much time did you need to complete the questionnaire?__________ minutes

- Were any of the questions difficult to **understand**? Please identify the questions as well as specific words that require additional clarification.

____
____
____
____
____
____

- Were any of the questions difficult to **answer**? Please identify these questions.

____
____
____
____
____
____

- Please comment on the format of the questionnaire.

____
____
____
____
____
____

- Additional comments.

____
____
____
____
____

THANK YOU FOR YOUR PARTICIPATION IN THIS PRETEST.

APPENDIX 4

RESPONDENT COMMENTS ON PRETEST

Summary of comments from respondents for each evaluation item:
Were any of the questions difficult to understand? Please identify the questions as well as specific words that require additional clarification.

PO-01	What is the difference between temperature, thermal conditions, and thermal comfort?
PO-02	No.
PO-03	Assessment of your work - nine aspects, but includes ten columns.
PO-04	I didn't understand what was needed in the occupancy profile (p.10).
PO-05	Page 5 - definition of job responsibilities - Please clarify.
PO-06	Not really.
PO-07	No.
PO-08	On page 5, I had to read the instructions twice before I fully understood (assessment of your work).
PS-01	None.
PS-02	Unclear what first question on page 7 was referring to (I.e, risk perception for 'other occupants').
PS-03	Yes - importance of course with respect to future - good / bad? Also, the words in most of the questions were generic.
PS-04	Clothing levels: Trousers and Coveralls - I wasn't sure what to check off for jeans.
PS-05	No, They were not difficult.
PS-07	No questions were difficult.
PS-09	No.
PS-10	No.
PS-11	The 'other occupants' does not make any sense as they were the same questions as the previous one - Ex. How do you feel?
PS-12	No.
9101(O)	Question 1 on page 7 (risk perception with respect to 'other occupants). Page 8: Number of beverages - nothing about overall beverage consumption - soft drinks, water? Page 9: Not much allowance for females in non-dressy work situations (?) Page 10: Perhaps shouldn't administer before 10:00 a.m. In 8:00 to 5:00 schedule.
9102(O)	Page 7 of 11 - Other occupants - it took a few seconds to understand that I was determining if other occupants were a health risk.
9103(S)	No.
9104(S)	The total amount of time spent working at my area.
9105(S)	The first question on the 10th page - I was not quite sure what 'total' (total number of hours spent at workstation) meant. Therefore, I put the total hours since the beginning of this semester.

Were any of the questions difficult to answer? Please identify these questions.

PO-01	Questions on risk perception - I would not know 'precision known' answers. (I.e, responses to these questions may depend on respondent's knowledge).
PO-02	No.
PO-04	(P.6) Precision of knowledge re: health risk.
PO-05	No.
PO-06	No.
PO-07	I didn't like the way the questions were on page 10 (occupancy profile).
PO-08	No.
PS-01	No.
PS-03	Yes, the one mentioned (i.e, assessment of your work).
PS-04	No.
PS-05	No.
PS-06	The occupancy profile was a bit obtuse, as it is based on office building environment rather than a classroom / campus environment. My work times are more commonly from 1:00 p.m. To 2:00 a.m., with gaps intermittent, but almost always from 5:00 p.m. To 8:00 p.m.
PS-07	No.
PS-09	No.
PS-10	Slightly, Those questions dealing with health issues, my area could possibly be harmful to my sight with the direct, yet small amounts of light present. This condition is a voluntary decision by the group as well as pressure from instructors to appreciate the shadow. I agree, and don't really feel that this is an actual health risk.
PS-11	No.
PS-12	No.
9101(O)	No, except as noted.
9102(O)	No.
9103(S)	No.
9104(S)	No.
9105(S)	N/A

Please comment on the format of the questionnaire.

PO-06	Good.
PO-08	Page 5 (assessment of work) seems overwhelming at first, until you go back and re-read the instructions.
PS-01	Format was logical and direct.
PS-02	Interesting path between general and specific questions, personal and public.
PS-03	O.K.
PS-04	Good.
PS-05	Interesting.
PS-06	The assessment of how you feel seems pretty hit and miss from person to person. I assume its purpose is to draw out chronic problems.
PS-07	It was very straight forward.
PS-09	Easy to read and do.
PS-10	It was adequate, easy to follow and understand. Not too lengthy.
PS-11	The format was easy to follow and laid out well.
PS-12	Straightforward.
9101(O)	Great.
9102(O)	Fine.
9103(S)	Nicely formatted.

9104(S) I guess the layout is fine.
9105(S) It was basically fairly easy and fluid.

Additional comments

PO-04 Consent form - the signature line should be below the permission provisions listed in section IX (signature applies to what precedes it).
PO-05 Good questions.
PO-08 This seems to be a very thorough questionnaire.
PS-02 Questions on pages 6 and 7 (risk perception) were vague - I could be judging anything from a complaint on lack of fresh air to asbestos cleaning.
PS-03 I don't see how any of these questions or answers could lead to any substantial qualitative exploration or understanding of the assessment of an indoor environment. For example, whether I were cool or warm, instead of numb and enjoying this state would depend on whether there were a fresh cool or warm breeze affecting me. Similarly, whether the lighting were artificial or natural would affect my opinion of it. Also, acceptable says nothing of desirable.
PS-04 None.
PS-10 None.
PS-11 I hope this helps you.
PS-12 Would like larger work stations.
9101(O) Well constructed - visually excellent.
If work environment at time is quiet, but generally is noisy or chaotic, there's no way to comment. Thanks.
9102(O) Taking this so early in the morning is definitely a factor in the answers. The quality of my space is much better at this time of day than even one or two hours later. My responses would have been much different in the afternoon. Thank you!
9103(S) None.

What does the word 'thermal' mean to you?

Most respondents initially said that 'thermal' pertained to 'temperature'. However, when further probed, (e.g., is humidity a factor?) said that they may have considered other factors in making judgements about thermal-related items.

PO-01 Mainly temperature, but may have unconsciously considered humidity and air movement.
PO-02 Mainly temperature, maybe humidity and air movement.
PO-03 Mainly temperature, maybe humidity and air movement.
PO-04 Mainly temperature. Humidity may be a factor if out of doors. A lack of air movement rather than air movement may be a factor.
PO-05 Not available for interview.
PO-06 Includes temperature, air movement and clothing. Humidity is not included because it cannot be controlled by the respondent.
PO-07 Mainly temperature, maybe humidity, air movement, air quality.
PO-08 Temperature and humidity, and maybe air movement.
PS-01 Variance in temperature.

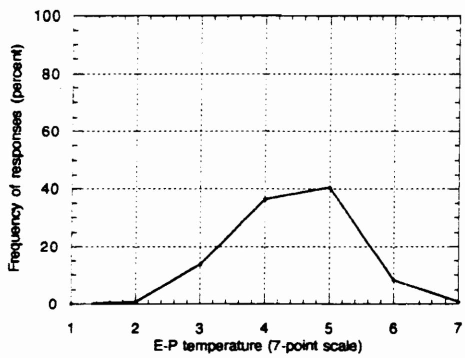
PS-02 The term 'thermal' implies: heating environment (not much in summer, only when one needs extra warmth), indoors, warm clothing, carpeting, dryness (important), air movement (warm heat), and 'fixing' something.
PS-03 Temperature of body with respect to environment, humidity if out of doors, no air movement.
PS-04 Temperature of air and state of body, humidity.
PS-05 Heat, how you feel, weather, mechanical system (important attributes), humidity, air movement, activity, occupant density, equipment.
PS-06 Lack of comfort, hot and cold, drafts, humidity, sensibilities - exposure time - adaptation.
PS-07 Not available for interview.
PS-09 Heat - temperature (body), humidity, air movement.
PS-10 Body temperature and surrounding temperature - how it can be altered, building / climate / ventilation, perception of temperature, humidity.
PS-11 Difference in body temperature and air temperature, humidity.
PS-12 Not available for interview.
9101(O) Temperature (surrounding), Weather - humidity and airflow.
9102(O) Quality of heat, air temperature, air pressure, air oppressive, quality of air movement.
9103(S) Temperature (hotness or coldness) and related to body (how I feel).
9104(S) Heat, temperature (warmth).
9105(S) Environmental climate (humidity, air movement, temperature).

Respondents comments during interview

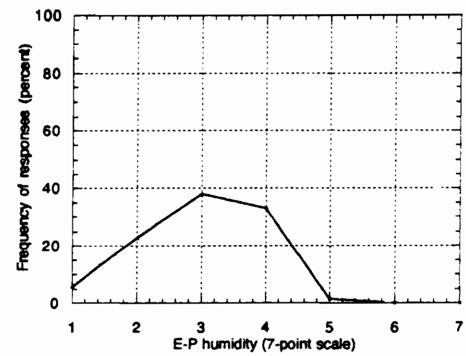
PO-01 For risk perception questions, it may be helpful to indicate to the respondent that these are *opinions*.
PO-03 Need clearer directions for responding to the risk perception questions (did not initially respond to each column for this item).
Need to improve format for the activity profile sheet.
PO-04 Occupancy profile - people may engage in more than one activity during each hour.
Include an 'other' category for clothing.
Stress 'opinion' for risk perception questions.
PO-05 Not available for interview.

APPENDIX 5

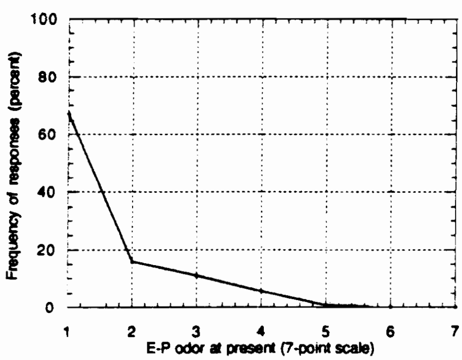
FREQUENCY DISTRIBUTIONS FOR VARIABLES IN THE REGRESSION EQUATIONS



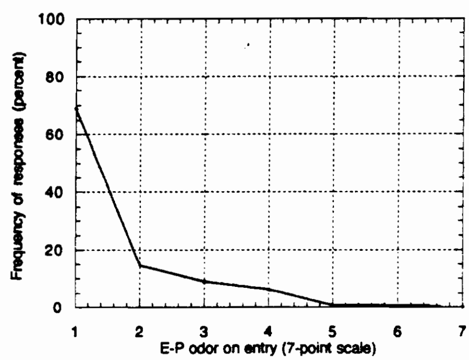
Temperature at workstation (E-P)



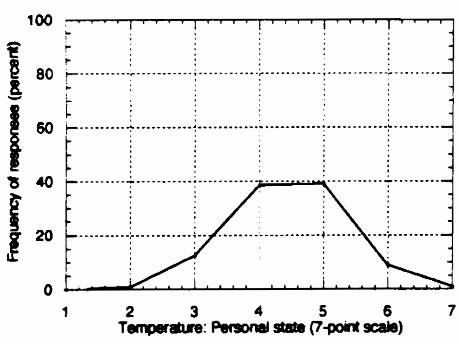
Humidity at workstation (E-P)



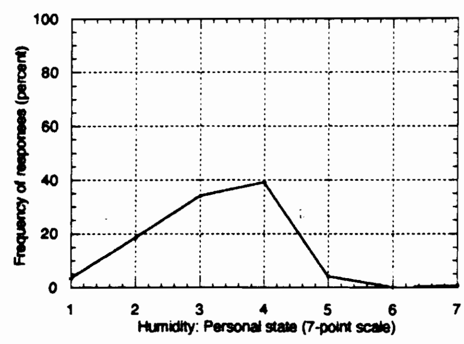
Odor intensity at workstation at present (E-P)



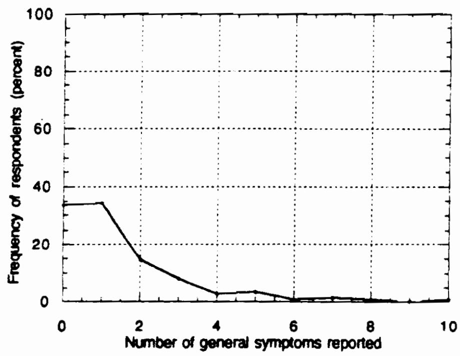
Odor intensity at workstation on entry (E-P)



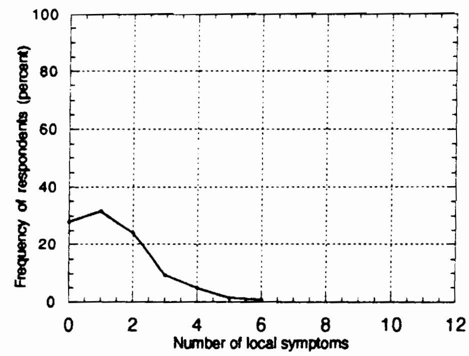
Temperature: Personal state (P-P)



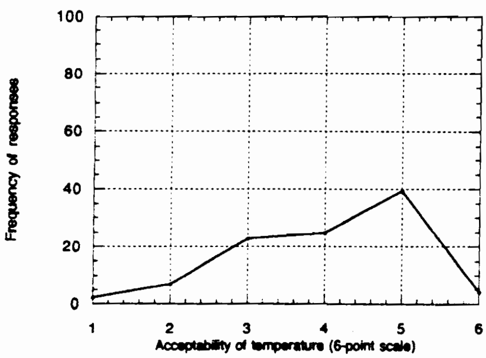
Humidity: Personal State (P-P)



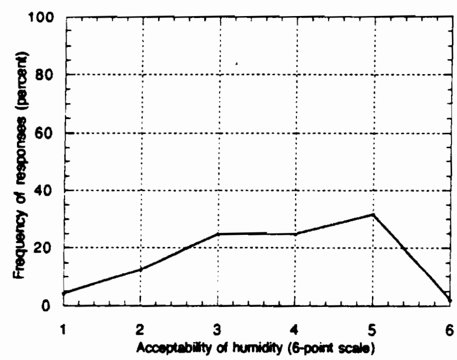
General symptoms (P-P)



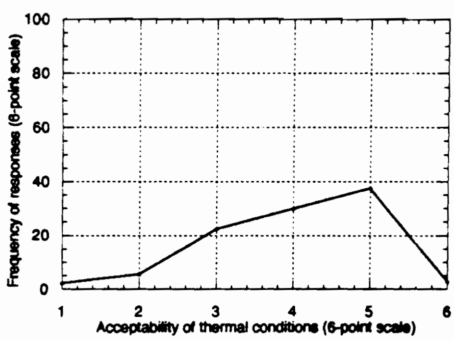
Local symptoms (P-P)



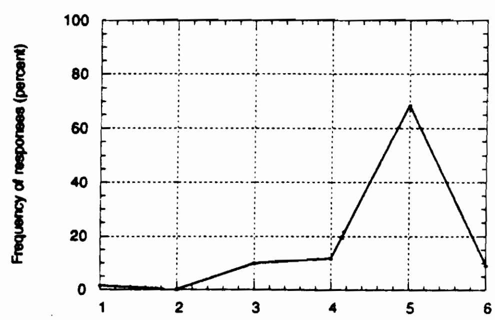
Acceptability of temperature (E-A)



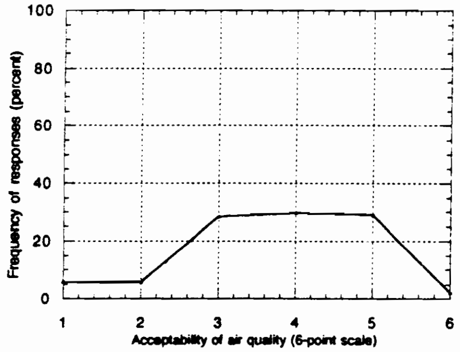
Acceptability of humidity (E-A)



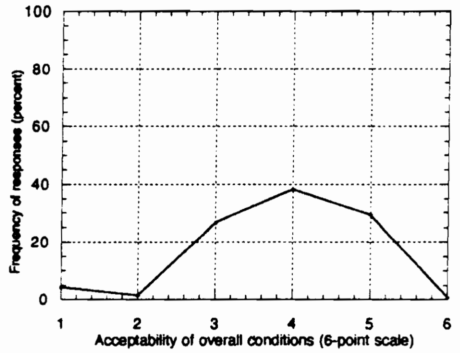
Acceptability of thermal conditions (E-A)



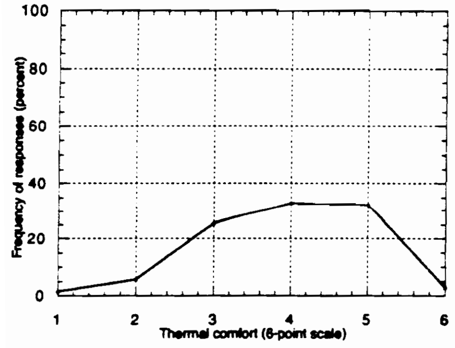
Acceptability of odor (E-A)



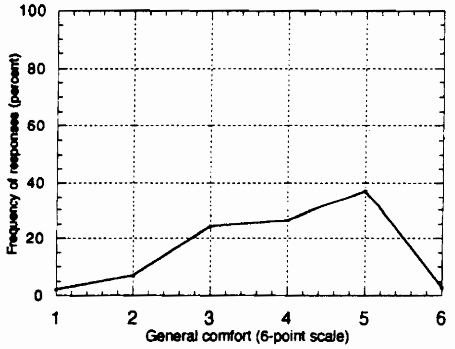
Acceptability of air quality (E-A)



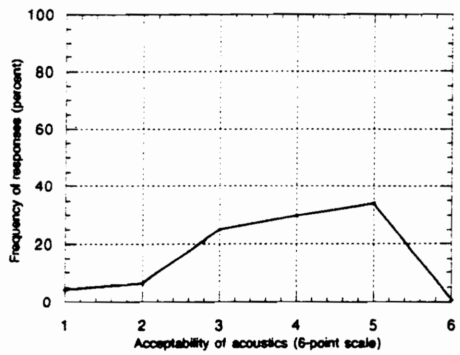
Acceptability of overall conditions (E-A)



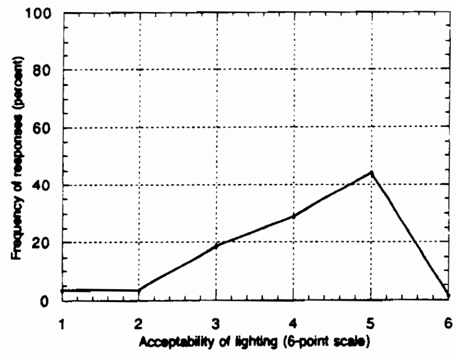
Thermal comfort (P-A)



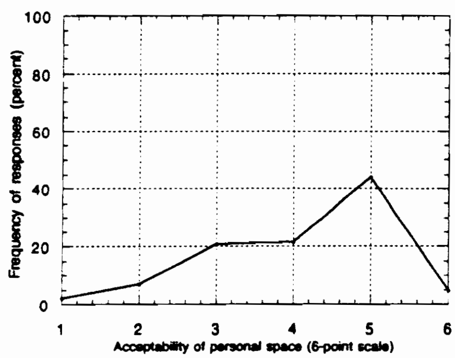
General comfort (P-A)



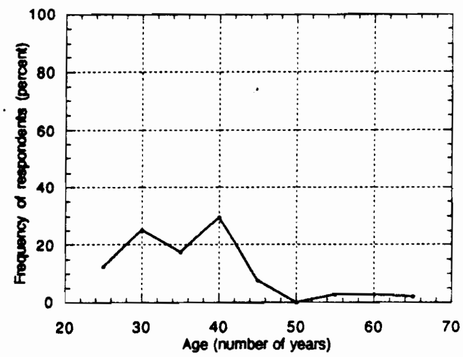
Acceptability of acoustics (other physical)



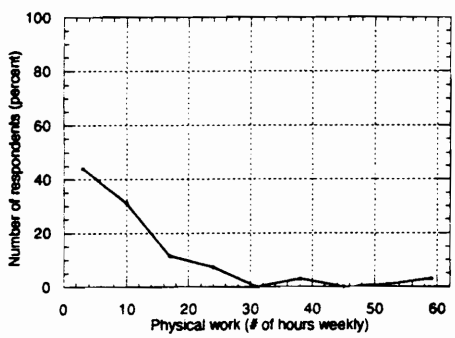
Acceptability of lighting (other physical)



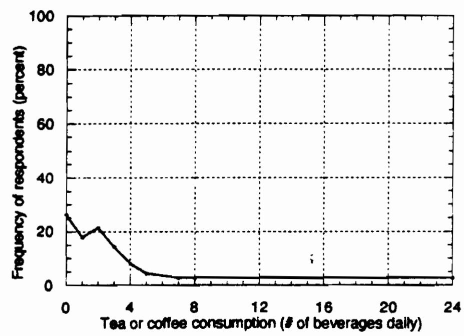
Acceptability of personal space (other physical)



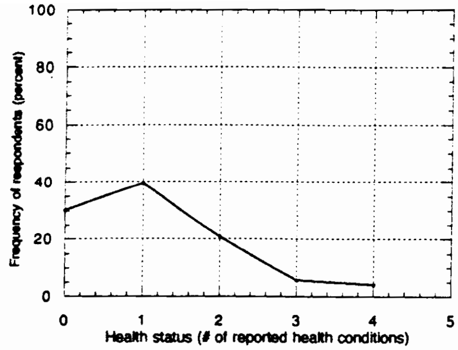
Age (intrinsic)



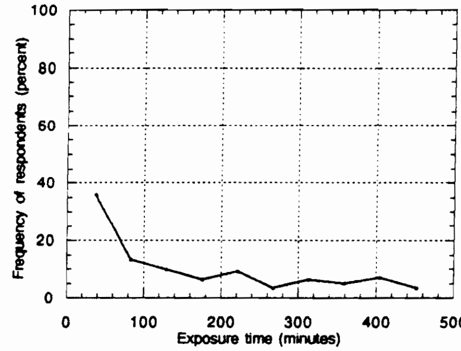
Physical work (intrinsic)



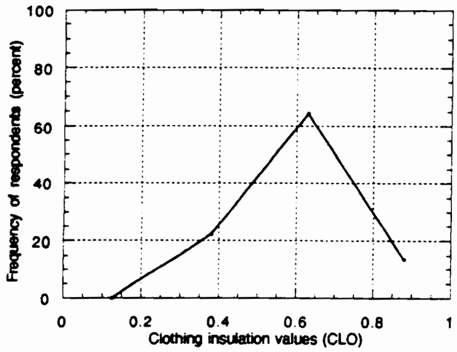
Daily consumption of tea or coffee (intrinsic)



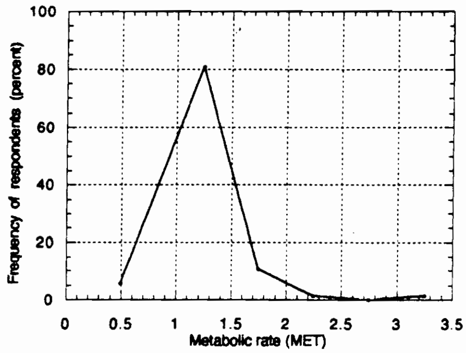
Health status (intrinsic)



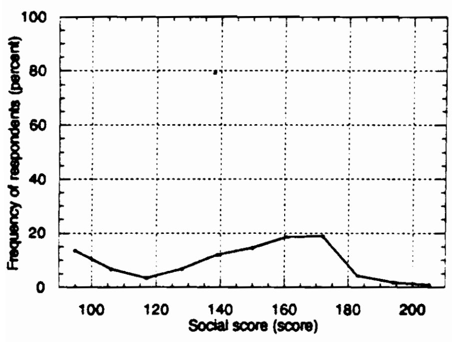
Exposure time (adaptive)



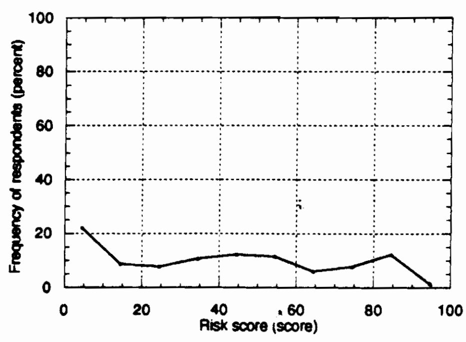
Clothing insulation values (adaptive)



Metabolic rate (adaptive)



Social score (psycho-environmental)



Risk score (risk perception)

VITA

The author was born in Bombay, India on the 28th day of August, 1965. She received her bachelors degree in Architecture from the Sir. J.J. College of Architecture, University of Bombay in 1988. She worked for a year and a half at Bhonsule Khambatta Architects at Bombay, India. She then joined the department of Urban Affairs and Planning at Virginia Polytechnic Institute and State University, and was awarded the Masters degree in Urban and Regional Planning in May, 1991. In 1991, she began working towards her doctorate in Environmental Design and Planning, and received the doctoral degree in December 1995.