36. ERGONOMICS AND THE LEARNING ENVIRONMENT

G. F. McVey
BOSTON UNIVERSITY

36.1 BACKGROUND OF TOPIC

36.1.1 Introduction

In seeking a universally acceptable definition of the *learning environment,* I have borrowed from Tessmer and Harris's useful publication *Analyzing the Instructional Setting* (1992, p. 15): "The learning environment is the physical space allotted for learning. This environment may be a classroom, training center, computer lab, study room at home, office desk, car, or some combination of any of these." In citing the work of Spivak (1975) and David (1975), Tessmer and Harris note (p. 18): "The environment exerts a powerful influence on learning and behavior, even though we may not be aware of it or may choose to disregard it." These authors go on to state that "... environment-based (facility) design is still more art than science." While I recognize that this represents the popular conception, I believe that it was more true in the past than it is today. And it is my hope that this chapter will serve to change such perceptions.

Recently there have been significant gains made in our understanding and awareness of ergonomics as applied to the design and utilization of various kinds of environments where people perform tasks not dissimilar to those performed in schools and training centers. I believe that much of that information is readily transferable to the educational sector. In addition, there have been other studies conducted by myself, my students, and by other academicians and their students specifically assessing the merits of design features in educational facilities, which I believe if used collectively with the previously mentioned information are sufficient to make possible educational-facilities design decisions based on hard science. That is one of the primary goals of this chapter, a goal that also embraces my own singular professional objective for more than 25 years.

36.1.2 The Components and Function of the Learning Environment

The learning environment consists of all those physical-sensory elements such as lighting, color, sound, space, furniture, and so on that characterize the place in which a student is expected to learn. This surround should be designed so that learning may proceed with minimum stress and maximum effectiveness. Thus, it should promote sensory comfort and high auditory and visual acuity; and its dimensions and physical layout should accommodate scheduled activities, allow for people's sense of personal space, and promote desirable patterns of social interaction and communication.

In addition to supporting human functioning, the learning environment must accommodate the equipment, tools, and materials that are used in education and training. The introduction of these media, be it chalkboard, computer terminal, video, or film display, inevitably alters the nature of the environment. When a medium is prudently integrated into the learning environment, it may be effectively employed in ways that are coordinated with basic human sensory processes. However, when media technology adds glare, noise, or excessive heat to the learning situation, it vitiates the design of that environment and interferes with those same processes

Consequently, guidelines are required that will enable the facility designer to create learning environments that recognize both how human beings function and how instructional tools operate. The science that investigates such matters is called either *human factors engineering* or *ergonomics,* and knowledge from this science is, I believe, essential for those who design educational facilities. And similarly, I believe that an understanding of ergonomics will help the educator better manage both the equipment and the physical surround to promote effectively his or her educational objectives. Thus, the facility designer, through prudent design in accordance with established ergonomic principles, and the educator, through effective teaching and media utilization, create the learning environment (McVey, 1985).

36.1.3 Defining Ergonomics Relative to the Learning Environment

Ergonomics simply stated is the study of the relationship between people, the work that they perform, and the environment in which such mental and physical activities take place. The term is derived from the Greek words *ergos*, meaning *work*, and *nomos*, meaning *laws*. Consequently ergonomic research methodologies are generally applied toward the multiple goals of determining how work (tasks) can be best designed to maximize an individual's performance, and how the work environment, including tools and equipment, can be best designed to promote the safety, comfort, and the effectiveness and efficiency of the worker in the performance of those tasks.

As noted above, another term considered today to be synonymous with ergonomics is *human factors engineering*. Alphonse Chapanis (1959), one of the long-time academic leaders in the field, describes human factors engineering as "the name applied to that branch of modern technology which deals with ways of designing machines, operations, and work environments so that they match human capacities and limitations." And more recently, the educational technologist Frederick Knirk (1992) identified the objective of ergonomics as "... to systematically define, design, and develop effective, safe, comfortable and efficient working, learning, and living environments." Up until around 1980, there seemed to be some minor distinctions between the two terms, with *ergonomics* being a term generally employed in Europe and characterized by a greater physiological focus, while *human factors engineering* was the term primarily used in the United States and characterized by a greater psychological emphasis. Today, such distinctions seem to have evaporated, and the term *ergonomics* has gained the wider usage on both sides of the Atlantic, as well as in the many other countries around the world boasting such organizations and programs.

36.1.4 Ergonomics in Education: A Short History

During the first half of this century, the focus of ergonomic study was on industrial and military tasks and settings. Beginning around the late 1940s and early 1950s, a good amount of this attention was turned toward transportation, the commercial sector, and office work. A smaller and less significant portion was directed toward education. Notable exceptions to this included a series of publications by the National Council on Schoolhouse Construction (today known as the Council of Educational Facility Planners International) aimed at applying research findings toward school facilities design, actually with some efforts made as early as 1921, but becoming more comprehensive during the early 1950s and continuing up to the present time. The initial and continuing purpose of this organization was "to promote the establishment of reasonable standards for school buildings and equipment with regard for economy of expenditure, dignity of design, utility of space, healthful conditions and safety of human life" (Gardner, 1971). As previously noted in recent years, this organization's publications have become increasingly more comprehensive, with such efforts including higher-education facilities and stressing guiding principles and planning goals rather than standards. Its bimonthly publication, *The Educational Facility Planner*, continues to offer summaries of research having a practical utilitarian bent for the facilities manager, planner, and designer.

36.1.4.1. The Pioneers, Bennett and Harmon. Another notable exception in educational ergonomics began during the early 20s as a doctoral study investigating the posture of elementary and secondary students and their classroom furniture. This study, involving about 4,000 students, was conducted in the schools of Des Moines, Cleveland, Philadelphia, and Winnetka by Henry Eastman Bennett, and culminated in the publication of his findings in the book *School Posture and Seating: A Manual for Teachers, Physical Directors and School Officials* (Bennett, 1928). From the time of that publication and for about a decade, little activity took place in school ergonomics until around 1940, when a series of highly significant studies were initiated by Darrell Boyd Harmon and completed in the early 50s. These involved a series of pioneering epidemiological studies of the physical effects of the school environment on elementary-level students and culminated in a series of comprehensive and highly informative monographs, chief among them *The Co-ordinated Classroom* (Harmon, 1951). Interestingly, this monograph and another by Harmon, *Controlling the Thermal Environment of the Co-ordinated Classroom* (Harmon, 1953), were published by a school furniture company and a heating control systems company, likely indications of the lack of interest shared in "classroom ergonomics" during that time period by the principal publishers in the field of education. In reviewing Harmon's *The Co-ordinated Classroom* and its implications for more ergonomically correct learning environments at the school and college level, Barrett Caldwell (1994) has succinctly stated:

> Harmon's approach conceived of the classroom environment as "an occupational environment—a working surround in which (students), through participating in organized experiences, can grow and develop in an optimum manner, and channel their unfolding capacities into constructive and satisfying living." He advocated a systematic approach to "occupational hygiene" to evaluate and improve the classroom, focusing on enhancing student's learning performance. Harmon's ideas integrate several major elements of the human factors perspective: organization of information and resources devoted to improving performance and satisfaction of persons in a complex environment. Nonetheless, his work, and that of his few intellectual successors, is largely ignored in modern classroom design.

Two of the main strengths and distinctions of the Harmon studies were its epidemiological approach and the reliability and validity of its findings, borne by the large population of its subjects (more than 160,000 school children) and supported by the controls only possible when conducted under the mantle of a governmental agency. A number of Harmon's findings were summarized and reported by the author in his own dissertation (McVey, 1969) and later in a monograph, *Sensory Factors in the Classroom Learning Environment* (McVey, 1971), funded by the National Education Association for its *What*

Research Says to the Teacher series, and then used in the development of the educational specifications that were used in the design of a new, ergonomically correct educational facility for the University of Wisconsin's School of Education. Figure 36-1 includes photographs of the then new (1972) instructional spaces designed in accordance with the environmental design principles, human factors guidelines, and design development details that I provided to the architect, and which, because of my full-time involvement in all phases of the project, ensured inclusion in the project. These photographs display a number of ergonomic features that will be discussed throughout this chapter.

36.1.4.2. Progress in the 60s. In the 1960s, the activity in school facility research, including but not specifically naming ergonomic issues, increased significantly, funded mostly by the government; in the U.K. through its Building Performance Research Unit, and, in this country, through various state departments of education and such private organizations like the Educational Facilities Laboratories. One of EFL's most influential school facility research projects culminated in the publications *SER 1, 2, and 3* produced by the *School Environment Research Project,* an activity of the Architectural Research Laboratory at the University of Michigan in Ann Arbor and directed by C. T. Larson.

SER 1: Environmental Abstracts is basically a collection of annotated abstracts of research that the project's investigators believed would advance the readers knowledge of the various relationships that link environment with human behavior, particularly as it applies to educational settings. *SER 2: Environmental Evaluations* presents "a series of technical papers, prepared by individual project staff members, which summarize and analyze what is now (was) generally known about the environment and its interactions with the individual and the effects of space, the thermal environment, the luminous environment, the sonic environment, and the social environment (Larson, 1965)." The third publication, *SER 3: Environmental Analysis,* presented proposed methods for investigation and processing of information needed in environmental design.

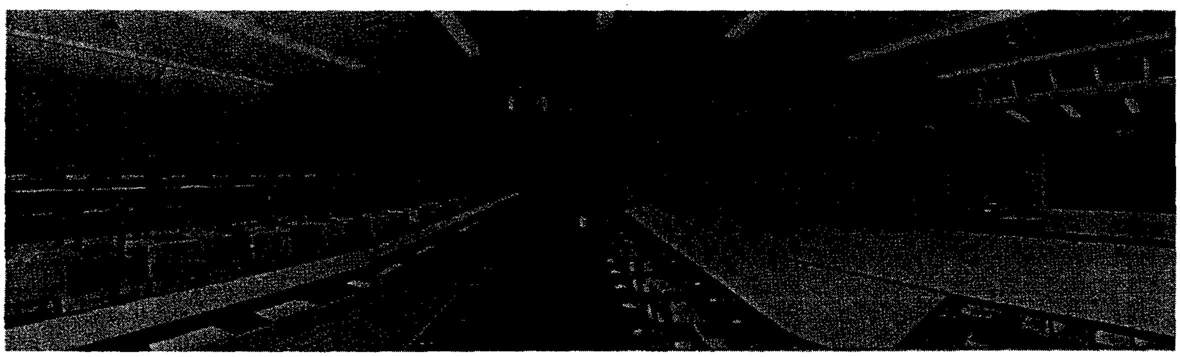
36.1.4.3. Today's Organizational Efforts and Research Dissemination. In the 1970s, 80s, and 90s, we have seen numerous publications on human factors engineering, ergonomics, environmental design, architectural research, and applied ergonomics flood our libraries from printing presses literally spanning the globe. During this period, we have also seen professional organizations such as the Human Factors Society (now the Human Factors and Ergonomics Society) and the Environmental Design Research Association gain in membership and prominence. Unfortunately, such progress has not brought with it a commensurate increase in ergonomic research specifically applied to educational settings. And, in fact, some educational facility planners even today have reported difficulty in finding relevant ergonomic research that they can use in their planning efforts. In a recent issue of the *Educational Facility Planner,* Lane and Richardson (1993) stated: "The literature dealing with human factors engineering and education is almost nonexistent. A literature search yielded few resources and little usable information." These authors went on to list only six citations they were able to find that they felt had some relationship to human factors engineering and educational-facilities design!

36.1.4.4. An Overview of the Research. The topic areas, and research designs considered appropriate for use in ergonomic research are no different from those traditionally conducted in the other behavioral sciences. An overview of such research is offered by Aikman (1994), who states:

> Research designs share a common element, namely, a systematic view of a given phenomenon by determining relationships among variables with the purpose of explaining and predicting the phenomenon. Once a research problem linking an aspect of environment and human behavior has been formulated clearly enough to designate the explanatory variables, the researcher must develop a research plan or design. Specific research variables are selected from the several possible explanatory variables. They are the variables among which the researcher wishes to find and to measure some specific relationships. They include both the "dependent" and "independent" variables, that is, the "predictand" and the "predictor" variables.
>
> Although there is no such thing as a single "correct" design, a design should include procedures not only related to the variables which are the objects of study, but also procedures for the control of as many as possible of other explanatory variables not included as objects of study. If the relationships among variables, the characteristics of which are ready-made, such as human characteristics, a given classroom environmental characteristic, an architectural feature of an educational facility, etc., the type of design of study is descriptive. Causality is not established. In contrast, in an experimental design, an independent variable is manipulated by the research to determine what effect or relationship it has, with a dependent variable as well as determining its relationship with other explanatory variables, either manipulated or controlled.
>
> Descriptive and experimental studies are sometimes defined by the setting in which a study is conducted, for example, field studies, field experiments, or laboratory experiments. Some of the other descriptive terms employed to designate studies in the behavioral sciences are "qualitative" versus "quantitative" and differentiated primarily by the precision of measurement; cross-sectional versus longitudinal, which reflect some variation in time orientation; single factor versus multiple factor, indicating the number of explanatory factors involved in the study. The two major statistical procedures employed in both descriptive and experimental studies in determining relationships among the research variables are various forms of regression analysis or analysis of variance.

The majority of ergonomic studies to date have been of an experimental nature carried out in laboratory settings specifically set up for this purpose. As such, these studies when properly conducted have included the four important features that Chapanis (1965) states must be present in human factors research : (a) controlled observations in (b)

306-Seat Multimedia Lecture Hall



132-Seat Multimedia Lecture Room

20–90-Seat Flexible Classroom

20-Seat Media Conference Room

Figure 36-1. University of Wisconsin instructional complex displaying ergonomic features specified by author.

an artificial situation with (c) the deliberate manipulation of some variable(s) in order to answer (d) specific hypotheses.

36.1.4.5. Studies to Be Included and Limitations. Later, I will review in detail a cross section of specific ergonomic/educational environment studies. Only representative studies with which I have been directly involved and that deal with ergonomic topics that relate specifically to educational facilities design have been selected. Others that relate to comparative instructional methodologies, instructional design, instructional coding and mapping, and so forth, and which given another interpretation or context could very well claim educational-ergonomic relevance, cannot be presented here. Ergonomic studies related to the design and utilization of environments other than educational will not be treated (cf. Burton, 1980).

36.1.4.6. Influences. Several educators and specialists from other fields played important roles in promoting the ergonomic or scientific approach toward educational facilities design during the past 3 decades. These individuals subsequently had a great influence on the research and on my own facility design efforts and countless others. Such direct and personal influences included the guidance and example of James MacConnell and his planning team from San Francisco in the preparation of the University of Wisconsin School of Education *educational specifications*—the critical building block for all good facilities design; the knowledge and environmental assessment examples of Drs. Darrell Boyd Harmon and Philip Lewis of the University of Wisconsin; Gene Ferris and John Moldstad of Indiana University for their pioneering 1961 survey, *Improving the Learning Environment,* which influenced the future direction of my own academic pursuits; Gaylen B. Kelley of Boston University's School of Education, for his practical insight into what constituted good media presentation facilities; Alan Green, formerly of the Educational Facilities Laboratory, and Don Ely of Syracuse University, for their tireless efforts at collecting and disseminating relevant information. Key influences outside the field of education included William Lam (lighting design), Robert Newman and Lyle Yerges (acoustical design), Jerry Dommer, O'Neil Ford, and Byron Bloomfield (architectural design), and Ray Wadsworth (audiovisual systems design); and from the field of human factors engineering, for their knowledge, critical analysis, and creative applications, Drs. Alphonse Chapanis, Harry Snyder, and H. Mac Parsons. The valued legacy of all of the above individuals can still be seen in numerous educational facilities across the country and overseas.

36.2 REVIEW OF SELECTED ERGONOMIC/ LEARNING ENVIRONMENT STUDIES

36.2.1 Introduction

The aim of this review is to summarize what constitutes ergonomic research as applied to educational facilities, and thus is intended to be representative and not comprehensive. In making my selection of ergonomically representative studies, I have chosen (1) two user preference survey studies that related student responses on a rating scale–type questionnaire to the physical measurements of environmental and display features; (2) an experimental study of social interaction patterns with different classroom seating arrangements employing television as an observational tool; (3) an experimental study investigating the effect of photometric brightness contrast on student preference, attention, visual comfort, and fatigue; and (4) an experimental study on display legibility that explored qualitative differences between front- and rear-screen projection. The first study reported is one of my own, and the other four were doctoral dissertations that I supervised at Boston University between 1976–91. By providing such a sampler, it is hoped that the reader will acquire some insight into representational methodologies in educational ergonomic research, as well as an awareness of the substance of their findings, which I believe hold considerable significance today relative to learning environment design and utilization.

36.2.2 Environmental and Ergonomic Features in Educational Facilities: Two User Preference Studies (McVey, 1979; Bethune, 1991)

36.2.2.1. Rationale for the Studies. Every year, millions of dollars are spent on the construction and renovation of educational facilities that are often inadequate for both students and instructors. Students and faculty alike frequently complain that classrooms are too hot or too cold, that they have uncomfortable seating, or that the seating location does not permit clear and accurate viewing of the room's display systems. Additional complaints relate to the difficulty in hearing lectures because of excessive internal noise or because of excessive sound reverberation within the room. Other problems are more subtle and frequently result in complaints like "My eyes seem to hurt after a lecture," or "I just can't seem to concentrate for very long in that room," or "I'm just not comfortable in there. I don't like the room."

These classroom conditions and complaints point out the need to determine why such facilities fail to meet the objectives of facility planners and architects. One reason proposed for this failure is the source material for the guidelines used in the planning and design of educational facilities. Discussions with numerous architects indicate that most rely almost exclusively on architectural standards such as those found today in Ramsey and Sleeper's *Architectural Graphic Standards* (1988), or those published by BOCA (Building Officials and Code Administration International, 1990), and rarely adopt or refer to long-standing and widely available ergonomic standards and references such as contained in the publications of Woodson (1981), Woodson and Conover (1973), Bennett (1977), Van Cott and Kinkade (1972), and Grandjean (1969, 1987).

To determine the relative efficacy of these two different sources of planning and design information, in either their earlier or current editions, the assessments of two college student populations, one from a large midwestern university, and the other from a large eastern university, were recorded approximately 20 years apart using two slightly different versions of the same questionnaire. In spite of the passage of time and changes in the student population and the schools' curricula and the increased sophistication of available educational technology, and although the statistical tools employed and the analysis procedures differed, the results of both studies were strikingly similar. Given the similarity of the research methodology employed in these two studies and their results, they will be presented here as a two-part case study.

36.2.2.2. Method (1973 Study). The first study conducted at a large midwestern university in 1973, and reported in 1979 (McVey, 1979), was basically a posttest- only comparison of the assessments of a static group of college freshmen, sophomores, and juniors (N = 214) who, during semester I, were assigned to three popular lecture halls that had been constructed in accordance with guidelines found in standard architectural handbooks, with a comparable static group (N = 289) assigned to a lecture hall constructed in accordance with guidelines found in ergonomic handbooks and other guidelines developed from the author's own human factors literature search (McVey, 1969) and verified by in-house laboratory experiments. The user assessment instrument consisted of a Likert-type scale (questionnaire) made up of 59 measurement items related to specific interior environmental factors, 10 items that tested face validity, and 10 subject identification items. The 59 measurement items were divided into 10 categories: seating, desks, acoustics, audio systems, visual display systems, lighting, color and reflectance, and two "other" considerations.

36.2.2.3. Rationale for Employing a User Assessment Methodology. My reasons follow for employing a combination of questionnaire (with a rating scale) to solicit student assessments of their classroom environments, with an analysis of those findings in light of actual physical measurements taken in the environments being assessed:

> One approach gaining popularity is the utilization of the users themselves as evaluators. Armed with instruments ranging from simple attitudinal scales and various modifications of the semantic differential originally developed by Osgood, Suci, and Tannenbaum (1957) to the more complex Guttman scales (Markus, 1974) and the various adaptations of the multitrait-multimethod model originally proposed by Campbell and Fiske (1959), researchers have evaluated such wide-ranging environmental settings as "school study areas" (Sommer, 1968), "landscaped offices" (Boyce, 1974), and "low and high use housing" (Francescato et al., 1975). Through these and other studies, strong justification for employing users as evaluators of their environments has emerged (Canter, 1975; Lee, 1973; Preiser, 1970; Wools, 1970), as has support for using the questionnaire to record this evaluation.

Canter (1970) notes:

> Using a questionnaire is one stage towards getting the user to set up hypotheses about the effect of the physical environment and to explain his interaction with it. . . . The investigator does not pressure to understand or to hypothesize the nature of the mechanisms by which the subject deals with the physical environment, but rather to get the subject to show how satisfied he is with the functioning of the environment in which he is (p. 14).

Discussing the legitimacy of this measurement approach as opposed to the more traditional, physiological response recording methods, Sommer and Becker (1971) state:

> A psychologist can take the position that a check mark on a scale indicating dissatisfaction, particularly when the respondent has no incentive to falsify or distort his reply, is just as legitimate a basis for remedial action as a physiological measure. . . . Our results make clear that psychologists must deal with organisms or environments separately (p. 416).

Other researchers believe that while the questionnaire can reveal important information about the efficacy of an environment, much can be gained by using a design that also allows the researcher to relate the user's subjective assessment to specific causes, i.e., the physical variables inherent in that environment. For example, asking students to rate a desk's design in terms of "How well does it support accurate and comfortable note taking" will reflect on such physical variables as the size, height, and inclination of the desk being evaluated.

An approach along this line was used with success by the Building Performance Research Unit of the United Kingdom to assess school buildings, one major basis for comparison being a building performance profile called a *psarchigraph* (Patterson & Passini, 1974). A similar multimethod approach also has been used to evaluate acoustic experience in concert auditoria (Hawkes & Douglas, 1970). It is theorized that such an approach should make it possible for the researcher to relate subjective effects to physical causes, thus improving the predictability of subjective experiences from physical data. Such information, on the face of it, would seem to be of considerable value to architects and facility planners as they make decisions regarding the design of new construction or remodeling projects.

36.2.2.4. Validity, Reliability, and Analytical Measures (1973 Study). The following statistical data were obtained for each variable in each class: arithmetic mean, standard error of the mean, standard deviation, unbiased variance, coefficient of skewness, coefficient of kurtosis, and .05 confidence interval for the mean. One-way analysis of the variance also was conducted for each group across the two semesters and the results of that analysis expressed as analysis of variance tables. Other data included statistics relating to the validity (UWMACC Factor 2 Program) and stability of the questionnaire (Hoyt Reliability Index), individual student seat location, and anthropometric data regarding the student population taking part in the study.

36.2.2.5. Results and Discussion (1973 Study). In the 1973 study, the completion of the questionnaire took an average of 25 minutes, with some students taking as long as 35 minutes and others only 15 minutes. Examinations of the distributions indicated that the 5-point rating scale (5 = exceptionally good, 1 = unacceptable) yielded considerable variance, since every point on the scale was used. Results found that students gave statistically significantly higher ratings ($p < .05$) to Room 204, the lecture hall that had been designed and constructed in accordance with ergonomic recommendations, than they did for the three designed and constructed in accordance with published architectural standards. Overall mean student ratings for each of the major categories are shown in Table 36-1.

When reporting the findings of this study in 1979, comparisons were made between the overall mean scores per category received by the ergonomically derived lecture hall and the overall mean scores received by the three architecturally derived lecture halls. These data supported the study's hypothesis. However, because of space limitations in that publication, it was only possible to report on the overall student responses to the main environmental and display system design features in the rooms. In order to determine the student's individual responses to specific room characteristics, it was left to the reader to look at each of those responses while cross-checking those ratings with the room photographs and the 60-item physical descriptor developed for each room.

Given the importance of specificity in design, that study has now been revisited by its author in order to compile a set of empirically defensible lecture hall design guidelines. These generalizations follow.

36.2.2.5.1. Viewing Location and Visual Display

- Given free choice in seat location and given the design features of an ergonomically derived room layout where viewers are located at distances between 2 and 6 times a projected image width and at lateral locations not greater than 60° off screen axis, students will rate all seat locations equally high.
- Maximum acceptable viewing distances are determined not so much by the apparent size of the screen but by the legibility of the materials (words, captions) displayed. Acceptable boundaries of the horizontal viewing sector are determined more by the ability of the display system (projector, lens, and screen) to deliver an adequately bright image than by the amount of trapezoidal distortion caused by oblique viewing.
- Sight lines with inclination angles greater than +25° (to the top of the display) and depression angles greater than -10° (to the bottom of the display) will be criticized by college students. Rear projection can be more effective than front projection when projection screen type, size, and location are carefully selected and coordinated with the room's viewing sector.

TABLE 36-1. STUDENT (MEAN) RATINGS (1–5) OF LECTURE HALLS (P < .05)

Room	204	147	2650	112
Thermal	3.7	3.2	2.8	2.7
Viewing location	4.3	3.3	3.7	3.3
Visual display system	4.4	4.0	3.7	3.5
Lighting	4.0	3.1	3.4	3.4
Color and reflectance	4.1	3.1	3.5	3.0
Seating	3.9	2.6	2.5	2.4
Desks or tablet arms	3.8	3.4	3.0	2.8
Acoustics	3.8	3.4	2.6	3.2
Audio system	3.9	3.4	2.9	2.9

36.2.2.5.2. Lighting and Color and Reflectance

- Illumination levels of 30 foot-candles from either incandescent or warm-white fluorescent will satisfy a student's note-taking requirement. Cool-white fluorescent illumination will require 50 foot-candles in order to achieve as satisfactory a rating as the above-mentioned lighting relative to the same student activity.
- Matte-finished, warm-colored walls (off-white, parchment, buckskin) and light-colored furniture (brown, tan, cream) will produce a more visually comfortable environment than specular finished dark-colored walls, even when the illumination level of the latter is double that of the former.
- While incandescent downlighting is well received by most students, some of those who wear glasses will report distraction and discomfort. The degree of this response will be affected by ceiling height, fixture design and spacing, and the overall brightness in the room.

36.2.2.5.3. Acoustics and Audio Systems

- College students are extremely sensitive to noise intrusion, either from outside student traffic or from inside mechanical, electrical, or heating and air-conditioning systems.
- An ambient noise level of NC10 will be perceived as being too low in terms of masking unwanted sounds, while ambient noise levels of NC30 and above will interfere with students' ability to hear clearly the unamplified speech of a lecturer.
- Amplified audio response systems will be well received by students in large lecture halls (4,000 SF +) but will not be as important in the smaller halls (1,200–2,000 SF) as will be room acoustics.

36.2.2.5.4. Space, Desks, and Seating

- In terms of physical comfort, ease of access and egress, a sense of personal space, and for book and coat storage, students will prefer separate swivel seats and fixed desks (counter) in a seating layout providing them with 7.5–8.0 SF over fixed nonswivel chairs with tablet arms in a layout providing 6.3 SF or less per station.
- In rating the following design features of chairs, students will give the highest ratings to the features shown in bold print: floor-seat pan height (**17"**, 15", 16"), seat inclination (**3°**, 0°, 10°, 17°), back inclination (**10°**, 20°, 22°), lateral spacing (**25-31"**, 20", 21"), frontal spacing (**48"**, 32", 28", 34").
- A linear span of 28"–31" of 18"–deep and inclined (15°) continuous counter writing surface will promote

more accurate and comfortable note taking during lectures and visual presentations than will flat or moderately inclined (2°–7°) movable tablet arms offering between 81 and 116 SF of writing surface.

36.2.2.5.5. Thermal

- When attending classes having the following thermal factors, students will prefer the combination of temperature, relative humidity, and air velocity as noted in bold print: Room A: (82°F, 15% RH, front: 0–75 fpm, rear: 0–280 fpm,), Room B: (82°F, 29% RH, 0–75 fpm), **Room C: (69.5°F, 47%RH, 0–25 fpm),** and Room D: (77°F, 29% RH, w/o AC: 0–10 fpm, w/ AC: 0–75).
- Students will complain of drafts when air velocities exceed 75 fpm.

36.2.2.6. Method (1991 Study). A second user assessment study—a doctoral dissertation by James Bethune employing a modified version of the questionnaire—used in the 1973 study was conducted in 1991 at a large eastern university to determine whether today's college students would also prefer educational facilities constructed on the basis of ergonomic design guidelines over those constructed in accordance with standard architectural references. Freshmen, sophomore, junior, and senior students (N = 145) evaluated the four lecture halls in which they regularly attended classes. Using a 5-point Likert-type rating scale questionnaire consisting of 152 items, organized into 46 major interior environmental factors, the students rated each item as it existed in each of the rooms. The results of this activity were then analyzed in an effort to determine the validity of current architectural standards and recommendations as applied to the design of lecture halls.

A comparison was then made in the 1991 study between what the students found acceptable and the current architectural standards in the design and construction of lecture halls. A similar comparison was then made between the student's ratings and the recommendations found in published ergonomic sources. A t test, developed by Kruskal-Wallis and Dunn (Dunn, 1964), and simultaneous confidence intervals were used to analyze statistically the student's responses and to validate their significance.

36.2.2.7. Results and Discussion (1991 Study). The 1991 study built on the work of the 1973 investigation and extended the user assessment techniques used in that study in order to evaluate the efficacy of applying ergonomic recommendations to the design of lecture halls. The four lecture halls used in the 1991 study were all built or remodeled within the last 10 years and therefore reflected current architectural practices.

A comprehensive set of measurements was taken of each architectural feature in each of the four rooms, and each item was categorized as being either in agreement with architectural standards or ergonomic guidelines. Modifications were made to the original questionnaire by eliminating a number of audiovisual display system items not present in the current rooms and by setting up four cross-comparisons between rooms. This resulted in 38 individual test items and a total of 152 evaluation factors. The questionnaire was distributed to each of the 145 students taking part in the study. The statistical analysis first tried to determine what a student's response should be to a hall that was acceptable both in terms of architectural standards and ergonomic recommendations.

This resulted in a mean score of 3.554, with a standard deviation of 0.411 ($p < .01$). A Kruskal-Wallis test and Dunn's method were used to show that the results from the four different lecture halls were statistically related, and "simultaneous confidence" intervals were used to compare the responses within a specific question. The evaluation concluded that the results both between the individual halls and the individual questions were reliable at the 95% confidence level.

Table 36-2 shows the mean responses to the individual items in the questionnaire. It was concluded that any response of less than 3.000 indicated student dissatisfaction, as 3.000 is greater than one standard deviation from the 3.554 expected satisfactory mean response. The same mean satisfaction level of 3.000 can be applied to the data in Table 36-1 from the 1973 study, showing a statistical similarity in student's assessments of their classroom environments despite the 20 years between the studies.

The results of the evaluation showed that of the 152 measured factors, students agreed with ergonomic recommendations 82% of the time. For 103 of the factors, the agreement was positive; that is, the factor was in agreement with ergonomic recommendations, and the student's mean assessment was within the satisfaction level. For 22 of the factors, students found specific room features to be unacceptable, a position consistent with ergonomic sources but not with architectural standards. There were 16 cases where students found specific factors acceptable which were not supported by the ergonomic sources. These factors were primarily related to seat spacing. Interestingly, students accepted frontal seating closer (34") than recommended by ergonomic sources (40") for seating comfort during notetaking, but rejected that same spacing when evaluating it for ease of access and egress. Similarly, 11 items related to lateral seat spacing that were within ergonomic recommendations (24") were found to be too close and therefore unsatisfactory.

The results of the 1991 study confirmed the conclusions of the 1973 study and serve to point out that when it comes to the design of lecture halls, there is still a discrepancy between architectural standards and ergonomic recommendations, differences that are noticeable to college students and who for the most part find greater agreement with the ergonomic guidelines than with the architectural standards. Students were invited to make written comments throughout the questionnaire. These qualitative responses in general supported the quantitative results presented above, as well as most of the findings of the 1973 study.

36.2.2.7.1. Student Comments. Some of the interesting

TABLE 36-2. MEAN RESPONSE SCORES: INDIVIDUAL QUESTIONARE ITEMS

	B33	SED130	Nick II	RM150
Lighting	1. 4.08	3.62	2.66	4.27
	2. 3.29	3.52	*	4.36
	3. 3.43	3.37	*	3.30
	4. 3.68	3.82	2.54	3.95
Color & reflectance	1. 3.56	3.82	3.17	3.93
	2. 3.84	4.12	3.67	4.20
	3. 3.57	3.74	3.34	4.06
	4. 3.79	4.03	2.82	3.88
	5. 3.76	4.18	*	3.88
	6. 3.88	3.85	*	3.50
Seating	1. 3.42	2.53	3.52	3.39
	2. 2.19	1.41	2.18	2.80
	3. 3.42	2.59	4.07	3.18
	4. 2.96	1.71	3.79	3.43
	5. 2.81	2.03	3.80	3.44
Desks	1. 3.20	2.91	*	3.32
	2. 3.75	3.35	*	3.61
	3. 3.47	2.68	*	3.50
	4. 3.42	2.88	*	3.54
Acoustics	1. 3.68	4.32	3.57	4.07
	2. 3.08	3.59	3.61	3.39
	3. 2.96	3.18	3.05	3.32
	4. 4.00	3.91	3.93	3.18
Thermal	1. 2.69	3.68	3.86	4.05
	2. 2.46	3.32	3.75	3.69
	3. 2.35	3.41	3.59	3.70
	4. 2.54	3.44	3.27	3.82
	5. 2.62	3.70	3.80	3.62
Viewing location	1. 4.20	4.20	4.14	3.97
	2. 3.76	3.79	4.15	3.18
	3. 3.84	3.82	3.84	3.78
	4. 3.84	4.03	3.34	3.79
	5. 3.04	3.35	3.84	3.23
Other considerations	1. 350	3.47	3.15	3.42
	2. 264	1.68	3.45	3.11
	3. 3.00	3.50	2.80	3.21
	4. 3.44	3.03	3.30	3.59
	5. 1.64	1.47	2.80	2.14
	6. 2.24	1.94	2.03	3.03

* = Question is not applicable to room. For example, there are no desks in NICK II.

student responses included the following:

- Only the small students or those of average height registered complaints with the seating. But the lack of response from the very tall or large students was apparently due not to their satisfaction but simply to the resignation they had developed over the years with the unsatisfactory seating to which they were continuously subjected.
- The combination of tight lateral and frontal seat spacing resulted in very low scores for the tablet armchairs relative to book and coat storage. Frequently, this situation combined with poor tablet arm design led to books and notes spilling onto the floor when students tried to enter or leave their seats.
- While Nick II was rated acceptable as a movie theater, its use as a lecture hall was very poorly received by the students. This result speaks to the frequent failure of multiuse designs for lecture halls, as well as the unwise assignment of such spaces as large-group classrooms by college administrators.
- Provisions for left-hand tablet arms were absent in all of the rooms used in this study. This omission was duly noted in the students' evaluations.

36.2.2.8. Conclusion. Both of these studies, although performed approximately 20 years apart, indicate the firm and continuing existence of a strong student preference for lecture halls designed in accordance with existing ergonomic guidelines than for those designed in accordance with standard architectural references and building codes. Consequently, it is recommended that now and in the future, facility planners and architects make every effort to utilize existing ergonomic guidelines and standards in their educational facility design, construction, and remodeling efforts. Many of these important guidelines and standards will be found in section 36.3. Others can be found in existing ergonomic handbooks and in the growing number of journals that are directing their focus toward ergonomic applications.

While the two studies just presented raise a number of interesting questions about the current state of educational facilities design, their results also generate some concerns relative to the current preparation of architects, inasmuch as valuable ergonomic information continues to be ignored in their work product. One of the questions that surfaces is: In the face of such evidence, why haven't architectural programs adopted the ergonomic guidelines that have been available for more than 20 years? A second question is: Why have architects ignored past research findings that clearly have demonstrated the benefits of designing educational facilities in accordance with ergonomic guidelines?

These questions go beyond the scope of this study, but they are clearly implied by the study's results. A third question raised by the study is: In light of the fact that both studies clearly showed that college students are reliable and objective evaluators of their learning environments, why are they not consulted more often in educational facilities planning and evaluation? While these questions merit considerable discussion, one can conclude from the findings of both the 1973 and 1991 studies the following recommendations:

- Educational facility planning and architectural design references and standards should adopt time-tested and proven ergonomic guidelines.
- Architects should seek out the observations and comments of college students in determining the successful and unsuccessful elements of their educational facilities before making final determinations as to the specific design features to be contained in new and proposed facilities.
- Architectural educational programs should include the study of ergonomic principles and guidelines.

36.2.3 An Observational Study of Classroom Seating Arrangements on Student Attention, Participation, Fatigue, and Preferences (Fulrath, 1976)

36.2.3.1. Background and Rationale for Study. In the mid-60s, the work of E. T. Hall and specifically his book *The Hidden Dimension* (Hall, 1966) advanced the science of "proxemics" and the concepts of "socieopital" and "sociefugal" spaces, i.e., those spaces that promoted human interaction and those that promoted noninteraction. This work followed the acceptance of earlier works on social interaction by Bass and Klubeck (1952), Steinzor (1950), and Leavitt (1951). It was also during this period that the sociologist Robert Sommer published research findings (1959, 1965, 1967, 1969, 1970, 1974) that strongly supported and justified specific seating arrangements to promote desired patterns of social interaction. It was in this context that the following study was rationalized and conducted.

Fulrath (1976, p. 23) states:

> Increasingly, educational and business facilities are being designed with spaces for small-group work. Schools, libraries, offices, and hotels have conference areas designated for, or classrooms that accommodate, both small-group work and media use. Typically, the furniture arrangement of the classroom is still that of the straight row, though rectangle arrangements prevail in offices. However, these arrangements may not be best for the individual, especially in view of increased media use, if they contribute to a negative response condition by the individual, either behaviorally or attitudinally. Other arrangements, such as the circle/hexagon, may better help to facilitate a positive response set, particularly where media tasks are concerned. The design implications of this issue concern future use of furniture arrangements that facilitate the optimal response of the user. In studying user responses to these varied arrangements, the question of whether to design predominately for comfort or for interaction may be partially answered.
>
> Similarly, use of the small group as a problem-solving mechanism is common in both education and business, as is the attendant use of media for information transfer. In the examination of the relationship of time to these factors, the results of this study may provide some specific answers about appropriate limits to task duration and involvement for the individual. That information would, in turn, augment existing knowledge about the appropriate utilization of media and small-group work.

36.2.3.2. The Research Question and Method. This study focused on two environmental variables and their effects on selected behavioral and attitudinal responses of the learner. The specific purpose was to determine the effects of seating arrangement and task duration on fatigue, attention, participation, and preference of individuals engaged in small-group media tasks. Circle, rectangle, and straight-row patterns constituted the three levels of the independent variable seating arrangement. Similarly, three levels of the independent variable task duration were 1 hour, 2 hours, and 3 hours. There were three hypotheses in the study:

1. There would be significant differences in fatigue and participation as task duration increased from 1 to 3 hours.
2. There would be significant increases in fatigue, attention, and participation between people in the circle seating arrangement and those in the rectangle or straight-row patterns.
3. There would be significant increases in preference for a seating arrangement between people in the circle pattern and those in the other arrangements.

The sample consisted of 54 adult students from various schools in the university who were nonmedia majors. Subjects were randomly assigned to six small groups of nine members each, and two groups each were then assigned to one of three seating arrangements.

The task used in the study was a 3-hour, visual-verbal media task in which groups rated 35-mm slide images according to criteria of visual design. The measurement instruments for fatigue included the *Pearson Fatigue Checklist* (Pearson, 1956), and a *Visual Discomfort Evaluator* developed by the researcher based on the work of Hultgren, Knave, and Werner (1974). Videotape recordings were used to assess attention and participation; and preference was measured by *Mehrabian's Approach-Avoidance Test* (Mehrabian & Russell, 1974). Testing occurred at four time intervals of the study, including the start of task, first hour, second hour, and third hour. The resulting data were scored analyzed by multifactor analysis of variance procedures. Figure 36-2. below shows the layout of the experimental setting used in this study.

36.2.3.3. Results and Analysis of Findings. Results confirmed the first hypothesis and revealed significant increases in fatigue between the start of task and the first, second, and third hours ($p < .001$). Similar results were recorded for three symptoms of visual discomfort as the incidence of tired eyes, sore eyes, and headache increased significantly between start of task and the third hour ($p < .05$). However, no significant differences in discomfort were found for five other symptoms (itchy eyes, watery eyes, sandy eyes, blurred vision, and double vision). Attention increased significantly between the third hour of the task and each of the other task times ($p < .001$), but here were no significant differences in participation.

These results held in all groups regardless of seating arrangement, and, with one exception, no significant differences were found between groups for either the second or

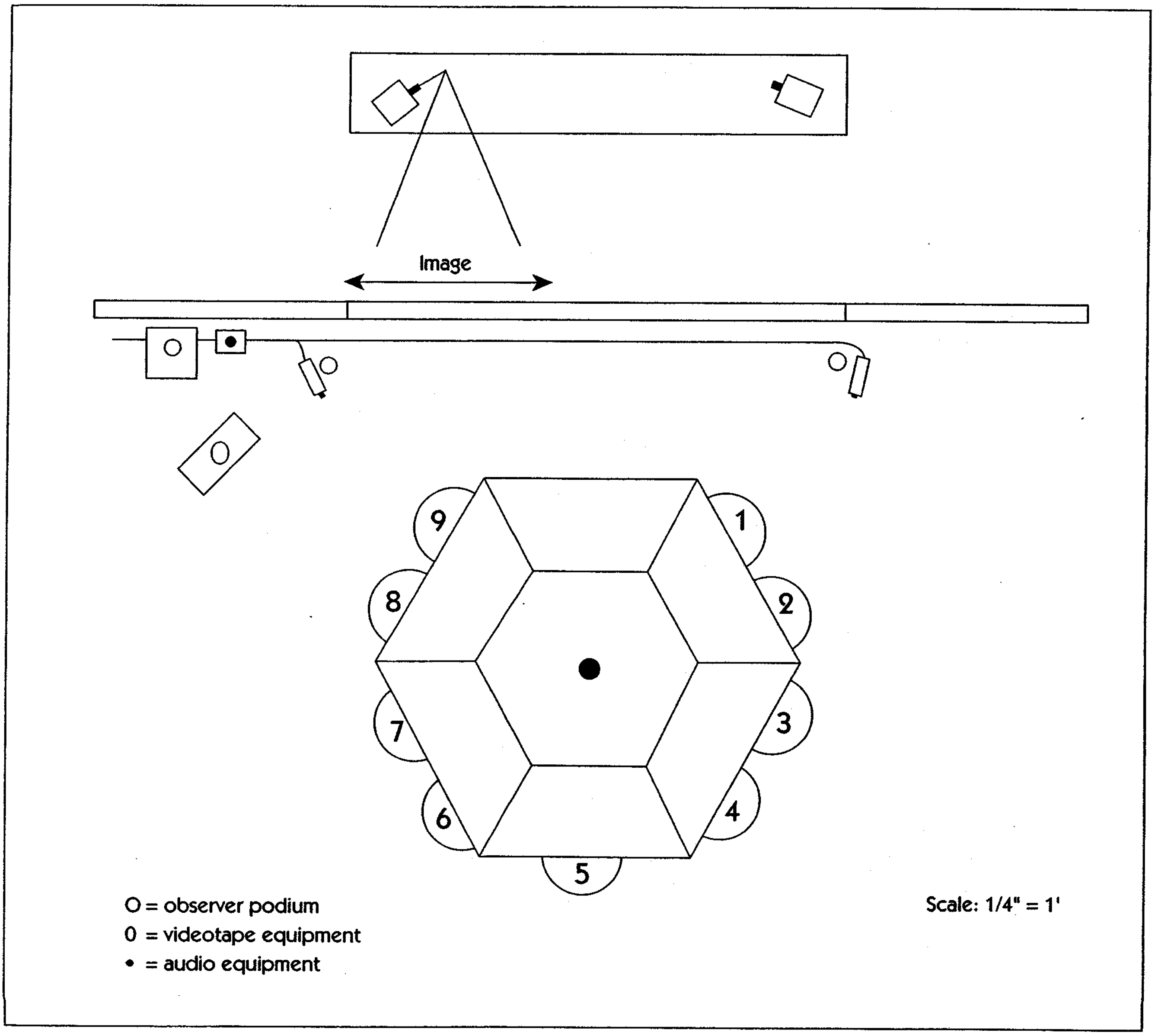


Figure 36-2. Layout of experimental room used in Fulrath study.

third hypotheses. The single exception was that attention in the straight-row arrangement was significantly greater than that recorded in the other two patterns ($p < .01$). Additionally, the use of blink rate as an index of fatigue and the relationship between fatigue and performance were examined and found to confirm the reservations that some behavioral researchers have found with this device as a reliable index of fatigue.

Several specific conclusions based on the general acceptance of the first hypothesis were formulated from the results of the study. The conclusions also reflect the clinical observations video recorded during testing. Those conclusions led to several recommendations, including two primary ones. It was recommended that, when using media tasks with groups of adults, optimal task duration should not exceed 1 hour without a break, or 2 hours if rest breaks are used. Study results also suggested that a single 15-minute break after 1.25 hours might foster changes in arousal levels and would be more conducive to continued task performance. Given media use, the straight-row arrangement may be preferred if attention to the screen were most important, but the rectangle may be preferred if attention to the group, or group interaction, were most important. Though equal to the other two patterns, the circle/hexagon arrangement could neither be recommended or rejected as being superior based on the results of the study.

Secondly, the *Pearson Fatigue Checklist* (Pearson, 1956) was found to be a valid, sensitive instrument, and its use was recommended for fatigue studies that would investigate other task types, task durations, learning situations, and age groups. It was further recommended that such studies also investigate the nature and pattern of the fatigue response as well as the psychophysical law to which it conforms. Finally, the study confirmed the value of television recording as a valued tool in the analysis of student behavior.

36.2.4 The Effect of Image/Surround Brightness Contrast Ratios on Student Preference, Attention, Visual Comfort, and Visual Fatigue (DesRosiers, 1976)

36.2.4.1. Background and Rationale for the Study. In the 1950s and early 1960s, Domina Spencer (1954) and her associate at M.I.T., Parry Moon (1961), created a stir in academic and engineering circles with their studies regarding luminance contrasts that attempted to quantify the patterns of photometric brightness that promoted comfortable and accurate viewing through enhancing figure/ground separation and three dimensionality of objects in interior environments. At the same time, Darrell Boyd Harmon's monograph *The Coordinated Classroom* (1951) related this work and that of others in the illuminating engineering profession to the classroom settings of elementary school children.

Two decades later, the lighting designer William Lam (1977) took major steps toward quantifying the perceptual aspects of lighting in school and office environments. Around the same time, LaGuisa and Perney of the Illuminating Engineering Society's Research Institute conducted their research of supplementary illumination on visual displays (1973, 1974) and discovered that attention was sustained longer and distractions reduced when classroom charts were illuminated in excess of the surround. Thus it was only natural that educational researchers in the field of media and technology would look toward establishing, through their own research, operational guidelines for establishing appropriate contrast ratios in media-related rooms. If such luminance contrast ratios could be verified, they could then be adopted with confidence in future educational facility design practices.

Such was the background of the DesRosier's study. Surprisingly, this study remains one of the only experimental studies to deal specifically with photometric brightness contrast ratios and remains uncited in the literature, even though influential organizations such as the Illuminating Engineering Society of North America and the Human Factors and Ergonomic Society regularly include similar luminance ratios in their published *Standards and Recommendations*. One would expect that those organizations could find their recommendations strengthened by referencing the DesRosiers' study (Fig. 36-3).

36.2.4.2. Method. One aspect of the visual environment, the photometric brightness contrast ratio (BCR) between a projected image and its surround, was investigated in two experiments. The nature of these two experiments was established by DesRosiers to include the four important features called for by Chapanis (1965): (a) controlled observations in (b) an artificial situation with (c) the deliberate manipulation of some variables in order to answer (d) specific hypotheses. In describing the experimental setting DesRosiers states:

> The experimental setting was essentially the same for both experiments 1 and 2. The room dimensions were 17'× 17' × 11'. The main feature of the room was a vinyl rear projection screen 10' × 15' which served as a translucent wall dividing the room into two smaller rooms, one for projection, one for viewing. Portions of the rear projection screen were designated for specific tasks:
>
> *Visual task*, the centrally located portion 26" × 17" on which the test slide presentation image was projected. *Distractor*, that portion 8" × 12" on which the distractor slides were projected. The position of this screen was 45° left of the center of the test screen. This distance was chosen based on earlier research findings. *Surround*, the remaining portion of the rear projection screen was transilluminated by supplementary lighting. The rear projection screen used had a gain of 120% at 0°. *Projection area*, the inner portion of the laboratory, 11.5' × 17', served as the projection area. Test *presentation system*, two carousel slide projectors, an audiocassette tape recorder with sync pulse capacity, a dissolve unit, a buffer relay system, a dimmer to control image brightness, and a rectangular image frame, a device to ensure that all illumination from the projectors (and only illumination from them) reached the portion of the screen where the visual task (image) was projected. The slide presentation system was controlled by a custom power supply and relay system to ensure that all luminances were as specified.

The videotape observation recording system consisted of a low-light sensitive video camera, a camera adapter, and a TV monitor. Forty one-half-inch 30-minute videotapes were used. *The audio-grid* is an instrument devised by DesRosiers to ensure consistent reading of the videotapes after the test period. This system required an audiocassette player and an audiocassette with oral cues to announce the change of slides. When played in sync with the videotape, the investigator could know what slide was being projected at any moment of the videotape. The *student station* consisted of a chair-desk combination positioned two screen widths from the screen. A dimmer for controlling the brightness of the image was positioned on the student's desk. The luminous environment of the viewing area was defined by identifying the range of the illumination on the subject and on the desk. A photo research illuminance meter and 2° luminance meter were used in the measurements.

36.2.4.3. Problem Statement and Methodology of Experiment 1. The first experiment attempted to answer these questions: What are the image/surround brightness contrast ratios preferred by students? How do these correspond to the task/surround brightness contrast ratios recommended by the literature? The currently recommended task/surround BCRs for conventional tasks suggest the hypothesis that, given a specific surround brightness, students will select an image brightness no less than that of the surround (1:1), and no greater than 10 times that of the surround (10:1). In a controlled laboratory environment, 14 high school students, given the surround brightness levels of 2, 6, and 20 footlamberts (FL), were asked to select their preferred image brightnesses. The mean brightness levels preferred were established, and the resultant BCRs were calculated.

36.2.4.3.1. Results of Experiment 1. AT 20 FL, the students selected a BCR of approximately 1:1 ratio; at 6 FL, a 3:1 ratio, and at 2 FL, an 8:1 ratio. Since the BCRs chosen were within the 1:1 to 10:1 range, there was strong

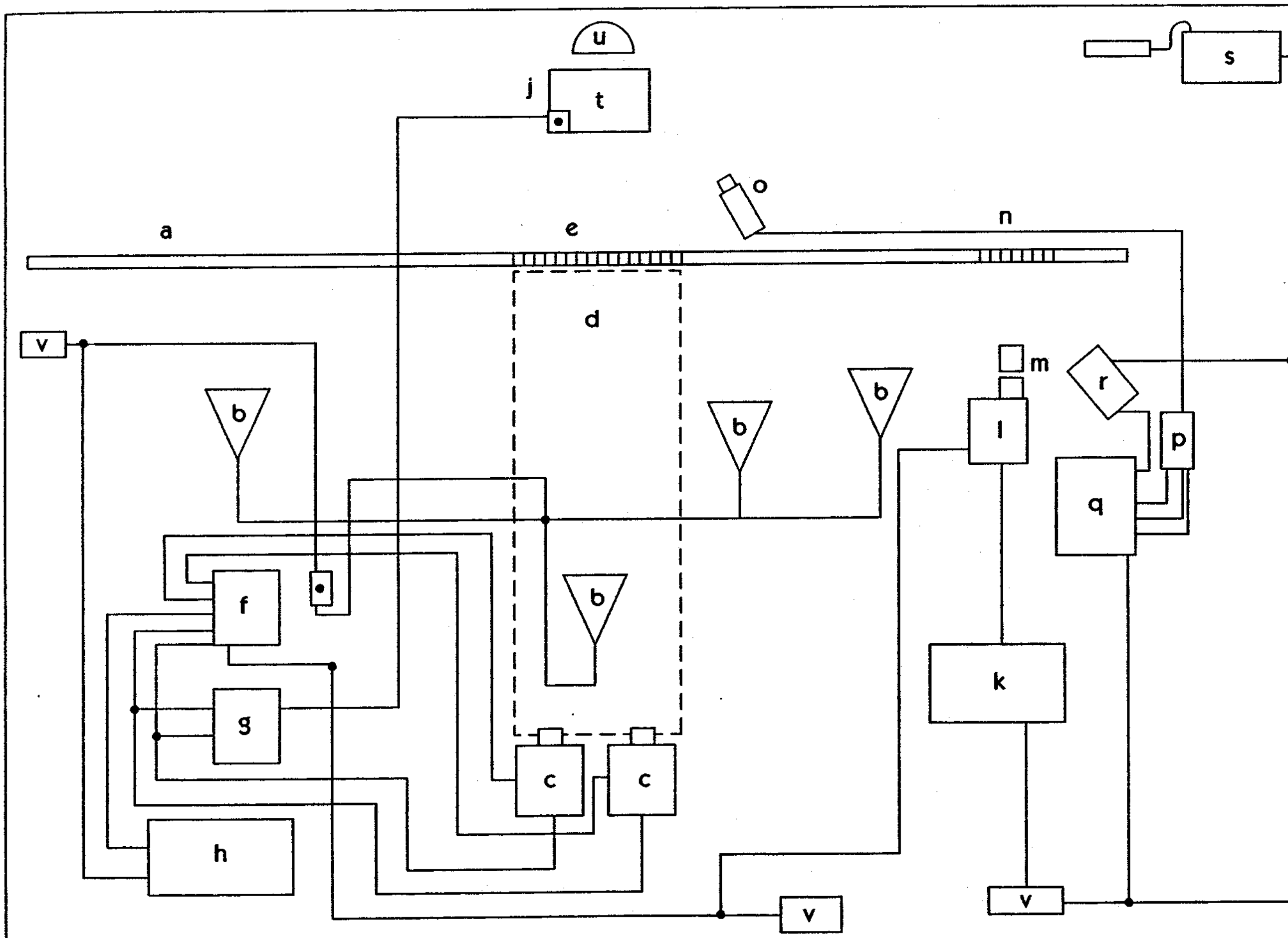


Figure 7. Schematic diagram of laboratory apparatus. a. rear projection screen wall; b. floodlights for surround brightness; c. carousel projectors; d.image frame; e. image (visual task); f. dissolve unit; g. buffer relay box; h. audiocassette recorder; i. control box for surround brightness; j. control box for image brightness; k. audiocassette recorder; l. carousel projector; m. polarized filters; n. distractor; o. video camera; p. television camera adapter; q. videotape recorder; r. television monitor; s. CFF apparatus; t. student desk; u. student chair; v. electrical outlets.

Figure 36-3. A sample of one of the measurement systems developed by DesRosiers for her study.

indication given that the general recommendations for task/surround BCRs are equally applicable to the projected image/surround BCRs. Furthermore, students chose a similar image brightness (17 FL) regardless of the surround brightness. As a result of this stable choice, a recommendation of 15 ± 2 FL was established as a "brightness task requirement for projected images." It should be noted that this recommendation is approximately the same as that recommended by the Society of Motion Picture Engineers (Kloepfel, 1969) for motion pictures for more than 3 decades.

36.2.4.4. Problem Statement and Methodology of Experiment 2. Current literature has suggested that the root of problems like inattention, visual discomfort, and visual fatigue encountered in media environments seems to lie in the characteristics of the visual display system and how it interfaces with its viewers, that is, the viewing angles, the luminance contrast between the display and its surround, etc. Experiment 2 dealt with this problem and investigated the effect of image/surround brightness contrast ratios on attention, visual comfort, and visual fatigue. DesRosiers states:

> Thirty-seven students between ages 14 to 19, assigned randomly to one of four experimental groups, viewed a slide presentation individually at an image/surround BCR of 40:1, 10:1, 3:1, or 1:1. The footlambert levels for these were 20:0.5, 20:2, 20:6.7, and 20:20, respectively. The Kruskal-Wallis One-Way Analysis of Variance by Ranks was applied to see if any relationship existed within the four BCRs. Each student was tested for attention by videotaped observation, for visual comfort by subjective evaluation using a checklist, and for visual fatigue by the two objective measures of critical flicker fusion (CFF) and threshold and eye blink rate recorded by videotape.

36.2.4.4.1. Results of Experiment 2. The hypothesis tested was: When the brightness contrast between image and surround is high, attention is greater, visual comfort is lower, and visual fatigue is greater. The Mann-Whitney U test for k independent samples was applied to the combined attention scores at 40:1 and 10:1 and to the combined scores at 3:1 and 1:1, yielding results that permitted acceptance of the first part of the hypothesis (that when BCR is high, attention is greater).

Results of the subjective evaluation of visual comfort gave some evidence that the second part of the hypothesis is true, that comfort is lower when BCR is high. Because of problems with the experimental process and the instrumentation used to measure visual fatigue (CFF and eye blink), there was no way of concluding whether or not visual fatigue was greater at high BCRs. It may be concluded that when the image/surround BCR is high, attention is greater and visual comfort is lower. It was also found that a "contamination effect" may occur when CFF tests and eye blink counts are employed in close succession.

In discussing her rationale for using the Mann-Whitney U test, DesRosiers stated:

> This test is used in order to determine whether the two independent groups have been drawn from the same population. One of the most powerful of the nonparametric tests, it is most useful as an alternative to the parametric t test when the researcher wishes to avoid the t test's assumptions (Siegel, 1956). The U test does not require that data be normally distributed or that sample variances be equal. It calls for a nominal independent variable and an ordinal dependent variable (Tuckman, 1972).

36.2.4.5. Implications of Study. In her study, DesRosiers concluded that:

> This study pointed out that often visual discomfort is the cost paid for a media environment conducive to high attention. Research is needed to determine a brightness contrast ratio which is the best compromise between these competing elements. The findings in this study have direct application to designers and users of media facilities, especially in preparing for the projection of slides, filmstrips, and motion pictures with rear-screen projection for high school students. They apply less directly for front-screen projection and for a broader range of audience than the target population in the current study. They have possible implications to designers and users of facilities for any visual presentation, including nonaudio visual setting, since the structural patterns of brightness used by architects are basically the same for all designs and environmental settings.

At the time of DesRosiers' study (1976), VDT use was in its infancy relative to educational environments, and so it is understandable that DesRosiers did not relate her findings to lighting and viewing conditions in VDT workstations. If provided that opportunity today, there is no doubt that given the validity and reliability of her findings, she could and would apply them to such educational environments with a high degree of confidence.

36.2.5 The Accuracy Recognition of Positive and Negative Symbols on Front- and Rear-Projection Screens Under Self-Selected Illumination (Hamilton, 1983)

36.2.5.1. Rationale for the Study. This study represents a response to two basic questions most educational media specialists were asking themselves during the early 1980s: How can I be sure that I am producing legible instructional materials? Should I use front- or rear-screen projection to display those materials? Adding confusion to the issue was the fact that most educational media guidelines available to the media specialist specified print size by dimensions such as 1/8", 1/4", etc., without any consideration of the distance at which those materials would be viewed. And second, there was considerable disagreement among information display specialists as to which was the preferred medium for information display, rear- or front-screen projection. In an effort to provide other media specialists with some "hard science" for guidance relative to making such choices, Mark Hamilton (1983) decided to investigate both sides of this issue and include as a modifying factor the self-selection of illumination level. By doing this, Hamilton anticipated discovering luminance-illuminance interrelationships that would affect performance and possibly serve as a guide for establishing ambient illuminance levels for future media presentation spaces. In noting his motivation, Hamilton stated:

> This investigation originated from recent visibility-orientated research and concern for possible misconceptions regarding the use of front and rear screens for projecting positive and negative symbols. . . . The study of projected visual images in teaching is one area in which there has been a move toward more systematic research. The increased use of projected images has amplified the potential benefits to be gained from good message design and optimum projection practice and has magnified the negative effects of inadequate materials and poor projection. An examination of published standards and research findings, as well as current classroom practices, show widespread confusion and disagreement on what should be the proper level of various factors of the projection environment.

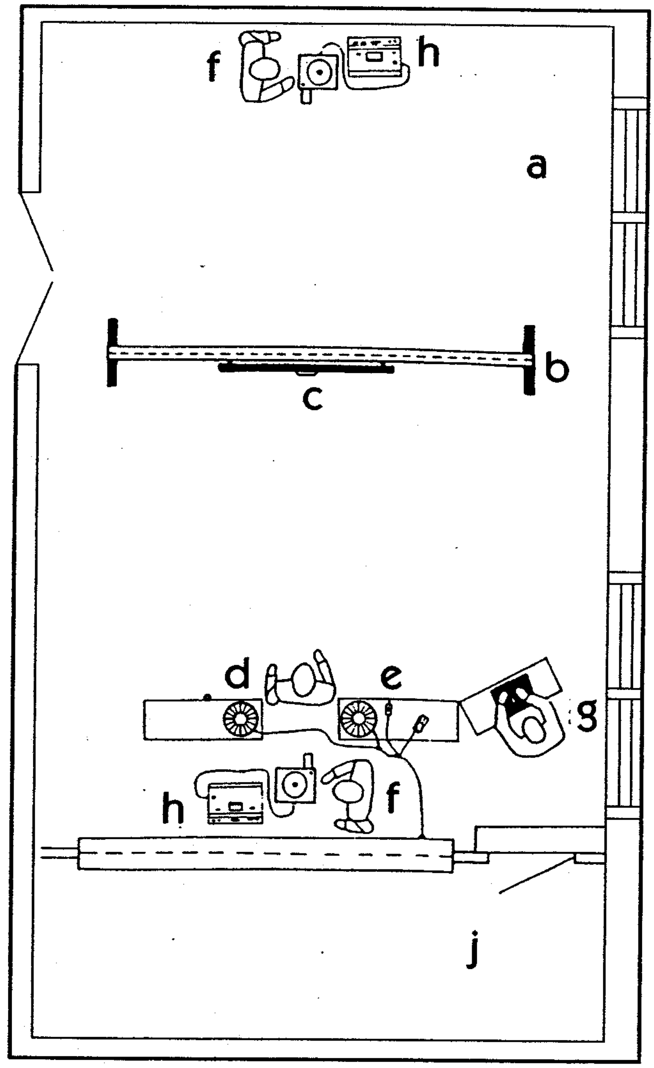
36.2.5.2. Problem Statement. This study was designed to determine the effects of projection screens, symbol polarity, and symbol size on accuracy recognition of projected symbols. The dependent variable was accuracy recognition. Three independent variables were: film-based projection systems, consisting of front and rear screens; symbol contrast, consisting of positive (white symbols on black) and negative (black symbols on white); and subtended visual angle, consisting of 7, 5, and 3 minutes of arc.

36.2.5.3. Procedure. Hamilton describes his procedure as follows:

> One hundred sixty college students with tested visual acuities ranging from 20/40 to 20/10 and including those with normal or corrected-to-normal vision were individually presented 81 randomly ordered letters for a total of nine slides displayed in a laboratory specifically set up for this purpose during evening sessions at a small private New England college. Subjects were randomly assigned to one of four treatments, i.e., front screen with positive symbols; front screen with negative symbols; rear screen with positive symbols; and rear screen with negative symbols, each having symbol sizes of 7, 5, and 3 minutes of arc. Subjects attempted to correctly identify the self-paced stimulus materials. Additionally, subject's preference for a general illumination level and responses were recorded. Data from the 2 × 2 × 3 factorial design were subjected to a three-way analysis of variance. Where significance at the .05 level was evident, individual differences between means were examined with the Newman-Keuls test.

36.2.5.4. Apparatus, Description, and Specification of Stimulus Materials, Display System, Lighting System. An excerpt of Hamilton's lengthy and precise description of his experimental setting and controls follows (Fig. 36-4):

> The photographic equipment used throughout was a 35-mm, single-lens reflex camera (Canon AE1), with a 50-mm macro lens (f3.5). The exposure used was f/11 for 1 second for the positive materials and f/8 for 4 seconds for the negative materials. The letters were originally derived from a Kroy lettering machine using the Helvetica Regular (24 point) disk. Letters were graphically laid out on grid paper to provide uniform spacing. The single sheet of letters and sample Es were then photographically reduced on a stat to a uniform height of 10 mm. When this appropriate size was attained, the letters were reduced by 30, 50, and 70% to produce symbol sizes of 7, 5, and 3 millimeters. . . . To eliminate slide "popping" due to heat, Gepe glass slide mounts were used. Each test slide, in the horizontal format, was projected on a front or a rear screen at an appropriate distance (12 feet) to provide the specified subtended visual



a. Rear projections area for treatments 3 & 4. **b.** Wooden partition (divides the room for rear projection, supports the 9×12-foot rear screen, and supports the 6×6-foot front screen to be pulled down for front-screen treatments).
c. Front screen. **d.** Subject. **e.** Rheostate dimmer control for self-selection of illumination. **f.** Experimenter. **g.** Assistant.
h. Slide projector and cassette player. **i.** Table lamps. **j.** Front projection booth (was not utilized).

Figure 36-4. Graphic representation of Hamilton's experimental setting.

angle of 7, 5, and 3 minutes of arc for the symbol. Projected image brightness for each of the test slides was 18 footlamberts. Two multiple slide sets were produced to control potential bleaching of the slides due to exposure of the projector lamp.

A single Kodak Ektagraphic AF-2 slide projector with a Kodak 100–150-mm f/3.5 flat field lens with a 300-watt ELH lamp was used in the tests. Screen luminance was determined by projecting stimulus slides on the projection screen and measuring it with a photometer calibrated in footlamberts. Test instructions and procedures were pretaped and synchronized on a cassette tape recorder to provide uniform presentation of test procedures. The range of illumination intensities available at the work plane was approximately 0 to 50 footcandles. General illumination was derived from two table top lamps, each fitted with one 150-watt bulb, positioned behind and to either side of the subject. One commercial, 100-volt (600 watts maximum) rheostat dimmer, wired to the 115-volt, 60-cycle electrical source, was utilized to provide a range of 0 to 50 footcandles at the work plane. The dimmer was contained in an enclosure and located to the right of the subject to allow easy selection of room light for each of the four treatments. The rheostat dimmer was preset to 0 before each subject entered the testing room.

In the remaining portion of his lengthy description of the experimental setting and controls, Hamilton provides specifications of the measuring instruments and display system characteristics, and describes his measurement procedures.

36.2.5.5. Research Design and Data Analysis. The dependent variable for the study was the number of judgments made on the criterion task, which consisted of one self-paced recognition accuracy task of symbols projected via 35-mm, 2 × 2 slides. Subject responses were judged either correct or incorrect, and therefore ratio data were obtained from the tests. The number of correct recognitions made by the subjects were computed and analyzed. There were three independent variables manipulated in this investigation. The first independent-variable, film-based projection system had two levels: (1) front-projection screen and (2) rear-projection screen. The second independent variable, direction of symbol contrast, also had two levels: (1) positive (W/B) projected symbols and (2) negative (B/W) projected symbols. The third independent variable manipulated in the study was subtended visual angle. This variable had three levels: (1) 7 minutes of arc, (2) 5 minutes of arc, and (3) 3 minutes of arc.

The basic design for the study was a true experimental design, Design 6, the Posttest-Only Control Group Design (Campbell & Stanley, 1963). This design was utilized because it can be delivered to students or groups as a single natural package and eliminates the awkwardness of a pretest. This design was also used because it permits an evaluation of treatment effects upon the criterion task while minimizing the effects of confounding variables (Issac & Michael, 1981).

The Posttest-Only Control Group Design consisted of a 2 (film-based projection system) × 2 (direction of symbol contrast) × 3 (subtended visual angle) factorial design with repeated measures on the third factor. The use of this design enables the investigator to assess interaction between the three independent variables (Ary, Jacobs & Razavieh, 1979). A three-way analysis of variance of the criterion task scores was applied to ascertain the presence of differences between treatments (Ary, Jacobs & Razavieh, 1979; Campbell & Stanley, 1963). Results with a statistical significance at the .05 level were considered demonstrative of reportable treatment effects. Kerlinger (1973) suggests the .05 level as adequate, being ". . . neither too high nor too low for most social scientific research" (p. 170). The Newman-Keuls multiple comparison test was used to compare means on the criterion task scores after analysis of variance had been performed if the results indicated its appropriateness. The Newman-Keuls test is an a posteriori comparison test and is employed when the investigator intends to make all possible simple pairwise comparisons among means if a significant overall F ratio is obtained in the analysis of variance (Howell, 1982).

The range of brightness patterns created in the testing environment for the present investigation was caused by the reflectance of the walls, ceiling, and floor surfaces, as well as the reflectance of screen areas adjacent to the projected image. Figure 18 illustrates the visual field of the present investigation, as seen by the subject during projection of stimulus materials. Specific target areas were preselected by the investigator, and footlambert readings were taken at each to determine a specific brightness pattern selected by the subject. All testing was conducted during the evening to eliminate external light sources from the testing environment. The 10 preselected target points are numbered.

36.2.5.6. Results and Discussion. Hamilton offers the following in his Results and Discussion section:

1. Given the relatively ideal viewing conditions and display systems used in this study, film-based projection systems, i.e., front and rear screens, of similar performance did not significantly affect the accuracy recognition of either positive (W/B) or negative (B/W) projected symbols of either 7, 5, or 3 subtended arc minutes. In fact, for all the single and multiple interactions with the other independent variables, there were no significant effects revealed in the accuracy recognition scores ($F = 0.44$).
2. For 7 minutes of arc little difference was found between the accuracy recognition of positive (W/B) symbols (94.6%) and negative (B/W) symbols (98.7%). For 5 and 3 minutes of arc, negative symbols (B/W) were more accurately recognized than the positive (W/B) symbols ($p < .01$).

It should be noted here that when determining the symbol sizes to be used in this study, it was assumed that any size symbol less than 10 arc minutes would result in accuracy recognition reductions, and that these losses would be directly proportional to the amount of reduction. This study proved this to be true, with 100% accuracy scores recorded in the field test conducted prior to the start of the study employing a symbol size of 10 arc minutes, and the following results recorded during the Hamilton study with the three smaller symbol sizes (see Table 36-3).

3. In the self-selection of ambient illuminance when displaying white symbols on the front screen, 31% preferred a light level between 0–1 FC, while the remainder of the test population were evenly distributed (about 15% each) in their selections of the following levels: 1–5 FC; 5–15 FC; 15–30 FC; over 30 FC. In the self-selection of ambient illuminance when displaying black symbols on the front screen, there were no majority preferences for any of the 5 footcandle ranges and were found to be fairly equal (20–25%) at the various footcandle ranges. Only at the 1–5 FC range did subject preferences drop to 9%. One interpretation of these findings is that when subjects view white symbols on a black background, projected on front screen, they prefer low illumination. On the other hand, when subjects view black symbols on a white background, projected on a front screen, they prefer a wide range of illumination.
4. In the self-selection of ambient illuminance when displaying white symbols on the rear screen, subject's selections for ambient light conditions were fairly evenly distributed for each of the 5 footcandle ranges, but with a slight reduction in preference for the 5–15 FC range. In the self-selection of ambient illuminance when displaying black symbols on the rear screen, a majority of the subject's selections (60.8%) fell on or with the 0–5 FC range, with the remainder equally spread over the range of 5 to over 30 ranges.

In explaining these results, it should be remembered that black symbols projected on a white background produce a bright image and hence a brighter room than do white symbols projected on a black surround. As a result of conditioning or believing that the existing light in the room was sufficient, subject preferences did not group around the higher footcandle ranges. In fact, in treatment 4, 24% of the subjects selected no additional illumination at their workplace. It should also be noted that this finding might have been different had the subjects been required to take notes during their period of participation.

TABLE 36-3. HAMILTON'S RESULT: MEANS AND STANDARD DEVIATIONS* ON PERCENTAGE ACCURATE BY FILM-BASED PROJECTION SYSTEM, DIRECTION OF SYMBOL CONTRAST, AND SUBTENDED VISUAL ANGLE

	Front Screen		Rear Screen	
Minutes of Arc	Positive	Negative	Positive	Negative
7	97.0 (5.2)	99.5 (1.9)	92.7 (10.6)	98.0 (11.6)
5	(84.6) (20.3)	97.6 (4.5)	72.3 (28.7)	94.9 (16.8)
3	(20.4) (20.6)	(50.8) (32.8)	17.5 (23.3)	51.7 (34.5)

*SD in parentheses.

5. The range of luminance contrasts for the target area and its near and far surrounds as expected were higher when projecting black symbols on a white background than when projecting white symbols on a black background. This was true for both front- and rear-screen display, with front-screen projection having more variance and slightly higher luminance levels recorded than rear screen. However, in all cases there were no luminance ratios that exceeded 3:1

36.2.6 Future Research Needs

There is a need for educators, architects, and ergonomists to continue the kind of research sampled in this section. User assessments have yielded important findings that have proved valid and reliable. Current research has applied a modified version of the instrument used in the McVey (1979) and Bethune (1991 studies in the evaluation of music education multimedia workstations. Preliminary results from this study appear to support the findings of the two earlier studies (Badolato, 1995).

But more importantly, there is a critical need to conduct the kind of epidemiological research that was conducted by Harmon and Bennett decades ago and unfortunately not repeated since. We need to find out how our young students are being affected by the learning environments in which they are expected to dedicate increasingly more time in VDT workstations and carrels. Are their maladaptations to the current nonergonomic facilities simply creating surmountable stress and fatigue? Or are they being exposed to conditions that threaten their normal growth and development, due to the fact that their physiological and sensory systems are yet fully developed? It is my own personal belief that we educators are sitting on a time bomb in this regard. And while substantive and well-sponsored research in the field of office design has produced corrective designs to mitigate if not eliminate repetitive motion disorders, no such mandate has yet been directed toward the learning environment. Hopefully, some concerned and well-positioned educational leaders will discover this author's quiet alarm signal and respond accordingly.

36.3 ERGONOMIC RESEARCH FINDINGS AND DESIGN GUIDELINES FOR THE LEARNING ENVIRONMENT

36.3.1 Foreword

Two of the primary purposes of research are to either effect change in an undesirable condition or to verify the efficacy of an existing condition. Consequently, when seeking guidance in developing learning environments, the educational facilities planner looks to the research and to planning handbooks for guidance. This is also true of educators when seeking ways in which a given learning environment may be utilized in order to have the most positive effect on a student's physical well-being and learning. Unfortunately, the topic of effecting learning gains through environmental design or manipulation of its features is beyond the scope and allotted length of this paper. Where I am aware of documentation of specific cause and effect relationships between some physical or sensory aspect of educational facilities and learning, I will report them, but the focus of this part of the chapter will be on those guidelines that are believed to contribute to the health, safety, and physical well-being of the student, as well as those that contribute to his or her orientation toward tasks and localization of information transmissions either from a teacher, other classroom discussants, or from some form of educational technology. For those readers interested in more substantive sources specifically regarding the environment and its effect on human learning, as an initial step toward acquiring such information the author recommends consulting Bruner (1961) and Tessmer and Harris (1992).

36.3.2 Introduction

In 36.1.4.3, I referenced Lane and Richardson (1993) who stated: "The literature dealing with human factors engineering and education is almost nonexistent. . . . A literature search yielded few resources and little usable information." Taking such statements at face value, we must then look to ergonomic research conducted in other physical settings and other relevant academic and professional disciplines like architecture and engineering in order to find guidance regarding the design and utilization of the learning environment. This approach is justified when one considers the similarity of tasks that take place in business and high-tech offices, conference rooms, auditoria, etc., and those that take place in educational facilities. In this way, I believe it becomes possible to establish supportable guidelines for educational facilities design.

In *Analyzing the Instructional Setting,* Tessmer and Harris (1992) offer six general questions that those involved in planning educational facilities need to ask of themselves and their project associates:

1. Will the learning space suit the attendance and strategies of the instruction?
2. Does seating facilitate the intended learning activities in the environment?
3. Are the instruction and resource environments accessible to learners?
4. Will the environment's temperature conditions be comfortable during the instructional activities?
5. Does lighting allow for sustained concentration and attention?
6. Will acoustics inhibit the aural messages of the instruction?

Should the answers to the first five questions be No, or to the last question, Yes, and should the facility's construction not yet be underway or, at worst, not yet completed, then some rethinking of the facility's design is warranted. If the facility is already constructed, then some form of intervention on the part of its instructors will be needed until the problems are corrected.

36.3.3 Objective

In this section, it is my intention to present guidelines and supporting documentation that should help the reader address these and related questions. And in addressing such questions and reviewing relevant materials, my focus will be on establishing guidelines to promote the efficacy of the learning environment and, as such, improving the comfort, safety, and task performance of the student or trainee. Developing a relationship between task performance and cognitive, affective, and psychomotor learning is beyond the scope of this chapter.

Furthermore, the primary audience sought for this chapter are those who have some say in the shaping of educational environments. This audience would include educational administrators, educational facility planners, media specialists, teachers who are members of a building development team, and the architects who serve them all. However, where deemed appropriate, suggestions are offered to help the teacher, trainer, the conference leader, and so forth to utilize better a given learning/training/presentation environment. These are presented in the form of classroom *interventions.* The number of such entries is intentionally limited and in no way should be viewed as comprehensive. For those interested specifically in finding more information on the environment's effect on learning or how a teacher can manipulate environmental factors for a desired effect, the following sources are recommended: Bugelski (1971); DeCecco (1968); Gagné (1965); Levy-Leboyer (1982); Proshansky, Ittleson, and Revlin (1970); Bruner (1961); and Tessmer and Harris (1992).

36.3.4 Getting Started

Traditionally, facility planning handbooks have proven to be a useful starting point toward the creation of an effective learning environment (Castaldi, 1977; DeChiara & Callender, 1980). However, even they need to be verified, modified, or simply supplemented and updated by information from the fields of environmental design and ergonomics in order to maintain their relevance. The relevance of the contributions of ergonomics to facilities design is supported by Hunt and Bernotat (1977), who stated:

> . . . the ergonomist is concerned both with improving the health and well-being of the individual human being and with improving the efficiency of the system of which the individual is a part. The improvement of man-environment combinations involves altering the machine and the environment; this part of the ergonomist's work has been called "fitting the job to the man."

The importance of continually updating educational facility planning guidelines has been given additional reinforcement by past and recent ergonomic studies (McVey, 1979, 1990; Bethune, 1991; Caldwell et al., 1993), three of a number of studies that specifically addressed educational facilities. In the McVey and Bethune studies, students rated specific environmental, display system, and ergonomic features in their classrooms and showed an overwhelming preference for rooms designed in accordance with well-established ergonomic standards. In the Caldwell et al. study, a student productivity loss of 26.2% was recorded and attributed to inappropriate environmental and ergonomic features in a lecture hall.

In addition and of equal importance are a number of the findings from ergonomic research conducted in libraries and nonconventional educational settings such as offices, word-processing rooms, and other work settings where computer terminals and visual-display units (collectively referred to as VDTs or VDUs) are employed and where tasks are similar to those found in today's schools, training centers, and conference facilities.

What follows is an updated look at those guidelines that have been shown to contribute to the establishment of efficacious learning environments. The focus of this discussion (lighting, acoustics, thermal factors, display systems, etc.) relate generally to all learning environments, including training and conference facilities. However specifics relative to space allocations and furniture dimensions, because of their anthropometric nature, relate specifically to post-ninth-grade students and adults. Those seeking information regarding elementary school and pre-tenth-grade settings are advised to seek it out in other available sources (Packard, 1988; CEFP, 1969; Castaldi, 1977).

36.3.5 The Physical Space

36.3.5.1. Room Size and Seating Considerations. The size of the teaching-learning space should be such that it comfortably accommodates the required number of students, space for the instructor's teaching station and apparatus, and the activities planned for that space. If these intended activities include media use, then additional space should be provided for the setup and use of equipment and for whatever empty floor space is needed to keep viewers from being seated too close to the display surfaces, i.e., chalk and marker boards, projection screens, television monitors, and so forth (McVey, 1985).

The importance of appropriate space allocations in classroom design is not only appreciated by teachers but also by their students. In a recent article, "The Learning-Friendly Classroom," Caldwell recounts the results of a survey he and Kathy Hoyt conducted involving eight classrooms at the University of California-Davis. In that study, an "uncrowded facility" was cited by 43 faculty members and 890 students as being one of the most important criteria determining the acceptably of a classroom's design (Caldwell, 1994).

The use of the word *seating* in this paper follows the description employed in the work of Tessmer and Harris (1992), who state (p. 31):

> *Seating* refers to both the kind and placement of seats within the learning environment. The seats may be chairs, desks, chair-and-table combinations, or computer workstations. They may be in a classroom, office, home or laboratory. . . . The arrangement of seats refers to the positioning of the students' and instructor's seats in relation to each other. The "type" of seating refers to the style, weight and features of the seat (back support, table-top, etc.).

36.3.5.2. Seating Arrangements and Social Interactions. Seating arrangements play an important role in determining social interactions in the classrooms. Students have been shown to experience greater feelings of equality and uniformity when seated around a rectangular table than when seated at a V- or Y-shaped one (Bass & Klubeck, 1952). In a rectangular arrangement, students tend to speak primarily to those opposite and closest to them. However, as soon as a person is seated at the head of the rectangular table, this interaction pattern changes dramatically; now those seated diagonally across from each other tend to engage in conversation about 6 times as often as those directly opposite each other, and about twice as often as those seated side by side (Hall, 1966).

Interaction in circular seating arrangements is affected by placement and distance as well as by postures and other physical impressions individuals make on each other (Steinzor, 1950). Students in small circular arrangements tend to speak to those opposite them, while those in larger circular arrangements (I have found to be a diameter of more than 18 feet) tend to have more interaction with those seated next to them. When there is an authority figure in the center of a circular seating arrangement, students tend to show more progress and produce a greater number of ideas. Nevertheless, students generally prefer the circular arrangement without the central authority figure (Leavitt, 1951). Figure 36-5 shows some seating arrangements and anticipated interaction patterns.

As implied in the work of Fulrath (1976), reported in 36.2.3.1, the theater style and conventional-row seating arrangement is generally recommended for lecturing, orientation, and media presentations (Fulrath, 1976). My own experience with designing training facilities finds the *U*-shaped seating arrangement, a minor variation of the circle, to be the most popular with high-tech and management training sessions, and with interaction patterns similar to those found with the circular arrangement. It has been noted above that a rectangular conference seating arrangement promotes interaction, with the locus of authority generally vested with those seated at each end of the table, and that the circular and "case method" seating patterns promote more uniform social interaction among the group (McVey, 1971). *Classroom Intervention:* As the manager of such environmental factors, the instructor needs to be made aware of the attributes of different seating arrangements and then employ them for their desired effect in the classroom.

Figure 36-6 is a photograph of a 40-student classroom designed by the author in collaboration with DRA Architects of Newton, Massachusetts, which employs a circular seating pattern, with each successive row of seats on risers for improved viewing of the rear-screen display, vertical operable marker board (behind wainscot), and flip-chart displays.

36.3.5.3. Seating Capacity, Configuration, and Room Size. Seating capacity and configuration are major factors in determining room size. As noted by Menell (1976): "Generally speaking, a 20- × 32-foot room will seat about 49 people theater style, 24 people classroom style, 18 people at a U-shaped table, and 15 people at a conference table." My own studies involving a room 25 feet wide by 32 feet long confirm Menell's assertions. Figure 36-7 shows four examples of the same-sized class/conference room with different seating arrangements, table requirements, and the occupancy levels possible.

The following are some guidelines relative to space allocations for different types of teaching spaces that have been substantiated through my own research and found to be useful in facility planning. Additional considerations can be found in the literature (Leed & Leed, 1987; Terlaga, 1990). My own recommendations follow:

1. Lecture halls and auditoria with tablet arm chairs (12 SF/student), with 18" × 30" countertop writing surfaces (15 SF/student). Arranging seating in the "case method" design will require between 50 and 75% more SF/student space allocation, depending whether fixed or castered seats are used.
2. Classrooms with conventional row-seating arrangement and movable tablet armchairs, spaced on 28-inch centers with 42-inch rows (15-18 SF/student); with 18" × 28" fixed table area and 48" rows (20–22 SF/student), and with 24" × 36" fixed table area and 60" rows (28–33 SF/student). These last dimensions are also acceptable for supporting a VDT if the tables or desks are equipped with a supplementary keyboard drawer. If not, then the VDT work surface should have a minimum dimension with a depth of 30" and width of at least 30" and preferably 36".
3. Classrooms or conference rooms with U-shaped arrangement and 24" × 30" table area (35–42 SF/participant); with 24" × 36" table area (45–50 SF/participant). Employing a circular seating arrangement will require approximately 10% more space per participant than the U-shaped arrangement.

Figure 36-8 shows a room I designed to employ the teacher-student, student-student interaction features of the

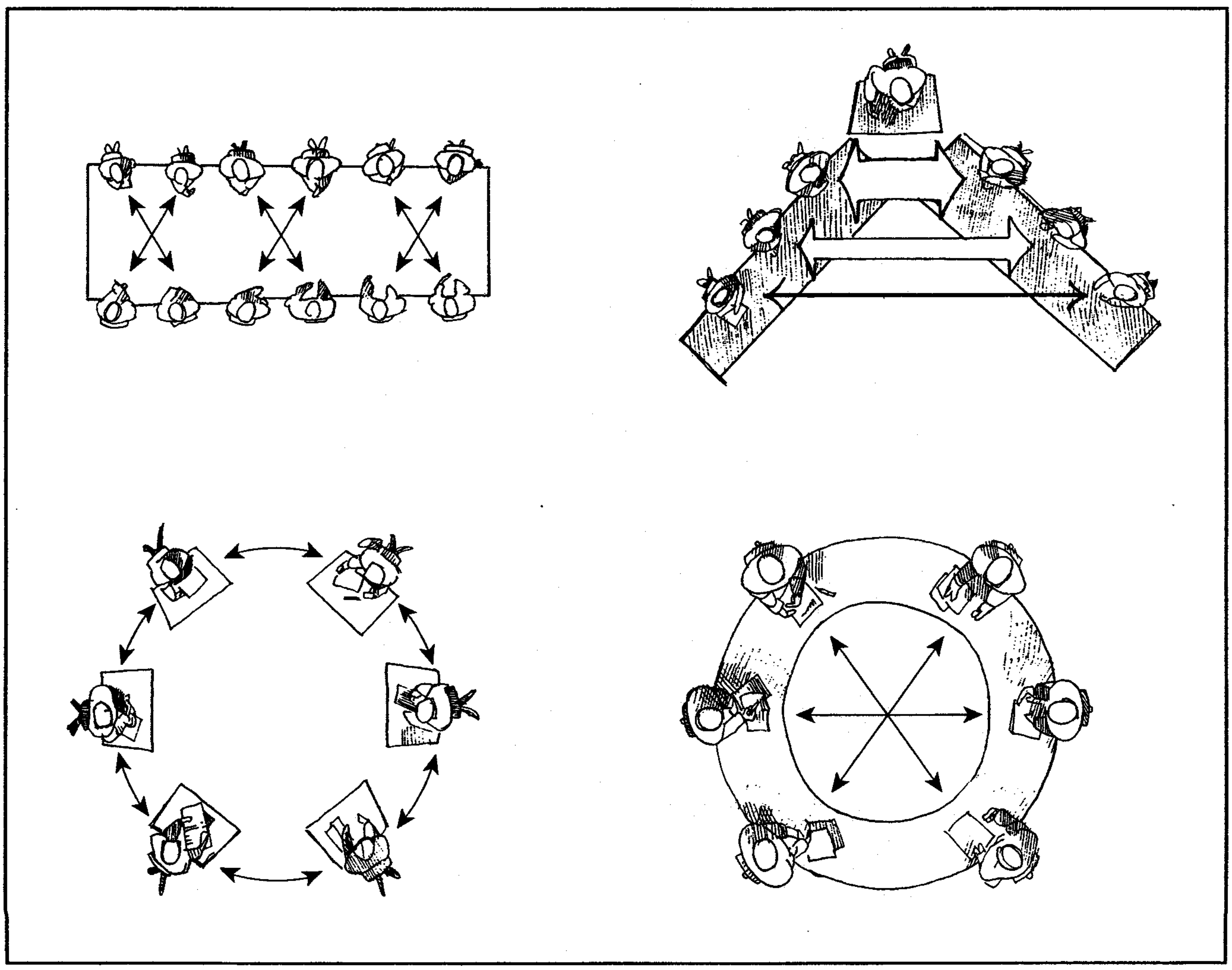


Figure 36-5. Seating patterns and social interaction.

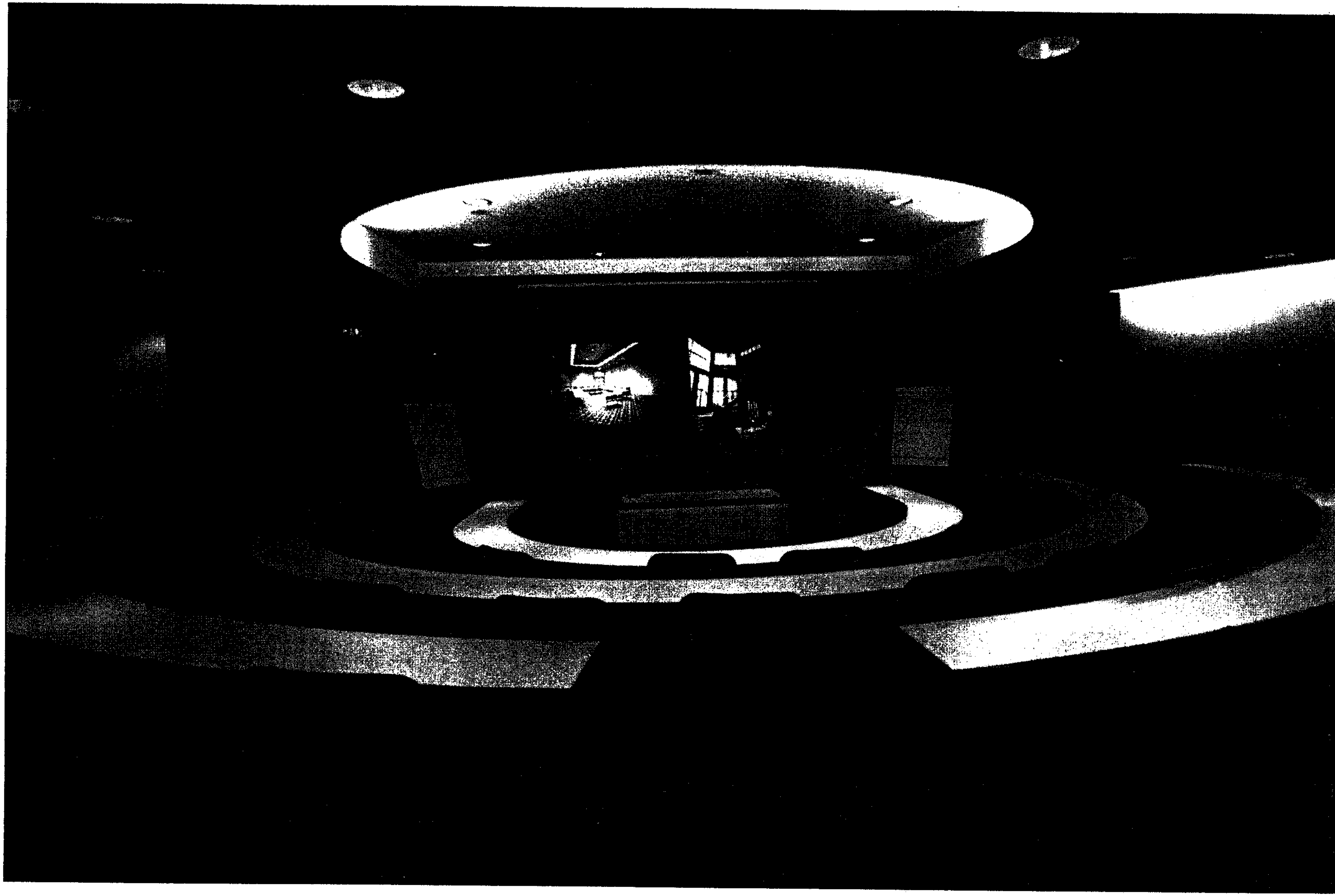


Figure 36-6. Circular seating pattern in media presentation room.

case method plan modified for improved viewing of projected media and demonstrations. This design also employs movable ergonomic chairs on casters and as such requires about 10% more space than the conventional case method plan using fixed seating.

36.3.5.3.1. Determining Classroom Size. In light of the variety of potential interactions available to the classroom teacher through employing different seating patterns in the classroom, Tessmer and Harris (1992) recommend that facility planners provide enough space to accommodate the

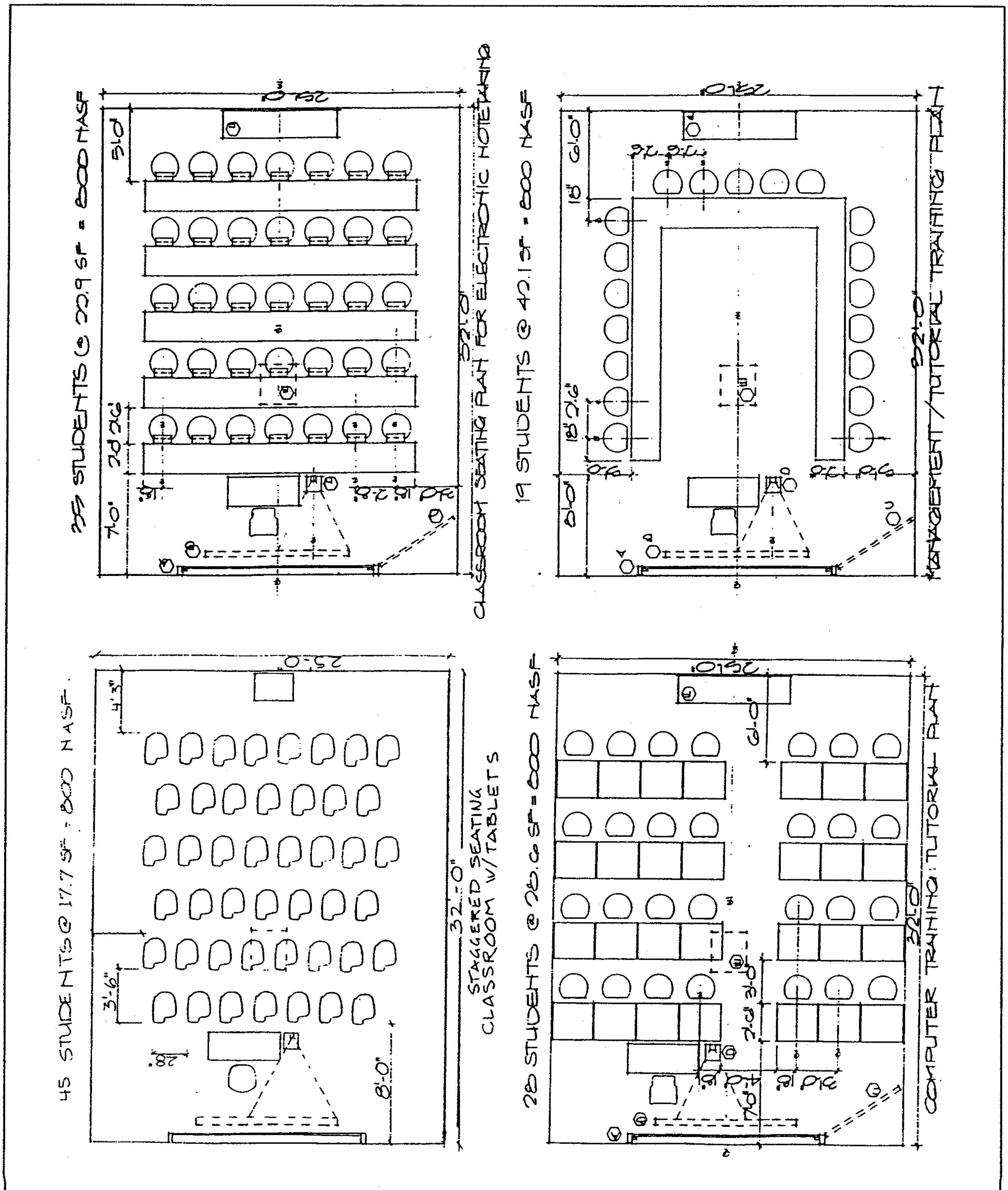


Figure 36-7. Room capacity relative to seating arrangement and table requirements.

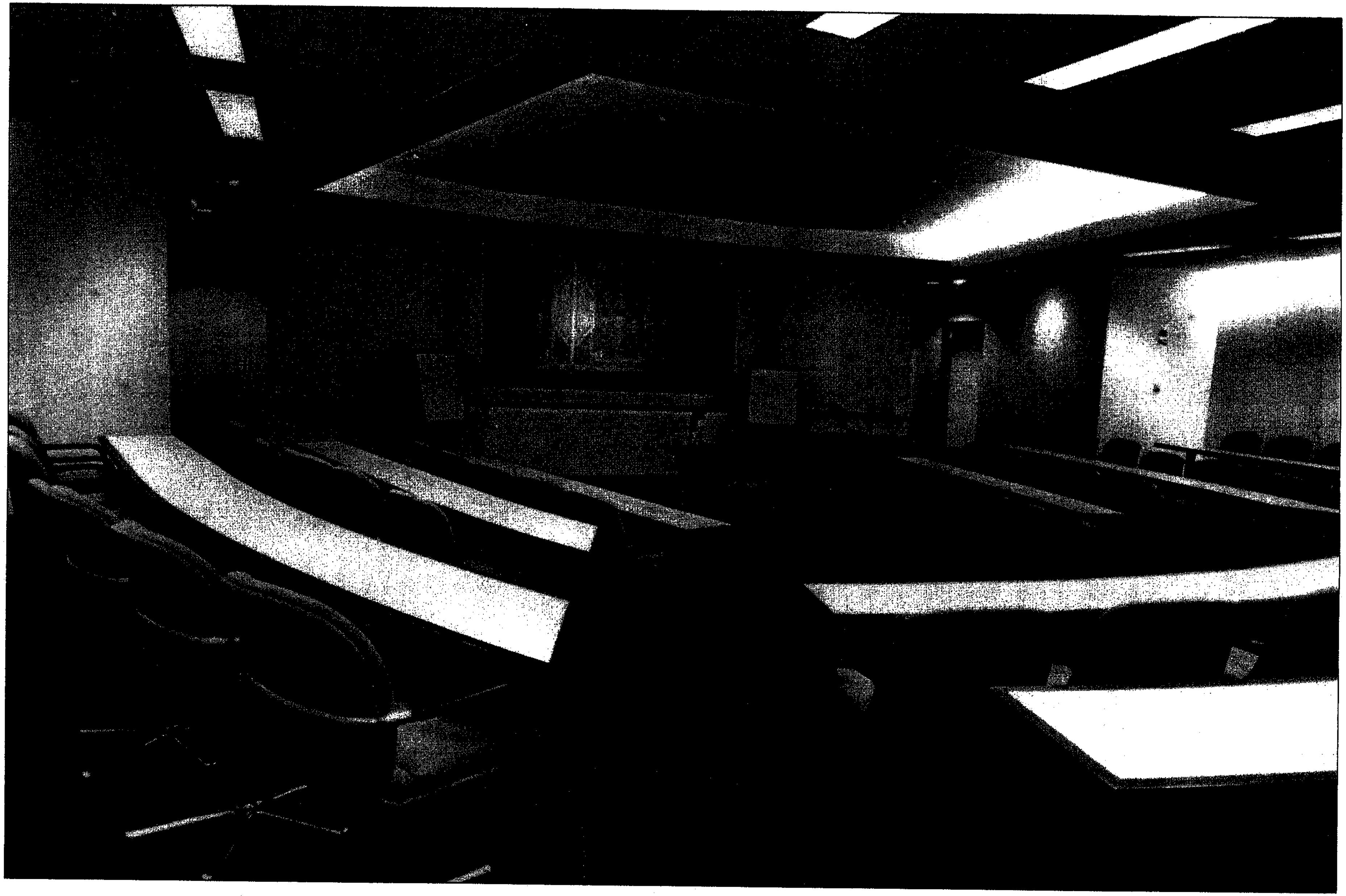


Figure 36-8. Modification of case method room design for improved viewing of presentation media.

conventional seating pattern that requires the most space, i.e, the U-shaped arrangement. When provided with the space needed to accommodate such space demands, then all of the other less space-demanding seating patterns will be possible.

However, the application of the above space allocation recommendations will not be met without some resistance. In the college, government, and business sectors, the primary reason will be budget, since additional space equates to additional cost. But relevant ergonomic data have been successfully employed in overcoming this argument. The greater challenge lies with the public school sector. The reason for this is that many states require strict adherence to their own less-generous program standards, standards that in most cases were developed before the computer arrived on the scene and before teachers were motivated to employ a variety of classroom seating arrangements in their teaching methodology. The inappropriateness of the space standards currently being enforced in most states was recently addressed by Ross and Stewart (1993):

> Documented space requirement standards for a technology classroom are still in development. The space requirements are larger than traditional classrooms requiring more area than student desks and involving many factors including the type of equipment involved, the instructional methodology anticipated, student age and size, and furniture and storage requirements.

Consequently, the school facility planner is currently faced with a dilemma. Ergonomic studies may provide more appropriate space guidelines, but legislation will dictate that current Department of Education (DOE) standards be applied. Operating under this constraint will require some ingenuity on the part of the educational facility planner. One approach would be to see that classrooms employing computers and other space-demanding technologies be programmed as "lecture/laboratory" spaces. This category traditionally applied to science-teaching rooms usually receives a more generous space allocation in the DOE program standards. And no doubt, there are other approaches that could and should be considered in the worthwhile pursuit for classrooms sized appropriately for the next decade.

36.3.5.4. Ceiling Height. One of the structural features of a room which often reduces the potential effectiveness of projected media is ceiling height (McVey, 1985). A room's ceiling height should accommodate a projection screen large enough to display images of adequate size and positioned high enough from the floor so that sight lines are unobstructed. In the conventional classroom, one can determine the required ceiling height by dividing the room's length by 6 to determine the vertical length of the required screen, and adding to this dimension a minimum of 4 feet (where the bottom of the screen will be positioned) and 6 inches for trim at the top of the screen. Additional ceiling height above the top of the projection screen is required in an auditorium to accommodate an acoustical canopy or "cloud" that can also serve as an enclosure for the room's program playback speakers.

However, it is also important that where generous ceiling heights have been provided, this vertical span is not used to raise the projection screen to a height that will cause viewer discomfort. According to Ramsey and Sleeper's Architectural Graphic Standards (Packard, 1988), the vertical viewing angle of the first row occupant to the top of the screen should generally not exceed +30°, and never 35°. However, this popular handbook provides no empirical evidence to support this guideline. And a major research study (McVey, 1979) clearly showed college students finding a +24° to the top of the projection screen to be more acceptable ($p < .0.5$) than ones of +32° and +47°. And subsequent field experiments in instructional spaces by the author indicate that sight lines with inclinations greater than +25° (to the top of the display) and depression angles greater than -24° (to the bottom of the display) brought about negative responses from viewers.

Sometimes having added ceiling height makes it possible to conduct functions that would otherwise be difficult if not impossible. And example of this is the divisible auditorium I designed in collaboration with the architects at Shepley, Bullfinch, Abbott, and Richardson for the Tufts New England College (see Fig. 36-9). Given the instructors' need to project video to one or both halves of the room while simultaneously video recording a conference setup at the front of the room, a high ceiling was the answer. Employing rear-screen projection above the video-recording stage permitted the beams from the video-recording light to be directed away from the screens, where it would have "washed out" the display, and focused on the people who were being recorded. Note that this screen does not begin at the second-floor level (an undesirable but popular procedure in the past) but is cantilevered forward and downward so that the bottom of it is only 7'3" above the finished floor (AFF). Note also that the screen is tilted forward in order to minimize geometric distortion and maximize uniform image brightness for the greatest number of viewers. It should also be noted that such an arrangement does increase the angle of the front-row vertical sight line to 35°, which, though not ideal, is still in keeping with Ramsey and Sleeper's recommendations cited above, and, admittedly, given the special needs of this project, appear to be an acceptable compromise.

36.3.5.5. Room Shape, Seat Location, and Spacing. A room's shape is a major factor contributing to a space's aesthetic character, its overall sense of perceptual appropriateness, and the kind of social interaction pattern that its planners desire to promote. In rooms planned for extensive media use, the configuration of a room and its viewing area can be one of the most significant factors contributing to the effectiveness of the display system, the viewer's comfort, and the strength and clarity of the instructor's voice.

36.3.5.5.1. Room Dimensions and Viewing Distances. The basic dimensions for lecture halls, auditoria, and large media presentation rooms should be 2:3 (width to length), with seating contained in a fan-shaped area beginning at a distance 2 times the height of the projected image [1.5 times

Figure 36-9. Divisible auditorium used for videoconferencing and distance learning by Tufts New England College.

the width (1.5W) for rooms employed for dual-image display systems, and 1W for triple-image display] and extending to a distance of 6 times the projected image height (3W for multi-image rooms) for media employing standard symbol sizes (minimum of 10 arc-min).

When displaying computer screens, this maximum viewing distance will vary considerably and be governed primarily by the character size employed in the display. For example, when displaying, say, a Powerpoint screen consisting of large alphanumerics (40 characters per line, C/L), the maximum viewing distance can be 12H. If the display consists of 60 C/L (as produced by 12 pt on a 9-inch Macintosh screen), this maximum distance needs to be reduced to 8H, and for 80 C/L = 6H. For "windows" where a 9-inch screen sometimes consists of 100–120 C/L, the maximum should be 4.5H. These minimum and maximum viewing distances differ from the widely used earlier recommendations (Wadsworth, 1983) in that they attempt to go beyond accommodating film-based media and consider the viewing legibility of computer screens at terminals or via video projection (McVey, 1991).

36.3.5.5.2. Off-Axis Viewing and the Shape of the Viewing Sector. As a viewer moves away from the axis perpendicular to a displayed image, an increasing amount of distortion will be experienced because a flat surface is being seen from a more and more oblique angle. The effect of this geometric distortion on symbol legibility can be compensated for by moving off-axis viewers closer to the display, thus increasing the observed symbol size. *Classroom Intervention:* Set up seating so that the seats off-axis at a point 45° from the display are 80% of the maximum viewing distance, and those located at a point 60° from the display axis are only 60% of the maximum viewing distance.

The viewing-seating area itself is fan shaped to improve horizontal sight lines. The boundary for the acceptable viewing area proposed by Ramsey and Sleeper (Packard, 1988) is an area within two lines extended out 45° from the far sides of the screen or other display surface, i.e., chalkboard, dry marker, etc. However, experimental research (McVey, 1979) has broadened that area to extend to two lines extending out approximately 30° (actually 27° in the study) from the far sides of the display. Such a wide viewing sector assumes the use of a well-designed display system. See Figure 36-10 for some of these relationships.

36.3.5.5.3. Recommended Room Configurations. The length-to-width ratios for standard-size classrooms are meant to accommodate different seating arrangements and room acoustics. These follow:

- Classroom style: a room 1.15 to 1.5 times longer than it is wide.
- U-shaped seating pattern: a room 1.0 to 1.3 times longer than it is wide.
- Circular seating pattern: a room 1.0 to 1.25 times longer than it is wide.
- Lecture hall or auditorium with standard seating patterns: a room 1.25 to 1.5 times longer than it is wide.
- With a "case method" seating arrangement: a room 0.8 to 1.2 times longer than it is wide.

Note that in classrooms, conference rooms, and auditoria where there is a requirement for simultaneous side-by-side projection and extensive marker board use, the length-to-width ratio approaches 1:1 and thus requires extra attention for acoustical treatment. Because of their relatively large size, auditoria also require special acoustical considerations. Figure 36-11 is a photograph of a computer classroom I recently designed to feature side-by-side simultaneous projection and marker board display. Note that both halves of the front wall are angled out at each end about 15° so that each display is perpendicular to the center of the viewing area.

36.3.5.5.4. Seat Spacing and Access and Egress. Research has shown that access and egress to seating areas in lecture halls is dramatically improved when seats are spaced a minimum 26 inches on center, and 38 inches front to back. When these chairs are equipped with tablet arms, the preferred spacing is 28 inches on centers and 42 inches frontal. For fixed 18-inch tables with pedestal chairs, the minimum frontal spacing should be 48 inches, including the table (McVey 1979).

Movable chairs with five-star pedestal and casters provide stability and ease of access and egress, and because of this are often employed in carrels, conference settings, and "case method" arrangements. This type of seating requires a minimum space of 32 inches, and preferably 36 inches between tables if the occupants are to have unrestricted access and egress, and 42 inches if an instructor expects personally to monitor a student's activities at a particular workstation.

Accessibility for all is an important design principle. An accommodation for the special needs of the physically challenged is the law of the land, and also provides access and egress as well as many other benefits to all occupants of a facility. It also contributes to one's sense of acceptance or rejection. As Burch (1993) stated: "Height, size, openness, and accoutrements are all part of the package that is this piece of instructional equipment." The need for accessibility is not limited to seats in the learning environment. Safe, easy, and convenient access to learning resources is also important (Tessmer & Harris, 1992).

36.3.6 The Chair, the Desk, and the Computer Workstation

36.3.6.1. Seating Design. Proper seating is an important factor in determining a student's relative comfort and effectiveness as a perceiver, recorder, and processor of information. Furthermore, there is a long history of evidence that improper seating may result in improper skeletal development in children between the ages of 11 and 16 (CCSE, 1938). Since chairs need to accommodate the body dimensions of those who use them, most schools need a variety of chair sizes to serve their student population. In fixed workstations, such as audiovisual/television carrels, video-display terminal stations, and operational control rooms, where a chair has to accommodate a varied user population, pneumatically adjustable chairs are recommended.

36.3.6.1.1. The Seat Pan. A chair's seat pan should have a modest concave contour so that an individual's weight is distributed evenly in the ischia area of the buttocks. The seat pan should have a "waterfall" shape at its front and should be lightly padded (about 1 inch) and covered with a porous textured "breathable" nonvinyl fabric. Overpadding the seat pan should be avoided, since the research indicates that leg discomfort increases with low, soft seat pans, suggesting that postural constraint is more important than thigh compression as a risk factor for leg discomfort (Sauter & Schlifer, 1991).

36.3.6.1.2. Materials and Components. The seat and frame parts that come in contact with its occupant should be made of wood or some other thermally nonconductive material. It should be equipped with a padded backrest that provides support both in the lower back (lumbar) and midback regions. Chairs that swivel are recommended for large-group lecture halls and other settings where tasks involve rotation of the torso (Tichauer, 1978). Adding a pneumatic seat height adjustment is desirable for conference rooms, and this along with numerous other adjusting mechanisms are required for chairs used in VDT workstations.

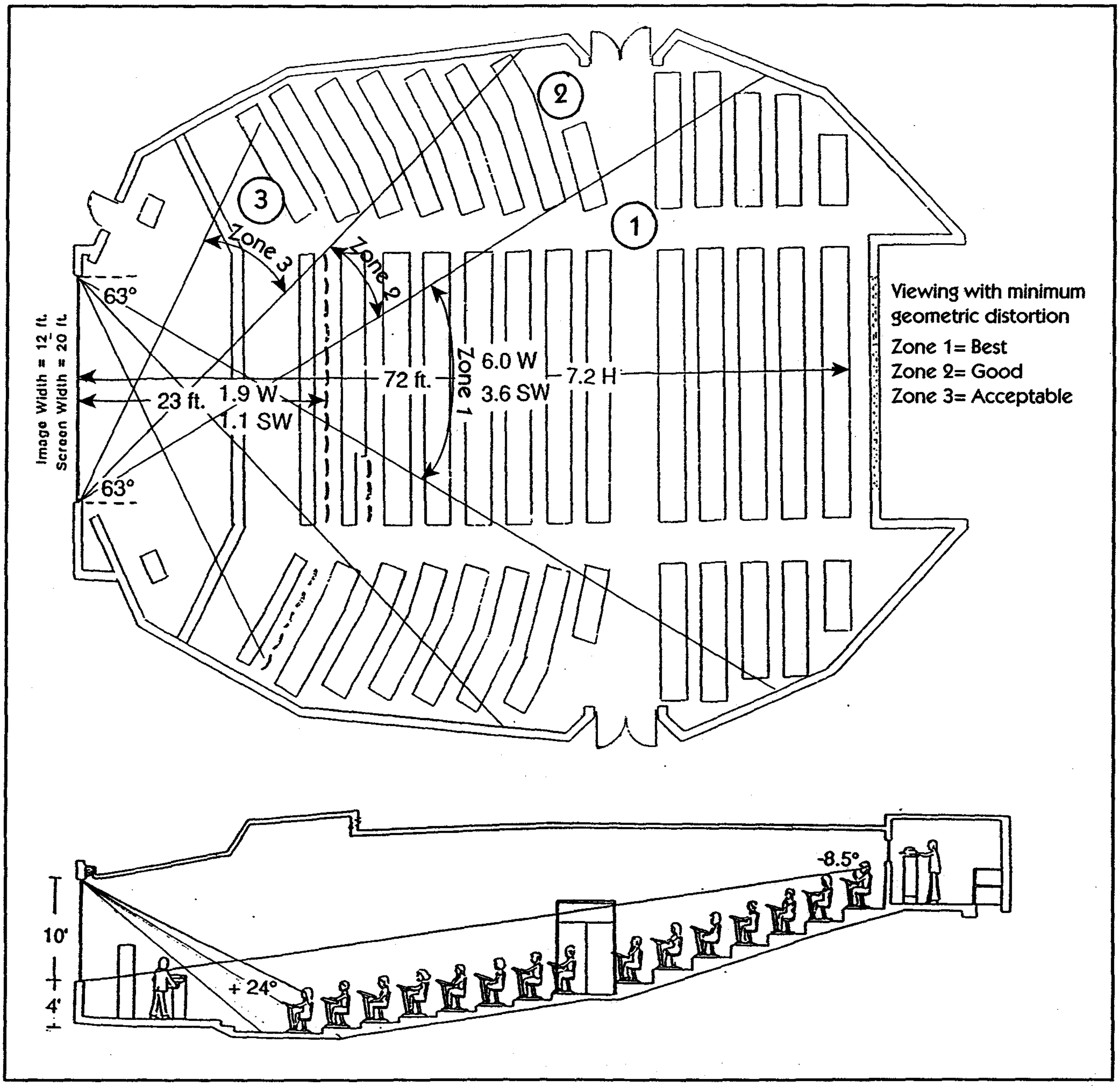


Figure 36-10. University of Wisconsin auditorium viewing parameters.

Figure 36-11. Computer classroom with simultaneous rear-screen and marker board display and individual VDT workstations.

36.3.6.1.3. Range of Adjustments. Since people, desks, and chairs all vary in height, units with adjustable height and tilt allow the greatest flexibility in avoiding problems (Davis, 1988). According to the Canadian National Standard (Carnovale et al., 1989), a workstation chair should have a minimum adjustable range between 15 inches to 20.5 inches, and ideally a desk's height should be adjustable between 24.8 inches to 30.0 inches. But if it has to be nonadjustable, then it should have a height between 27.9 inches to 28.3 inches. The use of a footrest is recommended, and a chair's backrest should be adjustable 104° to 120°, and the seat pan inclined backward 4° to 6° (Grandjean, 1988). Being able to change a chair's height, angle, and pitch will promote postural shifting, which is an important determinant for both physical comfort and work effectiveness. Such postural shifts are recommended for educational settings by Knirk (1992), "particularly for high cognitively loaded tasks such as those for computer-based training."

Classroom Intervention: Unfortunately, all too often the classroom teacher "inherits" chairs and desks that have little if any ergonomic merit. In such situations, Tessmer and Harris (1992) recommend adopting the following classroom management procedures in order to reduce the effects on learning of seating discomfort and inappropriate arrangement:

- Break instruction into shorter modules, thus encouraging students to take breaks from uncomfortable seating.
- Direct or advise learners to break sessions after no longer than 20 minutes via a message built into the materials they use.
- Provide seating graphics and user directions within instructor or student guides.

While the above procedures were intended for elementary and secondary classrooms, they are also appropriate for college and adult learning situations, with the exception of perhaps an adjustment of a seating interval being extended to 45 minutes.

36.3.6.2. The Desk, Computer Workstation, and Working Postures. The design of the notetaking, reading, and working surfaces also contributes to an individual's operational comfort and effectiveness. Horizontal writing and reading surfaces force students to bend forward excessively, setting up stresses in their skeletal and visual systems which can cause digestive, respiratory, visual, and postural problems (Harmon, 1951). And as early as 1938, one can find orthopedic reports showing that improper seating support can result in kyphosis (curved or bent back) and scoliosis (twisted spine) in children between the ages of 11 and 16 (CCSE, 1938). Another but more benign problem created by flat desks is noted by Tessmer (1994), who believes that excessive bending forward can affect a student's attention to learning tasks.

36.3.6.2.1. Inclined Reading/Writing Surfaces. Proper reading and writing posture is promoted by a desk or writing surface that is tilted somewhere between 10 to 20° from the horizontal (Freudenthal et al., 1991; Diffrient et al., 1974; deWall et al., 1991). In a major study at a large university, a writing/reading surface tilted 15° from the horizontal received significantly higher ratings from college students than did writing surfaces that were inclined 0°, 2°, and 7° (McVey, 1979). Figure 36-12 is a photograph of the desk designed by the author and constructed by the Haywood Wakefield Company for the University of Wisconsin's two lecture halls in the then-new (1972) School of Education facility. Note the 15° inclination of the surface and also its light color and matte texture. Also note the flatness of the paper/book restraining device. This was done to minimize pressure on the student's forearms and wrists when writing.

Having inclined writing surfaces is not only recommended for college age students but also has been shown to be particularly favorable for children (Bendix & Hagberg, 1984). Inclining the desk top 30° to 45° places reading and viewing materials at even more comfortable inclinations but will not allow items to remain unattended without falling off. This is why less-acute inclinations have thus far been favored. And it stands to reason that horizontal work surfaces have been found best for three-dimensional manipulative tasks.

About 40 years ago, the physiologist Darrell Boyd Harmon, in an effort to meet this challenge, designed for the American Seating Company a solid wood-metal seat-desk combination that was adjustable for students of different sizes and had swivel seats and an adjustable top that could accommodate the various work surface angles that were recommended for the full range of activities found in the standard classroom of the day (Harmon, 1951).

Classroom Intervention: Since most worktables and desks available to the student will probably be horizontal, the teacher should demonstrate for the students and encourage them to prop up their reading material with a thick book (3 inches), or by writing on a clipboard propped up by a 2-inch book. By placing these two tasks at these angles, the teacher will be promoting better posture, visual comfort, and speed and accuracy in reading and writing.

36.3.6.2.2. Accommodating the Computer (VDT). Today, the term VDT (visual-display terminal) is used primarily to mean computer monitor and keyboard, but its application is also extended to cover any display device employed at a workstation and its research findings applicable to all variations on this theme, i.e., video-display terminals, CRTs (cathode ray tubes), VDUs (visual-display unit, i.e., microfiche readers), etc.

Working at VDT workstations can be fatiguing and create physiological stress if seating-display relationships are not ergonomically correct. Working with VDTs, Sauter and Schlifer (1991) have found the erect seating posture to be associated with less-frequent discomfort than either stooped or reclining postures. This association is consistent with the classic view regarding healthy seating postures

Figure 36-12a. Ergonomic reading and writing unit at the University of Wisconsin (circa 1972).

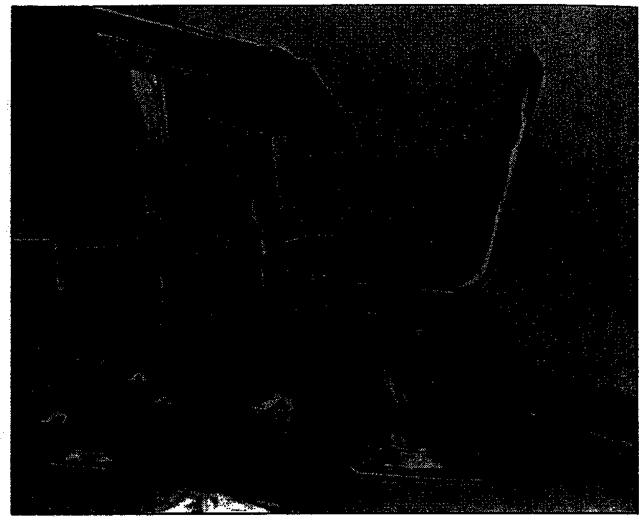


Figure 36-12b. Chair modified with addition of fabric-covered padding.

(Akerblom, 1954), but contrasts with at least one study that showed preference for reclining posture in VDT work (Grandjean et al., 1983).

36.3.6.2.3. Recommended Postures. Horowitz (1992) indicates that the right kind of furniture can help VDT users avoid crippling injuries by promoting what we have come to know as good posture. She recommends that furniture should be installed which promotes student posture with the following characteristics. It should be noted that these recommendations also apply to conventional reading and writing activities.

- The head should be directly over the shoulders, without straining forward or backward, about an arm's length from and at the same height as the screen.
- The neck should be elongated and relaxed.
- Shoulders should be kept down, with chest open and wide.
- The back should be upright or inclined slightly forward from the hips.
- Elbows should be relaxed and in a neutral position without flexing up or down.
- Knees should be slightly lower than the hips.
- Feet should be firmly planted on the floor.

One of the obvious objectives of Horowitz's recommendations is to establish a posture where the neck, back, upper arms, hips, and ankles are aligned at an angle approximately 90° to the floor, and with the forearms parallel to it. This is consistent with established ergonomic guidelines for VDT workstations (HFS, 1988). This arrangement will avoid positioning the head forward over the spine, with the shoulders and upper back following to produce an undesirable slump.

Given that the head represents a considerable weight (about 10% of the total body), maintaining such an unbalanced load sets up stresses in the musculoskeletal system. Sustaining such a posture while operating a keyboard for an extended period of time will result in excessive compression of the nerves and blood vessels in the neck, over the upper ribs, and down the arm. This cumulative trauma is referred to as a thoracic outlet syndrome. In addition to upsetting nerve control and circulation to the arms, the syndrome can also contribute to other CTD problems further down the arm (Hebert, 1989)

36.3.6.3. VDT Keyboard Height and Configuration. The coordination of seating, viewing, and work positions is important to those whose learning activities involve computer terminals, using microfiche readers, video monitors in carrels, or VDT workstations. Research indicates that "many existing desks are not deep enough to accommodate a VDT and leave room for a generous wrist/forearm support for the use of a keyboard" (Porter et al., 1992). Whatever the support mechanism, it is important that the VDT keyboard height be on a plane with, or slightly below, elbow level. Sauter and Schlifer (1991) found that arm discomfort increased with increases in keyboard height above elbow level, and their findings are in agreement with Bendix and Jensen's (1986) electromyographic data that showed reduced trapezius loads with lower keyboard placement.

The angle of the keyboard should be such that the user can assume a position where the hands can be held in a neutral position, without excessive "extension" (palm down and wrist bent upward), "flexion" (palm down and wrist bent downward), "ulnar deviation" (rotating or tipping the hand toward the little finger). Experiments with a "split" keyboard design and with solid keyboards where the two keyboard halves have an opening angle of 25° and shaped with a lateral support of 10° were found to lessen the extent of inward rotation of the forearms and wrists and reduce physiological strain (Zipp, 1983). Other recommendations relative to keyboard design include detachability (HFS, 1988) or movability on a desk, with a support for forearms and wrists, the keyboard having a minimum depth of approximately 6 inches (Grandjean, 1988).

Figure 36-13, taken from one of my student's current studies (Badolato, 1995), summarizes the principle characteristics and dimensions recommended by different respected sources regarding computer workstation design. In his study, Badolato has applied these to the analysis of his own experimental settings, a series of music training classrooms at the Berklee School of Music in Boston. Readers should find this summary useful in their own future design and furniture selection activities.

36.3.6.4. The VDT and Viewing Distances. Because of the time-intensive nature of most VDT work, this subject has received considerable attention by leading ergonomists. Their work concerning viewing distance and viewing angle is summarized in the form of recommendations, as follows:

36.3.6.4.1. Viewing Distance from the VDT Screen. The absolute minimum distance according to a British standard (BS7179, 1990) is 15.7 inches. But according to the research of Jaschinski-Kruza (1988), the minimum distance should be 19.6 inches. And according to a widely respected source (Grandjean et al., 1984), that minimum distance should be 24 inches. The recommended maximum viewing distance also varies depending on the above sources, with the Jaschinski-Kruza study recommending 32 inches as the preferred maximum viewing distance and the Grandjean study, 36.6 inches. The author's own studies indicate student preferences for VDT viewing distances between 20 to 28 inches.

36.3.6.4.2. Viewing Angle to the VDT Screen. Some sources recommend that the top of the VDT screen be on a plane with a person's eyes (Eggleton, 1983). Other sources recommend a more acute downward angle (Ankrum & Nemeth, 1995). Hill and Kroemer (1988) recommend that the line of vision center on a downward angle between -29° to -38°, with the viewing distance decreasing at greater downward viewing angles. Support for this change in recommended viewing distance with increased declination angles is offered by Ripple (1952), who describes the "near" visual field as being "a curved surface concave toward the eye and curving deeper in and down and flatter up and out."

The author's own experiments have shown a preference for a viewer-monitor arrangement where the top of the display does not extend above the viewer's -5° horizontal line of sight, and the bottom not below the viewer's -40° horizontal line of sight. Where lighting conditions permit, the display screen should be inclined backward somewhere between 20° to 45° from the perpendicular. It should be noted that while inclining the monitor in this manner minimizes perceived geometric distortion and makes use of the increased visual accommodation experienced at downward viewing angles, it will require special care in the room's lighting design in order to control for excessive reflected glare. Figure 36-14 shows a computer training classroom I designed employing student workstations where the computer monitor is located inside the desk and below its glass work surface. This concept has been shown to have merits as well as some limitations, particularly in educational programs in which students often work in pairs. Complaints with it relative to glare of its glass surface, as well as off the monitor, were generally eliminated with the use of the glare hood provided by the manufacturer and by fitting each monitor with an antiglare polarizing screen.

36.3.6.5. Repetitive Motion Problems. With the increased use of VDTs primarily in offices has come increased incidents referred to as *repetitive motion disorders* (RMD) or *cumulative trauma disorders* (CTD) affecting different parts of the body (arms, shoulders, neck, legs) and a variety of sensory functions. A 5-year prevalence rate for RMDs of nearly 35% has been reported in some Australian organizations (Hocking, 1987), and Japan experienced a similar phenomenon during the 1970s (Nakaseko et al., 1982).

In the U.S., the most prevalent RMDs are carpal tunnel disorder (CTD) problems, which are primarily caused by the excessive compression of the median nerve in the wrist and which account to up to 3% of all VDT users. According to the National Institute of Occupational Safety and Health (NIOSH, 1991), CDTs are primarily caused by inadequate physical and psychological workplace design or ergonomic factors (NSWI, 1992).

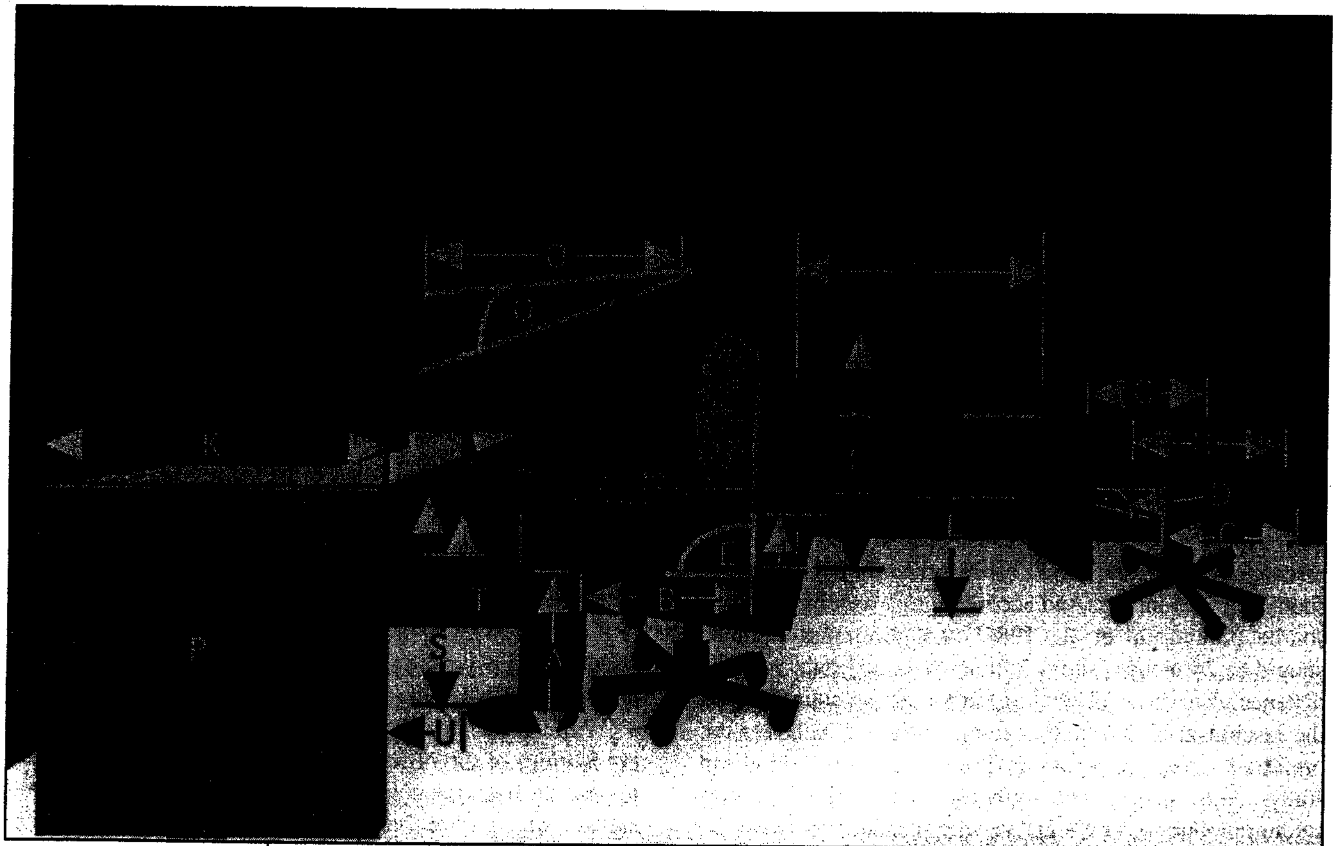
While great strides have been made in improving the ergonomics of the office work environment, little attention to date has been given to classrooms, libraries, and resource centers where extensive VDT use is a regular occurrence. It is anticipated that significant levels of RMDs including CDTs will soon be noted in the education sector. Today's educational facility planners should look to office design research results for guidance in preventing the onset of such problems.

36.3.7 The Acoustical Environment

36.3.7.1. Room Shape and Acoustical Treatment. There are a number of sources that can help the facility planner and designer create the proper acoustics for a space (Yerges, 1969; Doelle, 1972). The following generalizations apply: A room's shape affects its acoustics. The orientation of a room's walls, ceiling, and floor should be such that sound is reflected from the front of the room toward the back. To accomplish this, side walls should be nonparallel (splayed). In large-group media rooms and auditoria, floors should be stepped or inclined.

The ceiling section over the instructor should also be inclined toward the audience so that the speaker's voice is projected forward, although part of this sound should also be reflected at a slight downward angle so that instructors will have no difficulty hearing their own voice. A room's shape should propagate sound throughout, but in a diffused fashion. Consequently, concave curved walls are usually not recommended, since they tend to refocus reflected sound waves.

The character of each room surface should be consistent with the general acoustical treatment of the space. The ceiling above the lecture stage should be sonically reflective. If reflecting panels (acoustical clouds) are used, they should be no smaller than 8 feet wide, or else they will not



Dimension	ANSI/HFS (1988)	Grandjean (Salvendy 1987)	Woodson (1992)
Seating			
A–Height	16.0–20.5 in. (40.6–42.0 cm)	13.0–22.0 in. (32.0–55.0 cm)	15.0–18.0 in. (38.0–46.0 cm)
B–Depth	15.0–17.0 in. (38.0–43.0 cm)		16.0 in. (43.2 cm)
C–Width	18.2 in. (45 cm) minimum		19.0 in. (48.0 cm)
D–Pan angle	0–10°		5°
E–Angle btw back and pan	90–105°	90–120°	105° (10° free pivot)
F–Backrest height	no specific recommendation		15.0–18.0 in. (38.0–46.0 cm)
G–Backrest width	12 in. (30.5 cm) minimum		
H–Distance btw armrests	18.2 in. (45 cm) minimum		
I–Lumber support	6–10 in. (15.2–24.4 cm) abv seat	4.0–8.0 in. (10–20) abv seat	
Worksurface			
J–Width	sufficient for equipment and task		32.0 in. (81.0 cm)
K–Depth	sufficient for equipment and task		24.0 in. (61.0 cm)
Keyboard			
L–Support surface height	23.0–28.0 in. (58.4–71.1 cm)	27.5–33.4 (70.0–85.0 cm)	
M–Upper arm/forearm angle	70–135°	90° observed avg posture	
N–Slope	0–25°		
Video Display			
O–Viewing Distance	12.0 in. (30.5 cm) minimum	19.6–29.5 in. (50.0–75.0 cm)	
P–Support surface height	position within viewing angle Q	35.4–45.2 in. (90.0–115.0 cm)	
Q–Viewing angle	0–60° below horiz. line of sight	+2 to -26° observed	
Clearance Envelopes			
R–Leg clearance width	20.0 in. (50.8 cm) minimum		
S–Leg clearance height	26.2 in (66.5 cm) minimum	23.6 in. (60.0 cm) minimum	23.0–28.0 in. (58.4–71.0 cm)
T–Depth at knee level	15.0 in. (38 cm)		
U–Depth at toe level	23.5 in. (59.0 cm)		

Figure 36-13. Principle characteristics and dimensions of VDT workstation design. (After Badolato, 1995.)

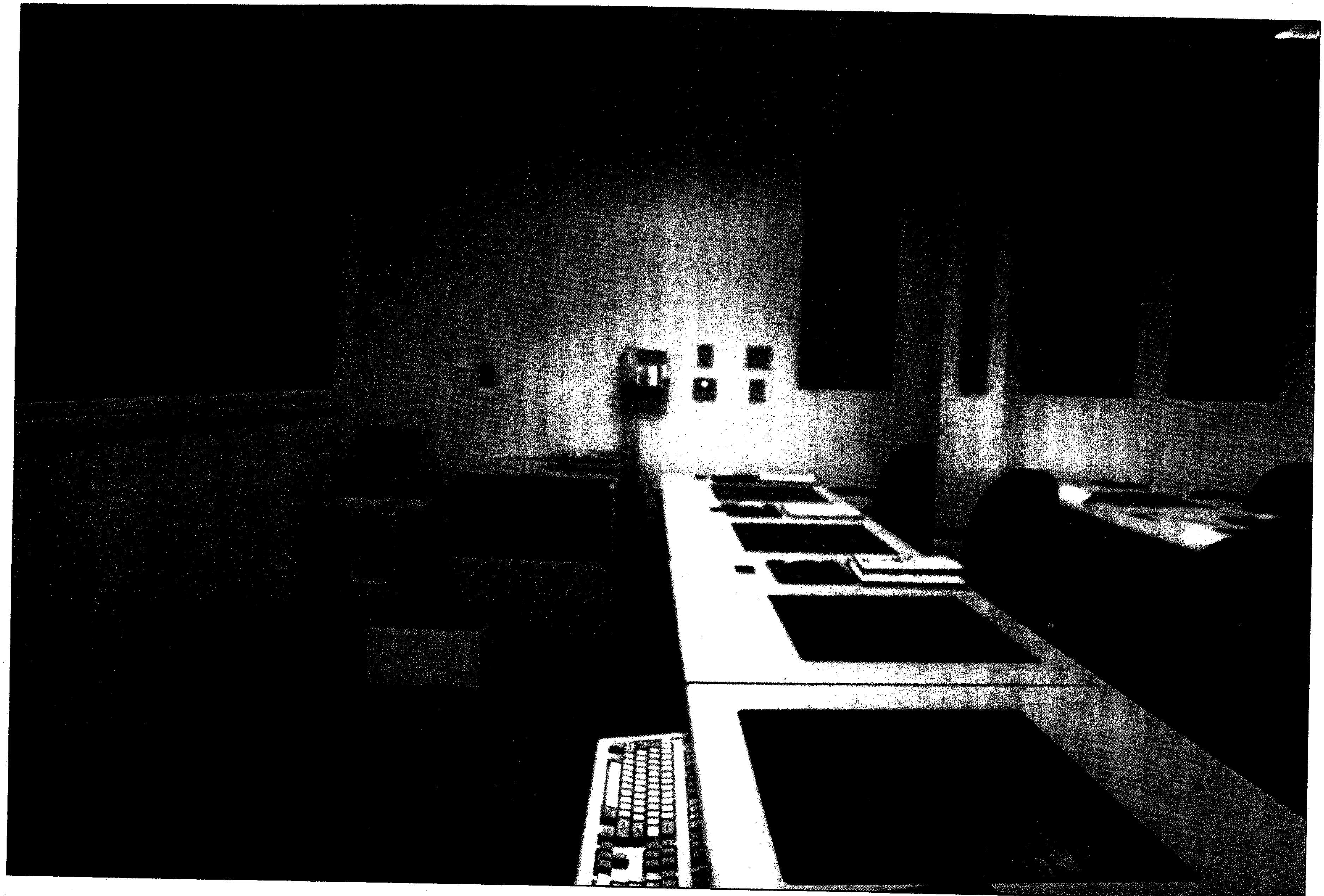


Figure 36-14. Below-surface VDT student workstation.

should be no smaller than 8 feet wide, or else they will not reflect the lower sound frequencies. While it is generally recommended that the front half of the space be acoustically reflective, it is also recommended that the rear half of the room be acoustically absorptive so that sound waves will not be reflected back toward the front of the room. This condition can usually be accomplished by putting acoustical tiles on the rear one-third of the ceiling and acoustical carpet or other sound-absorptive material on the rear and side rear walls.

Installing carpeting on the floor area usually completes the acoustical treatment of a room while adding a welcomed bit of texture and color to the space. In a large auditorium that is used for a variety of activities involving groups of varying numbers, the addition of upholstered chairs may be required to keep the room's reverberation time near a desired constant.

The reader should note, however, that getting an educational institution to provide upholstered chairs for its lecture halls is not an easy task. Back in 1970 when I had selected the seating for the University of Wisconsin's ergonomically designed auditorium/lecture hall, I was successful in getting the university to agree to adding padding and fabric to the seat pan and backrests of the Haywood Wakefield swivel chairs selected and installed at the site. And, interestingly, the only justification they would accept for such an expenditure was for improved acoustics. Student comfort was not enough. However, before the modifications could be made, the university's swimming pool sprung a leak, and the money allocated for the chair modification was diverted to that emergency. And since I left that institution at the start of the next fiscal year, there was no one to "champion" spending the additional money to make the desired modifications, and so that particular ergonomic improvement was never made.

36.3.7.2. Noise and Performance. Noise, i.e., unwanted sound, is generally not desired in learning environments. However, broadband "white" or "pink" noise, sounding somewhat like an open TV channel or an air-conditioning unit, is used at moderate amplitudes as a noise-masking agent to create speech privacy in open offices and open classrooms. Some of the general affects unwanted sound has on people include annoyance, distraction, or interference with communications, leading to altered performance of some tasks (Eggleton, 1983). The effects of noise have been investigated by a number of people (Broadbent, 1957; Cohen, 1969; Kryter, 1970; Miller, 1971; Taylor, 1988; Kjellberg & Skoldstrom, 1991).

36.3.7.2.1. Noise Measurement. Ambient noise is usually measured either in decibels on the "A" scale (the scale most closely approximating the human hearing curve) or by plotting decibel levels at each of the nine major center octave bands. The set of curves that results from this activity are either called *noise criterion* or *NC curves* or *preferred noise criterion* or *PNC curves.* The PNC curves were developed by the originators of the NC curves, about 14 years later, as an improved version of ambient spectra that could be recommended for specific activities. The two sets of curves are nearly identical, except with the PNC being less permissive in the very low and very high frequencies by 4 to 5 dB. Basically, one determines a room's NC or PNC curve by plotting the sound pressure levels of the principle octave band frequencies on either set of curves, i.e., contours, and notes the highest rank contour tangent to or touched by any one of these readings. That upper-curve designation is used to identify the room's NC or PNC number. And, since the research cites both versions, as well as the benefits of decibel levels on the A scale as predictors for acceptability, all three versions will be used as they were originally cited in the literature.

36.3.7.2.2. Noise Limits. While total quiet is never recommended, it is important that the learning environment provide spaces of relative quiet to serve as retreats from the din of school and nonschool activities. Noise levels exceeding 70 dBA will not only interfere with communication and mental performance but also produce a disorienting, chaotic learning environment. Noise levels of 85 dBA and above are generally considered psychologically and physiologically excessive. It is well known that prolonged exposure to excessive noise levels causes both temporary and permanent hearing loss. Such loss is usually thought of as an adult problem, but this is a misconception. Even our youngest citizens are not immune. One study of 3,000 students at three grade levels revealed that 5% of the sixth-graders, 14% of the ninth-graders, and 20% of the twelfth-graders showed some measurable hearing loss induced by the general noise level of their environment (Lexan, 1969). Temporary hearing loss may become permanent unless the victim is given a sufficient hearing recovery period away from the noise. Other disabilities that can be caused by excessive noise include cardiovascular disorders, nausea, weight loss, fatigue, irritability, insomnia, and impaired tactile functioning (CEQ, 1968). Again, relief can be found only by eliminating the noise or by moving away from it to a quieter environment.

Classroom Intervention: Efforts to reduce noise are based on isolation, absorption, and containment. *Isolation* means eliminating the medium a sound needs in order to travel. For example, placing a rubber or neoprene pad under a noisy projector or printer can do much to keep its noise from being transmitted via the table and floors. Likewise, placing audiospeakers away from the front wall of a classroom will keep their sound from being transmitted as vibration through the structure and disturbing the adjacent room.

36.3.7.2.3. The Character of Noise and Its Consequences. Excessive decibel levels are not the only problem. Someone else's music or conversation can be perceived as noise by others. Grandjean (1987) has shown that conversation is one of the most disturbing types of noise that can intrude on mental concentration, specifically because of the informational content it contains. It has also been shown that excessive conversational noise, in the range of 60 decibels on the "A" weighted scale (60 dBA), can negatively affect reading comprehension, particularly of students most susceptible to such distractions (Veitch, 1990). And while noise adversely affected performance on a proofreading task, this affect was only significant when this task was machine paced as opposed to when it was self-paced (Kjellberg & Skoldstrom, 1991). Weinstein (1979) found that noise levels between 68 to 70 decibels decreased student performance even on short-term tasks. Glass (1985) found that loud, distracting noises interfered with the performance of complex mental tasks and led to fatigue. Noise features that are likely to degrade performance include:

- Variability in level or content
- High-level repeated noises
- Intermittency
- Frequencies above approximately 2,000 Hz
- Any combination of the above

Ross and Stewart (1993) cite the work of Bobker (1991) in making their case that technological equipment by itself tends to make annoying and disconcerting sounds. They report that some computer users have complained of ringing in their ears (tintinnabulation), and that many multimedia programs, employed in schools, have built-in sound effects for student motivation. They state: "The continual din of these can be disconcerting to classroom instruction." It is important that designers of computers be encouraged in their continued efforts at quieting their machines, and it is critical that the problems associated with the audio components of multimedia workstations be thoroughly researched so that these new technologies be made to coexist with other important learning activities, otherwise their continual adoption by educators may be resisted because of their "noise" intrusiveness.

36.3.7.2.4. The Too-Quiet Room. It is also known that an environment that is too quiet can also lead to distractions and annoyance. Given the tasks that a student is likely to perform when using a VDT, one can predict greater awareness to noise distractions if the ambient noise level is lower than 35 dBA or NC30. Generally, one can usually expect the lighting and the heating, ventilation, and air-conditioning (HVAC) systems, and the fans in the computer itself, to generate at least this level of ambient sound. However, when an environment is too quiet for its programmed activities, the addition of artificially generated broad spectrum sound is recommended. It is in this regard that Harmon (1966) noted that the addition of 30 dBA of "white" noise, a soft "whooshing" sound, produced the optimum body tonus necessary for alignment of attention to a performance task.

Classroom Intervention: When students need to concentrate on a demanding task, a small amount of "white noise" (meaningless sound made up of tones of all audible frequencies) may be used as a sound-masking device to keep them from being disturbed by extraneous classroom sounds like talking or traffic. Personal "white noise" generators are currently available for around $100, but the classroom teacher can produce an acceptable substitute by simply making a tape recording of the sound generated by a TV set when it is turned to an unoccupied channel. The teacher can then play this recording, at a low level, which will sound very much like white noise in the classroom whenever he or she wishes to mask extraneous and distracting noises. The currently available environmental recordings of the sea, wind, etc., can also be used as noise-masking devices.

While people have different reactions to noise-masking systems, most seem to accept broadband steady-state sounds as a constant element in their environment as long as the levels do not exceed 47 dBA or NC43 (Yerges, 1978; ASTM, 1976). Given that spaces with many VDTs require more cooling than the standard classroom environment, extra care needs to be taken with HVAC design to ensure that the general background noise level correlates with the levels recommended for its programmed activities and in no instance exceeds 47 dBA.

36.3.7.2.5. The Role of Background Music. Music, in general, tends to speed up the fundamental physiological processes and to raise the level of body tonus (the muscular and nerve readiness to perform). Because it also tends to increase muscle endurance, music can reduce or delay the fatigue associated with a physical worktask. In recent years there have been many attempts to use music as background sound for various school tasks. The success or failure of such attempts has depended on the nature of the music and the nature of the task. While nonfamiliar music, especially if it has few major frequency and volume shifts, can help many students concentrate on their work, familiar music can be an informational distraction. The rhythm of the music is most important. If it does not match the rhythm of the worktask (typing, handwriting, or whatever), it can cause a decrement in the student's performance.

36.3.7.3. Noise and Communication. Figure 36-15 shows the preferred noise criteria (PNC) curves and the excessive ambient noise conditions I recorded in six elementary classrooms. These readings show the extent of the problems that can be created by window ventilators and room air–handling systems.

Most of the experts are in agreement with Kryter (1970) that in classrooms where unamplified speech is used in teaching, the background-noise level should be not less than NC 25 (30 dBA) and no more than NC 35 (35 dBA). These same classroom background-noise levels are also recommended for classrooms serving students with hearing disabilities (Ross, 1972; John, 1960). The recommended ambient noise level for auditoria is NC 25, and for recording facilities, NC 15-20 (Doelle, 1972). See Table 36-4 for the preferred noise criteria ranges recommended for various indoor-activity areas deemed relevant to the reader.

Increasingly, a variety of media are being employed in educational and training environments at all grade levels from elementary schools through postdoctoral and corporate educational programs. Today it is not uncommon to find anywhere from 10 to 30 VDT workstations in a classroom setting where background-noise levels have to be low in order for accurate verbal communications, an essential element in the teaching-learning process. Here again, the NC 35 level has been shown to provide an acceptable noise level for such activities.

36.3.7.3.1. Signal-to-Noise Ratios. The contribution to communications efficacy made by relatively low ambient noise levels is seen in the signal-to-noise (S/N) ratios found in classrooms. The relationship of the sound pressure level (SPL) of a person's voice to a room's background or ambient sonic-energy levels is termed the *signal-to-noise ratio* (S/N). Woodson and Conover (1973) note that at S/N ratios of +15, +10, +5, and 0, one can expect word intelligibilities of 82%, 78%, 70%, and 58%, respectively. And Van Cott and Kinkade (1972) indicate that 75% word intelligibility is required for reliable conversation to take place.

Furthermore, this same source notes that reliable conversation will barely exist for people as close as 12 feet using normal voice levels (reported by Van Cott & Kinkade to be 49 dB at 12 feet) when the room noise level is 43 dB (S/N +6). They also report that when this background noise level is raised to 49 dB, accurate conversation is barely possible even at 12 feet when using a raised-voice level of 53 dBA (S/N +4). It should be noted that ambient noise levels of 49 dB and even 43 dB, while considered excessive, are not uncommon in today's classrooms where window air circulators or overhead air diffusers are improperly set up or balanced, or where the noise from computer peripherals such as printers is not attenuated through either acoustic absorption or isolation.

Figure 36-16 offers a good visual representation of how reductions in S/N ratios, caused by window ventilators,

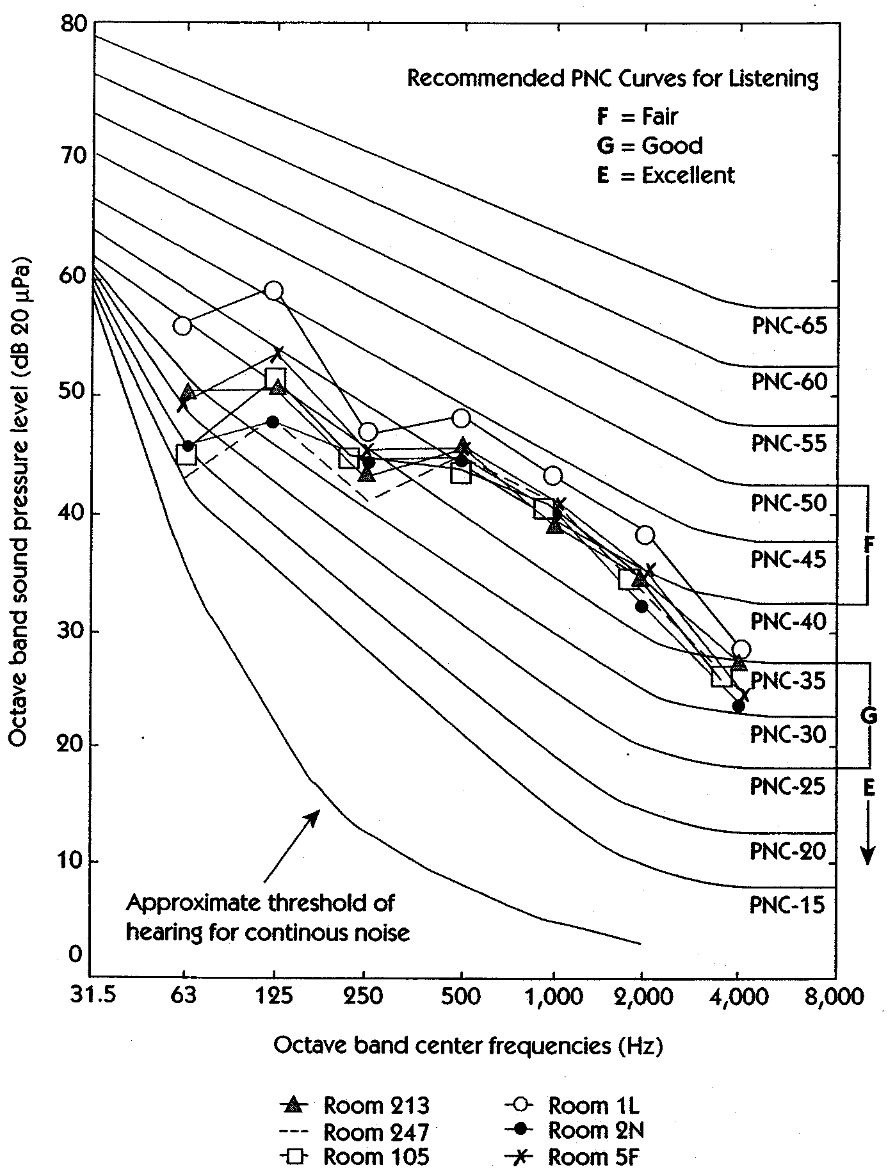


Figure 36-15. Preferred noise criteria (PNC) curves with noise spectra plotted for six elementary classrooms.

TABLE 36-4. NOISE CRITERIA RANGE FOR VDT-RELATED ENVIRONMENTS (Adapted from AFSC-DH 1-3, 1980, Kryfer, 1970, Doelle, 1972)

Type of Space (and Approximate Acoustical Requirements)	PNC Curve	LA, dBA
Broadcast and recording studios (distant microphone pickup), concert and recital halls (for listening to faint musical sounds)	10–20	21–27
Large auditoria, large drama theaters (for excellent to good listenting conditions)	Not to exceed 20–25	Not to exceed 25–30
Broadcast television and recording studios (close microphone pickup only), video conferencing room, small auditoria	Not to exceed 25	Not to exceed 30
General 25–30 seat classroom	25–35	Not to exceed 35
Libraries, private or semiprivate offices, small conference rooms, etc. (for good listenting conditions)	30–40	38–47
Large meeting and conference rooms (for good listening), or executive offices and conference rooms for 50 people (no amplificaiton)	Not to exceed 35	Not to exceed 42
Large offices, reception areas (for moderately good listening conditions)	35–45	42–52
Laboratory work spaces, drafting and engineering rooms, general secretarial areas (for fair listening conditions)	40–50	47–56
Light maintenance shops, offices, and computer equipment rooms (for moderately fair listening conditions)	45–55	52–61
Shops, garages, power-plant control rooms, etc. (for just-acceptable speech and telephone communications). Levels above PNC-60 are not recommended for any office or communication situation.	50–60	56–66
For work spaces where speech or telephone communications is not required, but where there must be no risk of hearing damage	60–70	66–80

affected speech intelligibility by masking consonant sounds as heard in six different elementary classrooms tested by the author.

Classroom Intervention: The classroom teacher can promote a desirable signal-to-noise ratio by preventing extraneous sounds from entering the classroom through open doors or windows. The S/N ratio for a student sitting by a door leading into a noisy corridor often approaches zero. Whenever climatically feasible, classroom doors and windows should remain closed during those hours that require mental and verbal activity. Students as well as teachers have a right to quiet, and they should express that right whenever noise intrusion hinders their learning activities. The sense of freedom in the classroom should be such that a student who is being disturbed by outside sounds will not hesitate to leave his or her seat and close a door or window.

A common occurrence is where instructors leave a slide or overhead projector on long after they have finished showing their visual materials. This unwanted noise reduces the intelligibility of the instructor's voice at a time when continued use of these devices serves no useful purpose. It is one thing to suffer unwanted background noise while the media are in use, but it is simply inconsiderate and poor classroom management to continue to generate such noise and negatively affect S/N ratios after such equipment operations are no longer required.

36.3.7.4. Reverberation Time. A room's reverberation time (RT) refers to its liveness and deadness and is expressed as the number of seconds that it takes for a sound level to decay 60 decibels. Traditionally, recommendations for RTs have been associated with the size and function of a given space, and according to Kryter (1978), "Normally, smaller rooms should have shorter times than larger rooms; and music spaces usually require longer times than spaces used principally for speech." Today's study areas, resource centers, and open-plan classrooms and offices, however, while large in overall size, consist of numerous small and independent workstations where speech privacy and accurate personal and, in many cases, telephone communications are to take place. Consequently, it is recommended that such spaces have RTs at the lower end of the scale, i.e., 0.6 to 0.8 seconds. Classroom RTs between 0.7 and 0.9 seconds are considered optimum for normal-hearing individuals (Ross, 1972), with a RT of 1.0 second as a limit for the conventional-size classroom (Niemoeller, 1968).

36.3.7.4.1. Reverberation Time and the Hearing Impaired. Given that mainstreaming hearing-impaired students into general educational programs is the norm, we should look at their special needs regarding reverberation time. Studies from the field of clinical audiology and sensory disabilities have shown that such individuals experience noticeable difficulty when RTs exceed 0.7 seconds (Niemoeller, 1968; John, 1960), leading John (1960) to recommend that RTs for rooms in which hearing-impaired students are to be placed not exceed 0.5 seconds. The only practical way such low RTs can be achieved in today's classrooms is through adding significant amounts of sound-absorbing materials to a room's surfaces. The positive effect of such acoustical treatment on speech discrimination in general classrooms has recently been supported by the research of Pekkarinen and Viluanen (1990).

Classroom Intervention: The different reverberation times in different rooms should always be considered by teachers making tape recordings, for these will affect the intelligibility of the tapes when they are played back. When an audiotape made in a recording studio or a classroom having a short reverberation time is played back in an auditorium or classroom having a long reverberation time, words seem to run into each other, pauses are lost, and speech becomes unintelligible. A teacher can compensate for this problem somewhat by making a concerted effort to slow down his or her speech when recording in a studio or any other room with a short reverberation time.

36.3.7.5. Acoustical Design and Corrective Work. Guidance for acoustical procedures, including isolation, containment, and surface treatments, can be found in numerous sources (Doelle, 1972; Harris, 1957; Close, 1966; Yerges, 1978; Propst, 1968; Packard, 1981). The need for innovative acoustical design is expected to increase in importance with the development of new educational technologies. Parsons (1986) claims that the demands of new electronic technology are not getting the attention of individuals who traditionally are responsible for designing learning environments. According to Allen and Charles (1986), "as more voice-operated machines are introduced, effective sound separation will become even more crucial, so that machines will be able to identify and respond to their masters." Thus, the acoustical needs of the tomorrow's learning environments will increase rather than lessen.

36.3.7.6. Sound Systems

36.3.7.6.1. Sound System Quality and Directionality. Sound enhances visual perception by giving it contrast and adding information. Sounds can be used to direct attention to related visual elements (Broadbent, 1958). People tend to position their bodies in a direct line with the apparent source of a sound. Therefore, in setting up audiovisual aids, teachers should coordinate the placement of a projector's loudspeaker with the projected image and, of course, the classroom seating. The better-designed movie theaters provide the ideal arrangement: The loudspeaker used to play back dialog and critical localizing sounds is located directly behind the projection screen at a height approximately two-thirds the vertical span of the screen. Such theaters use a fixed perforated projection screen that allows sound to pass undisturbed right through it, thus creating the illusion that the sound is coming from the elements appearing on the screen.

Classroom Intervention: For most classroom audiovisual presentations with portable equipment, placing the loud-

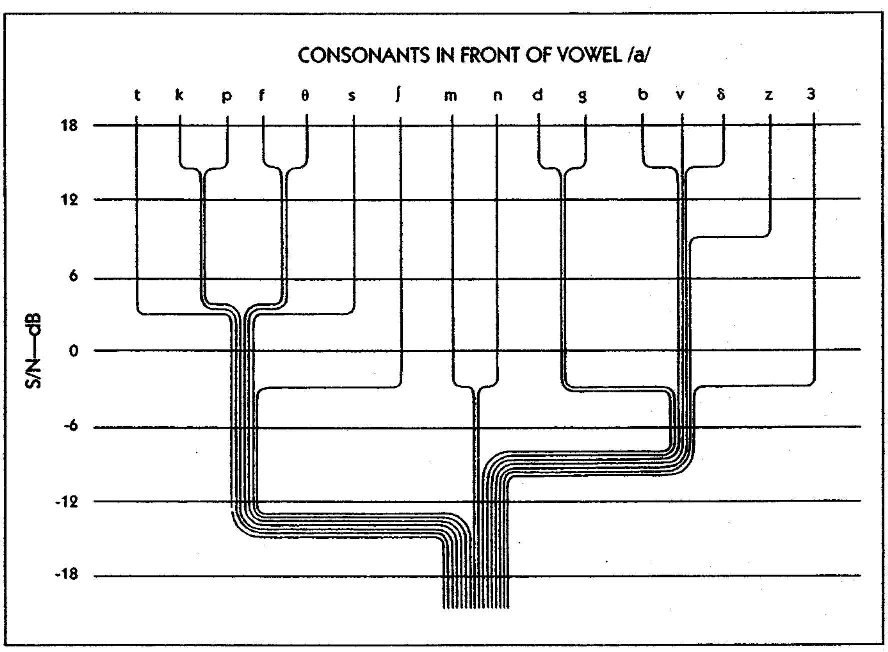


Figure 36-16. How reduced S/N ratios affect speech intelligibility. (After Kryter, 1970.)

speaker on a bench or chair directly in front of and below the extended projection screen will be acceptable.

36.3.7.6.2. Sound System Selection. It is a well-known fact that audio amplification and distribution systems can contribute to the effectiveness of audiovisual materials. A good playback sound system should reproduce both monophonic and stereo signals and have sufficient power, good sensitivity, low distortion, and smooth frequency response. Ideally, as noted above, reinforced sound should appear to emanate from the informational display area (e.g., the projection screen). In an auditorium, this effect can be achieved by mounting a central monophonic speaker cluster or stereo speakers in the acoustical cloud above the projection screen or in smaller rooms at each side of the projection screen about 7 1/2 feet from the floor, preferably recessed into the wall.

While it is possible to use the program playback speakers for voice amplification, usually in lecture halls and auditoria, it is recommended that a separate distributed speaker system be installed in the ceiling. Standard-size classrooms and conference rooms generally require only program playback speakers, not voice amplification systems.

A ceiling-distributed speaker system is a practical solution that works well for rooms with low ceilings or poor acoustics. This is because people have difficulty sensing the displacement of a sound's source when it is in the vertical plane, unless it is displaced from the vertical by more than 45° (Wysotsky, 1971). Consequently, in a properly spaced ceiling-speaker system, the illusion that the sound is coming from the lecturer or the display is maintained even though the speakers are located overhead. In such a system, speakers are spaced at distances from each other equal to the ceiling height minus 4 feet, multiplied by a factor of choice between 1.25 to 1.34. For example, given a finished ceiling height of 10 feet, speakers should be spaced no farther apart than on 8-foot centers, i.e., $1.34\ (10 - 4) =$ between 7.5 and 8.0 feet; while with a 16-foot-high ceiling, they would be spaced on centers between 15 to 16 feet. Understandably in an auditorium with a stepped or sloped floor, the ceiling-speaker distances from each other should vary with the changing ceiling height.

36.3.7.6.3. Assistive Listening Devices. In auditoriums and other educational spaces where the public is likely to gather for special events, provisions for assistive listening devices need to be provided for the hearing challenged. Since there are a variety of different types, with each type having unique features, it is recommended that a detailed study of the particular needs of a facility and its likely occupants be conducted before any specific system is purchased.

36.3.8 The Luminous Environment

36.3.8.1. Lighting Systems

36.3.8.1.1. General Lighting. A learning environment requires lighting that produces a pattern of brightness from room surfaces which is aesthetically pleasing and which promotes good depth perception. Illumination or, using the currently more correct terminology, *illuminance,* on major and supplementary task areas, such as chalk or dry-mark boards, tackboards, desks, and other work surfaces, should allow participants to complete visual tasks in comfort and with a high degree of efficiency. Because of their long life and energy efficiency, fluorescent luminaires are preferred over incandescents, except in special situations where directionality and modeling are critical or where room aesthetics are a major factor (Bennett, 1985).

36.3.8.1.2. Supplementary Lighting. The use of supplementary lighting on flip charts, maps, models, etc., capitalizes on the natural attraction that people have toward bright areas within their visual field. Research shows that people are less distracted by a room's surroundings and give more attention to displays with supplementary illumination than those without (LaGuisa & Perney, 1973, 1974). The message here for both the facility designer and the classroom teacher is a fairly simple one: Provide and utilize supplementary lighting on all principal display surfaces.

36.3.8.1.3. Indirect Lighting. Wide-angle dispersion indirect lighting has proved particularly desirable in rooms where VDTs are used, since it minimizes distracting reflections from luminaires seen on the VDT screen (Hedge et al., 1989). But a direct-lighting component is a practical requirement during media projection where notetaking is required and control of light away from the display areas is necessary. Consequently, the ideal lighting system for today's classrooms is one that combines a wide-dispersion indirect-lighting unit for general learning activities and computer work, and a second component with narrow-dispersion direct low-level illuminance on notetaking task areas, separately controlled, to be used during audiovisual presentations.

36.3.8.1.4. Lighting Control and Windowless Rooms. Illuminance control is imperative, particularly in rooms where visual-display media are used. Ideally, there should be no windows in rooms used primarily for computer training and for media presentations. They introduce unwanted light, heat, and noise. However, if windows are required, then the room should be equipped with sunscreens, audiovisual blinds, and/or opaque drapes so that sunlight does not "wash out" projected images or create glare on marker boards and VDT screens. The controversy surrounding the absence or presence of windows in educational spaces has yet to be settled. Knirk (1992) covered the topic about as thoroughly as anyone when he stated:

> Research does not support those claiming that windowless learning spaces will allow increased concentration and thus higher achievement. . . . On the other hand, data do not support those educators fearing that the absence of windows will have harmful psychological or physical effects on the students and staff. Windowless learning spaces provide more control over the learner's environment. . . the level of visual and auditory distractions are lower . . . with computers, windowless environments reduce glare and light levels. Temperature can be regulated and chances of vandalism are lessened in windowless environments.

My own experience has indicated that having both windowed and windowless rooms in a learning environment are desirable. The windowed spaces should be allocated to standard classrooms and office spaces, while the windowless areas relegated to those spaces that are to be used to house computers and training/conference rooms having extensive media-display components. And while the preference at the elementary and secondary school level is clearly for windowed rooms, college students seem to accept equally both kinds of spaces, if the wall color treatment and the lighting of the windowless rooms is to their liking. And in high-tech and business training and meeting environments, particularly those having extensive display facilities, there seems to be a preference for windowless rooms, particularly where the room lighting has been appropriately designed. Figure 36-17 shows photographs of one of six windowless rooms I designed for the New England Telephone Learning Center in Marlboro, Massachusetts. These rooms all featured an indirect-lighting ceiling cove that served to draw the attention of the occupants inward and away from the room's perimeter. They also included scene switched fluorescent lights, incandescent downlights on dimmer, and wall washers. These room's proved to be more popular to the attendees and their session leaders than the 12 other rooms having windows. One of the reasons cited for this preference by the session leaders was the additional tackable walls for displaying their flip-chart materials and product display artwork. The attendees on the other hand seemed to feel that the windowless rooms were less distracting and visually more comfortable over long sessions than the windowed rooms. It should be noted that in this environment and in the training program, there were many opportunities and places for the attendees to have extended views of the outdoors.

36.3.8.2. Illumination (Illuminance) Levels. The preferred term for illumination today is *illuminance,* measured in either foot-candles (FC) or Lux (1 FC = approximately 10.7 Lux). Since most of the research cited herein has used "foot-candles," this term will be used throughout. However, with the unit equivalent just provided, readers may easily make their own conversions to Lux. And where research and luminance standards specifically refer to Lux, such units will be cited.

36.3.8.2.1. General Tasks. Illuminance levels of 30 to 50 foot-candles (FC) are recommended for general educational activities, with the lower end of that range being appropriate for exclusively VDT work (Zmirak, 1993), and the upper end for reading books and writing (McVey, 1971). According to Zmirak (1993), providing an illuminance level of 30 FC in computer labs where students only work off the screen will result in improved student efficiency and reduced energy costs. Christinaz and Knirk (1987), while accepting a 30 to 75 FC range for general activities, note that when designing for VDT use, illuminance levels should be based on the readability of associated materials and the surrounding area. They warn that strict adherence to raw foot-candle standards will not in themselves ensure sufficient or efficient task illumination. Support for this more qualitative approach can be found in Grandjean (1982a), who states (p. 271) that:

> Specifications for lighting levels can be no more than general guidelines, and other circumstances must be taken into account in any particular situation, for example: (a) the reflectivity (color and material) of the working materials and of the surroundings, (b) the extent of difference from natural lighting, (c) whether it is necessary to use artificial lighting during the daytime, and (d) the age of the people concerned.

36.3.8.2.2. Visually Demanding Tasks. Levels of 100 to 150 FC are recommended for critical visual tasks (artwork, etc.). A variable illumination range of 0 to 30 FC is recommended for AV/TV use (the lower levels used for video, LCD panel display, and motion picture projection; the upper levels for slide projection, and even higher levels for standard overhead transparency projection). Classrooms and conference rooms used for participants 50 years old and older need more illumination for notetaking than rooms used exclusively by their younger counterparts (NRC,1987).

36.3.8.3. Reflectances. *Gloss* refers to the specular (mirrorlike) nature of some finishes. The combination of excessive gloss and direct illuminance can create distracting glare. Consequently, low levels of gloss, i.e., matte or satin finishes, are recommended for all furnishings that students are to read from. And the ANSI/HFS (1988) standards specifies this limit to be 45% or less when measured with a 60° gloss meter or equivalent device.

The term *reflectance* refers to the percentage of light that a finish is capable of reflecting. Too little reflectance in a finish can create a "gloomy" environment, while reflectances that are too high can contribute to a "glaring" environment. To keep reflections at comfortable levels, the following surface reflectances are recommended (Kaufman, 1981):

- Desktops: matte finish, 30–50%
- Floors: natural woods or light-colored tile or carpet, 30–50%
- Chalkboards: green, not to exceed 20%; gray or black, under 10%
- Walls: matte finish, 40–60%
- Ceiling: 70–90%

36.3.8.4. Brightness (Luminance) Contrast Ratios. The term *brightness* refers to a perceptual value and has been incorrectly used for many years; researchers meant *photometric* or *measurable* brightness. The preferred term for photometric brightness today is *luminance;* it is measured in either footlamberts (FL) or candela per square meter (cd/m^2), sometimes called a *nit.* One nit is equal to approximately 0.3 footlamberts. Since most of the research cited herein has used *footlamberts,* this term will be used throughout. However, with the unit equivalent just provided, readers may make their own conversions to cd/m^2. And where research and luminance standards specifically refer to cd/m^2, such units will be cited.

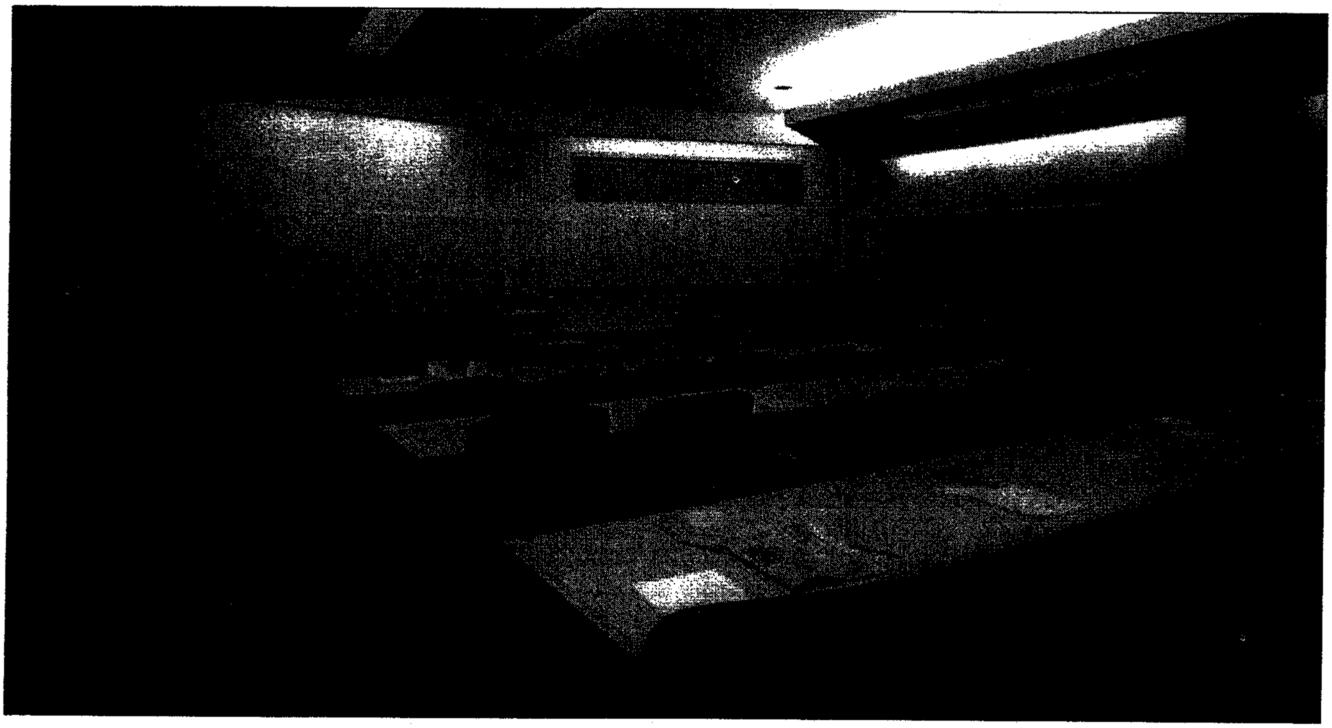


Figure 36-17a. Windowless training conference rooms showing special lighting and display features. (Note vertically operable marker board in "use" position in front of rear screen.)

Figure 36-17b. Same room but set up in U-shaped seating arrangement. (Note extensive use of acoustic/tack panels, chart trays, magnetic strips, flip charts, and perimeter lighting.)

As noted in 36.2, for about 50 years the Illumination Engineering Society of North America has promoted guidelines that state that the LCR of large adjoining areas should fall somewhere between 1:1 and 3:1, with the task area brighter than its surroundings. For areas adjacent to the visual task, the acceptable LCR should fall somewhere between 3:1 and 10:1 (Kaufman, 1981; Woodson, 1987).

It is believed that observance of the recommended luminance ratio limits will lessen or eliminate visual problems, such as transient adaptation and disability glare at the VDT workstation. The rationale used to support this is based on the fact that when the eye fixates on a task, an adaptation level is established. This adaptation level is initiated by a combination of task luminance and field luminance. As the eye redirects its focus from an area having one luminance level to another area having a different luminance, the eye readapts to the new luminance level. If that luminance difference is significant, the adaptation process will require time. And if that luminance difference is excessive, the reaction will be discomfort, attended by a transient pupillary response. To avoid this, luminance levels of large adjoining areas need to be kept within appropriate limits.

There is, however, recent evidence to indicate that the recommended luminance contrast range between task and surround, i.e, between a VDT screen and its adjacent source document, given certain conditions may be extended to a ratio as high as 1:20 without affecting visual performance (Haubner & Kokoschka, 1983).

This extended range of luminances seems particularly appropriate when the central visual task involves a VDT with a negative polarity screen (light characters on a dark field). It is thought that this is due to the lower average luminance levels created by the dark screen. Support for this can be found in studies by Grandjean (1987), where he noted a marked preference for lower illuminances (and thus luminances) in workstations supporting negative polarity screens than in those supporting positive polarity screens. One reason for this is that negative polarity screens are more adversely affected by excessive ambient illuminance than are positive polarity displays.

This extended luminance range may also be appropriate for users of multimedia software or computer-aided-design workstations. Here, users may require lower surround luminances in order to enhance the readability of text and discrimination of the fine detail that is usually present in these types of displays.

Figure 36-18, taken from Badolato's (1995) current study, provides an example of the kind of luminances he found at his music workstations. This figure should help readers conceptualize the concept of plotting luminance patterns and lead them toward taking the same approach in evaluating their own learning environments.

36.3.8.5. Glare. When recommended luminance contrast ratios are exceeded by a significant amount, such as when there is an unduly bright source of light in the visual field or when specular (mirrorlike) reflectances fall on a display surface, they create glare. Glare is a luminous condition that brings about discomfort and/or a reduction in visual acuity (Kaufman, 1981). Most glare in the learning environment equipped with VDTs can be eliminated or reduced by the following methods:

- Place the display perpendicular to the light source to reduce reflected glare.
- Shield the eyes from light sources.
- Use filters or a coating of the VDT screen; a flat or even slightly concave filter will reduce the area reflected by a curved VDT screen.
- For lighting, use indirect sources or use several low-intensity lights rather than one light of high intensity.

As people age beyond 50 years, they become increasingly more sensitive to glare (NRC, 1987). The careful control of all glare sources is especially important for the comfort and visual efficiency of older members of the workforce and training programs.

36.3.8.5.1. Controlling Luminaire Glare. In order to keep glare from light fixtures (luminaires) at acceptable levels at the VDT screen, the Illuminating Engineering Society of North America produced a standard for VDT workspaces (IES, RP-24). Under this standard, indirect lighting systems are strongly recommended and luminance emission limits for direct lighting luminaires given maximum limits relative to specific viewing angles. The maximum allowable luminance at a viewing angle 85° from the vertical is 175 cd/m^2; at 75°, 350 cd/m^2; and at 65°, 850 cd/m^2. This standard is currently being complied with or even exceeded by today's luminaire manufacturers. While compliance with this standard will reduce excessive glare at the VDT screen, it will also result in perimeter walls being excessively dark, unless illuminated by supplemental wall washer lighting or unless the spacing currently used between luminaires is reduced significantly. Consequently, there are those who find this IES standard problematic (Rea, 1991).

36.3.8.5.2. Display/Surround Luminance Ratios. There is a perceptual conflict when a display is surrounded by areas of greater brightness than its own, such as when a TV monitor or computer screen is set up next to an unshaded window. If this difference is modest, then at best this conflict will result in only a distraction from the visual task. If this difference is great, then viewers are faced with the dilemma of attempting to attend to the visual task while their autonomic defensive mechanism is unconsciously directing them to look away from the area in order to maintain visual comfort.

Classroom Intervention: Set up visual displays where there are no excessively bright areas to surround it. If the display is not the self-illuminated kind, i.e., TV, computer screen, then provide supplementary illumination on the display.

36.3.8.5.3. Luminance Contrasts within the Visual Display. The above luminance contrast limits between adjoining visual areas relates to relatively large areas, i.e., the overall VDT screen brightness relative to the area surrounding it. However, these contrast limits should not be confused with those recommended for visual elements within the task itself—for example, print in a book, chalk or marker on a board, alphanumerics on a slide or vugraph foil, a motion picture scene, etc., all of which need to be greater than those recommended for large adjoining areas. Lack of sufficient contrast between the design elements within the visual itself will seriously affect its legibility and readability. Contrast ratios of 10:1 between the dark and light elements of video or vugraph display are generally accepted, while ratios of 25:1 for slides with dark elements on a light background and 5:1 for light elements on a dark background are recommended. Recommended contrast ratios between dark and light elements in a motion picture film can be as high as 100:1 (Caravaty & Winslow, 1964).

Classroom Intervention: Chalkboards and marker boards should be kept clean of old chalk and marker dust so that there is sufficient contrast between what is written on the board and the board itself. All projected visual media should be shown in rooms dark enough so that image details and colors are accurately rendered, but no darker.

36.3.8.6. Other Properties of Light. In addition to providing radiant energy with which to see objects, there are spectral aspects of lighting that can effect how accurately colors can be seen, the appearance of the lamps themselves, and contribute to a number of psychological and physiological conditions affecting people.

36.3.8.6.1. Light Quality and Control for Media Use. Since all types of artificial illumination reproduce colors differently, the selection of lamps should be based not only on the amount of light they produce but also on their color appearance (how they will look in the room) and color-rendering qualities (how objects will appear under their illumination). Also, since there is a need to control illuminance levels during media presentations, this factor should enter into the decision in lamp selection as well. To accommodate such special needs, it is recommended that one use incandescent downlights on dimmers (or low-wattage compact fluorescent in parabolic fixtures) for low light levels in front-screen presentation rooms, and quartz lights or asymmetric fluorescent fixtures with lamp color temperatures between 3,000° and 3,500° Kelvin and color indices of 80 or higher for rooms where video conferencing and video recording are planned.

Classroom Intervention: The teacher needs to realize that objects will take on a different color appearance when illuminated by different lamps. Efforts should be made to acquire lamps with high color rendition accuracy for art rooms and to display artworks under the same kind of illumination under which they were created. Replacing the three or four lamps in a fixture above a critical display is a relatively simple and inexpensive matter, and the lamps have a life expectancy of about 20,000 hours. When trying to match colors, and where high color rendition fluorescent lighting is not available, do your matching under daylight, which has a color rendition of 100.

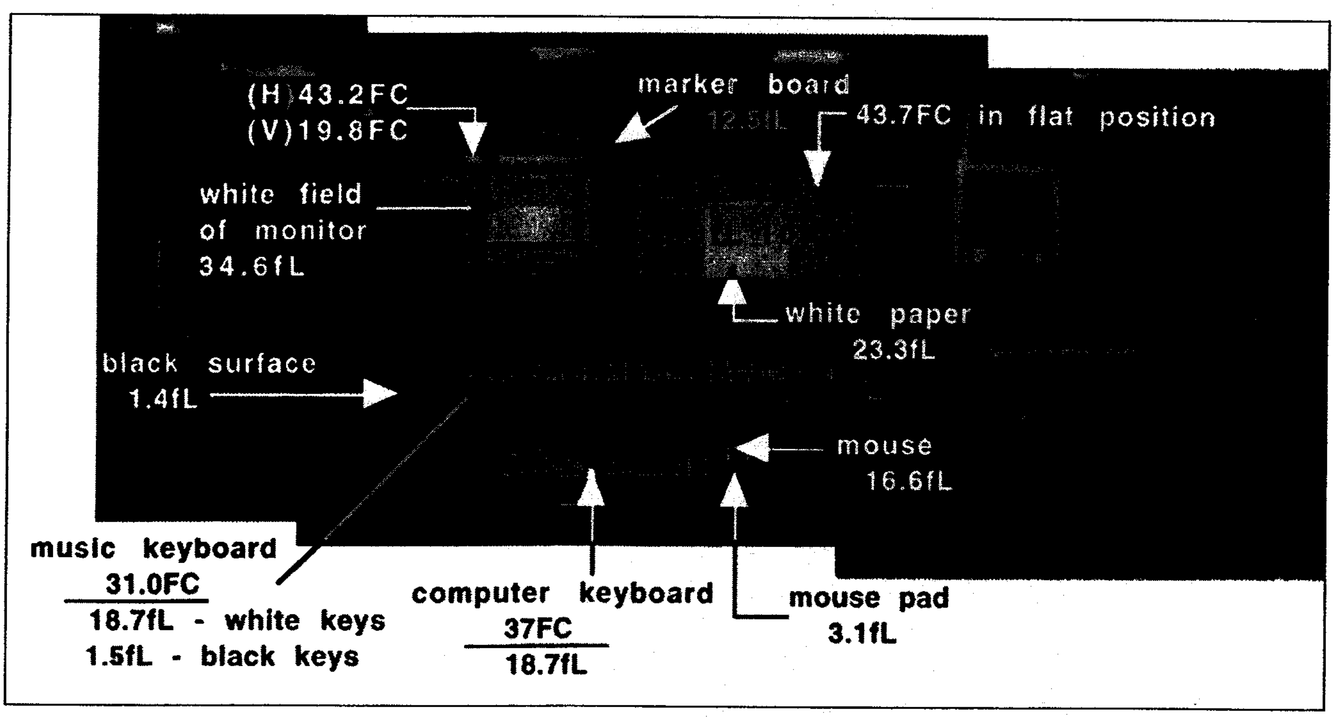


Figure 36-18. Illuminance levels and resultant luminance patterns in a music education workstation. (After Badolato, 1995.)

36.3.8.6.2. Light Quality, Moods, and Physiological Benefits. Research by Hathaway (1988) has shown that the color of light and its quality are important to the learning atmosphere, and he recommends UV-enhanced full-spectrum lighting, particularly for geographic areas where seasonal affective disorders (SAD) are noted. According to Hathaway (1994), under such lighting, elementary students developed fewer dental cavities (an accepted stress index) and had better attendance, achievement, and growth and development than students under other lights. This study went on to report that students under high-pressure sodium vapor lamps had the slowest rates of growth and development, as well as the poorest attendance and achievement. While the full-spectrum UV-enhanced lamps appeared to offer some physical benefits over cool-white fluorescent, there were no differences found in achievement. It is unfortunate that this study did not include the 32w T8 tri-phosphor lamps that currently are being selected for many schools and offices because of their high color rendition, pleasant color appearance, and energy benefits. It would be useful to know how such lamps stack up to the full-spectrum UV-enhanced lamps promoted in Hathaway's study. A review of the literature finds the research to be equivocal on the benefits of full-spectrum lighting (Boray et al., 1989).

36.3.8.6.3. Light Quantity and Physiological Benefits. Similarly, there are strong advocates for using inordinately high light levels (300 FC+) to "optimize human health, performance, and well-being, and recommend such levels for treating depression, sleep disorders, and dysfunctions of the circadian system related to jet travel and shift work" (Brainard, 1994). However, more research will be required before facility planners will be able to justify the added energy costs required to produce such levels, and to mount effective arguments for exceeding state energy codes. In the meantime, the popularity of tri-phosphor T8 lamps for general classroom/training rooms has grown over the past decade and seems to be here to stay for some time, given their high color rendition and color appearance qualities and their reduced energy consumption.

36.3.9 Color

36.3.9.1. The Power of Color. Color is a vital part of our lives. It can change moods and judgments of size, weight, and distance, induce body tonus, and in general enhance the quality of life. Many of our psychophysical responses to light have been attributed to the phenomenon known as *chromatic aberration,* where the lens of the eye has to physically change its shape in order to bring different colors into focus. Depending on the direction of this adjustment, a color will appear to be perceived as "approaching" or "receding." At least one researcher (Harmon, 1951) believes that chromatic aberration is the likely physiological basis for the psychological effects of colors, i.e., for our perception of colors as "warm" and "stimulating" or "cool" and "relaxing."

When used properly and combined with the right kind of illumination, color can be an effective tool for the facility designer and the classroom teacher. In spite of some ambiguity in the literature as to the uniformity of human responses to different colors (Cohen & Trostle, 1990; Mikellides, 1990), it is generally accepted that color has relatively predictable behavioral concomitants both as a surface treatment and as a light source. Different colors evoke different physiological awareness levels and emotional/attitudinal responses (Gerard, 1958; Ali, 1972; Birren, 1969) as well as producing different psychospatial effects.

36.3.9.2. Responses to Color. Burch (1993) recently referred to cognitive and emotional responses as being byproducts of the lighting and color used in the learning environment when he stated:

> Architects have known . . . that light and color created moods within spaces. Now we know that the neo-cortex of the brain, the conscious rational side, responds to subtle, sophisticated colors, while the limbic, or emotional set of the brain, responds to vivid hues.

Other researchers have noted the effect of colors on blood pressure, respiration, task confusion, and reaction time (Kwallek & Lewis, 1990; Sanders & McCormick, 1987). Knirk (1987) believes that room colors are powerful instructional tools that can be used to "assist the student into a mental state conducive to the behaviors required by the objectives." In making his case, he goes on to report the work of Zental (1986), who found that test scores increased by 12 points on an IQ test in a room that was light blue; whereas in a white or brown room, the scores decreased by 14 points. Knirk concludes from this and other studies that ". . . in classrooms and labs, where there is close visual and mental work, tints of blue-green, gray, or beige are desirable colors."

My own research supports these statements leading to the following generalizations:

- Room colors, particularly areas within the visual field, should be relatively neutral and in desaturated tones, such as off-white with umbra added, light gray, sandalwood, light buckskin, etc. If bold colors are desired in the classroom, they should be confined to surfaces outside the line of sight of the students, such as the back and side walls, and the floor.
- Fully saturated bold colors, particularly blues and reds, are stressful, and should be avoided on walls, especially on surfaces that may be used as backgrounds for visual displays. Such colors should be confined to artwork, wall murals, display exhibits, and the like, where exaggerated feelings of depth or visual excitement are specifically desired.
- Light chalk green, gray with a touch of umbra, off-white, and beige are visually neutral and should be used for end walls that are planned as backgrounds for visual displays or projection screen locations (McVey, 1988).

Classroom Intervention: Many elementary school teachers make use of the effects of chromatic aberration by wearing bright and colorful clothes on days when they plan to introduce new and difficult lessons. Their experience has been that the students seem to sense that something new and interesting is going to happen. Visual displays such as slides, bulletin boards, and dioramas can also make good use of the psychospatial effects of colors by highlighting the most important elements with red and orange and adding depth to the backgrounds with shades of blue.

36.10 Thermal and Air Quality Factors

Thermal comfort is a product of many interactions. Auliciems (1989) cites the interaction of such personal and atmospheric factors as a person's metabolic rate, which relates to the physical demands of the task, clothing insulation, air temperature, radiant temperature of surroundings, rate of air movement, and atmospheric humidity as the contributory factors. To this, Heijs and Stringer (1988) add the personal factors of one's knowledge and experience, gender, age, and place of residence, as well as such architectural elements as lighting and furnishings. Figure 36-19, adapted from Woodson (1992), illustrates the effects of season, clothing, relative humidity, or temperature requirements. It is because of such interactions that ASHRAE developed its concept of the "effective temperature" scale as a better predictor of comfort than the standard temperature scale.

36.3.10.1. General Effects of Heat and Humidity. The nature of the exchange of heat and humidity between people and their surroundings is a major factor affecting mental alertness, level of comfort, and the effectiveness with which they complete their tasks. The amount of environmental heat necessary for comfort will vary with a person's age, level of physical activity, clothing, and adaptation to local climate. Girls, in general, seem to prefer a warmer environment than boys, and young children prefer a cooler one than all but the oldest adults.

One study indicates that a student's achievement level may affect his or her sensitivity to heat (Lane, 1966).

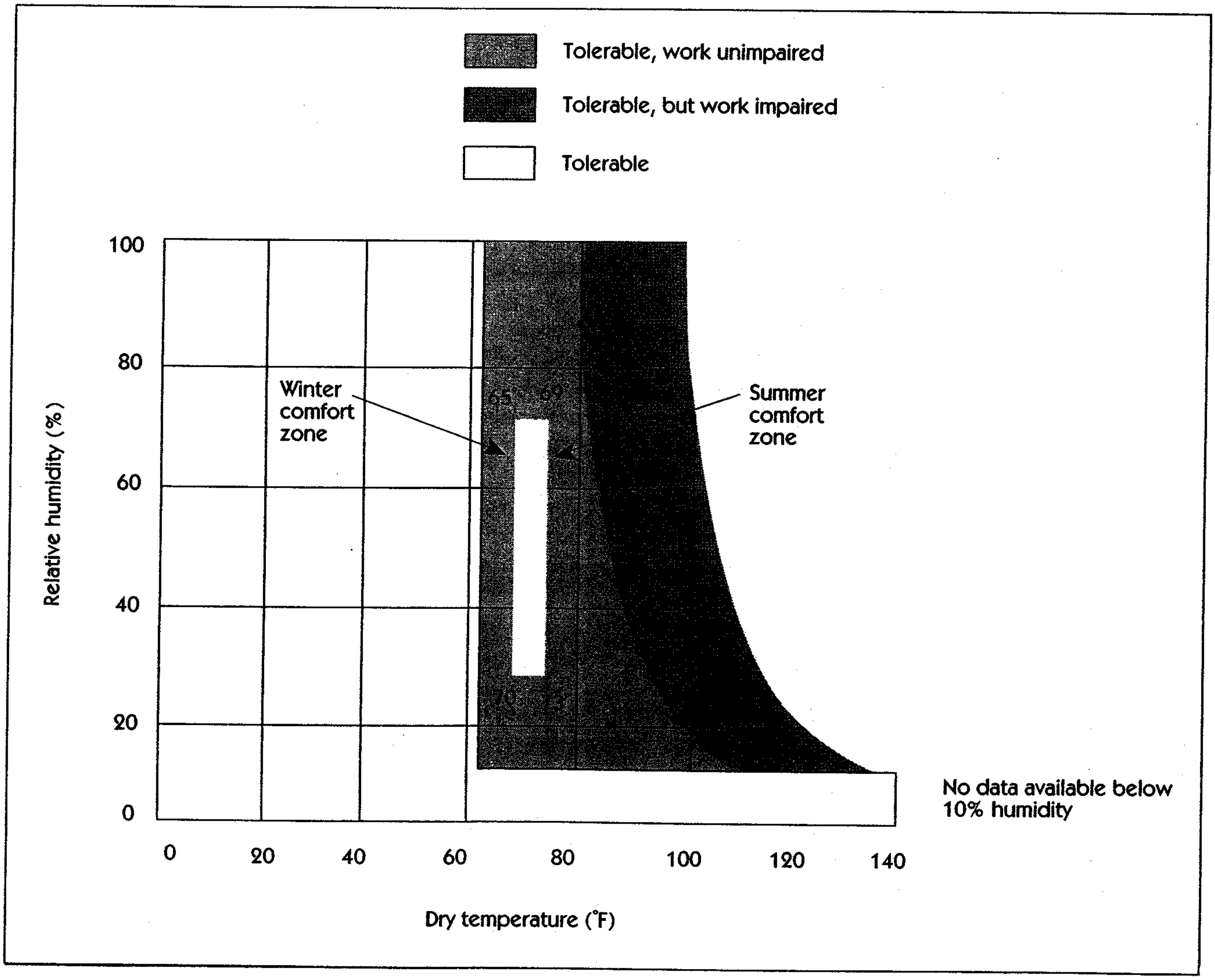


Figure 36-19. Effect of season, clothing, and relative humidity on temperature requirements.

Another study has found that certain temperatures evoke high levels of arousal, while others evoke dull attention (Wyon, 1970). An improper thermal environment can alter growth, development, and learning (Harmon, 1953). Children tend to become restless in a cold room and listless in a hot one. According to one researcher, there is reason to believe that students may experience a 2% reduction in learning ability for every degree that the room temperature rises above the optimum (Gilliland, 1969). Room temperatures between 68°F and 76°F generally promote normal functioning, given standard recommended levels of relative humidity and air velocity.

36.3.10.2. Effects of Heat on Performance. There is support in the literature for one to accept that thermal and air quality factors are perhaps *the* most important environmental elements in the work environment (Rohles, 1989). High temperatures can influence performance of various tasks. With young adults, Eckenrode and Abbot (1959) found 80°F to be the maximum temperature for the normal performance of the following tasks, with 87°F being the temperature where demonstrable impairment was noted:

> Typewriter code (scrambled letters), locations (spatial relations code), mental multiplications (problems), number checking (error detection), pursuit (visual maze), and lathe operations (hand coordination).

Additional tasks and their normal performance/demonstrable impairment (N/I) temperatures follow:

> Morse code reception 87.5/92, block coding (problem solving) 83/87.5, visual attention (erratic clock test) 79/87.5, Pursuitmeter 87.5/92, reaction time (simple response) 93/. . . , motor coordination 64.5/91.

There are not many studies available concerning the optimum classroom temperature for the very young student. One such study from Canada by Partridge and MacLean (1935) indicates that the optimum temperature in summer for young children is 70.5°F, with a relative humidity of 50% or a dry bulb temperature of 75.5°. In winter, this optimum temperature was said to change to 66.5°F, with a relative humidity of 35% or a dry bulb reading of 71°. This, however, cannot be accepted as a rigid recommendation, for thermal needs are quite individualistic, and, furthermore, these readings are not totally consistent with the most recent ASHRAE recommendations, which will be discussed later.

Classroom Intervention: There are those who cite the higher rate of metabolism that children have as being the reason why they seem to operate more effectively at lower temperatures than adults, and this has led to the suggestion that an effective rule of thumb for a teacher to follow is to wear a sweater or jacket in class and set the temperature for his or her comfort. The children, because of their higher rate of metabolism, should now be comfortable in their shirt sleeves. Tessmer (1994) suggests that moving the seat locations of students further apart from each other can increase airflow between seats, thus reducing the sense of a classroom feeling too hot as well as too crowded. This is particularly true when students have returned from a gym session or recess.

36.3.10.3. Solar Heat Gain. Radiation from the sun may also aid or play havoc with student comfort. Solar energy radiated in the form of visible light passes through classroom windows and is absorbed by objects lying directly in its path, which then convert the light into heat. This heat, in turn, is radiated to the rest of the room. The average classroom is like a greenhouse, a one-way trap for infrared radiation. While the glass windows allow sunlight in, they do not allow much of the resultant radiant heat to escape. This heat can affect the overall room temperature and cause wide temperature swings during a day. Most affected are students seated next to the windows, who may actually be receiving excessive heat exposure even though the average room temperature is not above normal. This "greenhouse effect" can be minimized by (a) better site planning with regard to the sun's transit, (b) large roof overhang, (c) tinted windows, (d) fewer or no windows, and (e) reflected shades or blinds.

Classroom Intervention: The classroom teacher should monitor the seats closest to the windows for excessive solar heat gain, adjust the shades accordingly, and provide additional ventilation when needed by opening windows at student work height. The students should also feel free to make adjustments on their own, as long as doing so does not negatively affect others nearby, or simply move to another seat if bothered by excessive solar heat exposure.

36.3.10.4. Air Movement. Some researchers feel that providing enough heat for the students is not the problem; the problem is providing proper ventilation, air circulation, and cooling. In one study, it was found that any time the outdoor temperature reached 50°F, the classroom temperature rose above the desirable level, unless cooling was introduced (Lane, 1966). No wonder, since physiologists tell us that each child of elementary school age radiates heat equivalent to that radiated by a 100-watt incandescent lamp. It is not unusual for a classroom to show a 4° to 5° rise in temperature shortly after the students return from an active recess. In educational facilities, air conditioning should not be considered a luxury, but rather an integral and critical environmental component.

Air movement's role in the thermal environment is to promote convection and evaporation, two natural methods of heat dispersion that help the body rid itself of excessive heat buildup during the performance of work and study tasks. If this work-related body heat is not lost, performance and physical comfort will be affected. In fact, some specialists have gone so far as to claim that most of the headaches, fatigue, dizziness, and nausea experienced in crowded, poorly ventilated rooms are caused not by high temperature, high humidity, or even high concentration of carbon dioxide, but rather by inadequate body heat loss due to lack of air movement (Lane, 1966). Although air movement is vital for the elimination of superfluous body heat, excessive air movement results in too much body heat loss and makes it necessary to increase the overall room temperature in order to maintain comfort. Needless to say, drafty rooms should be avoided as places of study.

36.3.10.5. Effect of Humidity on Performance. Knirk (1992) notes that when a room's relative humidity (RH) rises above 70%, it impairs human performance. He goes on to cite the work of other researchers who found that low relative humidities also reduced the quality of the learning experience and that "students attending schools with relative humidities between 22% and 26% experienced nearly 13% greater illness and absenteeism than students in schools with 27% and 33% RH.

Excessive humidity in the thermal environment can also affect the reliability of equipment. Excessive humidity has been known to cause serious damage to computer equipment. General recommendations adapted from the 1992 ASHRAE handbook, which will serve both people and sensitive electronic equipment, follow:

1. Air temperature should be kept constant within a range of 68 to 74°F during the winter and 73 to 79°F during the summer (with lighter clothing).
2. Relative humidity should be kept within a range of 30 to 60% in most classrooms and 50% constant in computer training rooms.
3. Air velocity should be kept with 15 to 25 feet per minute for low-activity rooms. and 25 to 50 fpm for rooms programmed for greater physical activity.
4. Outside air in quantities of 10 to 25 cubic feet per minute should be provided for each occupant.
5. The room's ambient temperature should be uniform (+/− 2°F) at working height throughout the room, within 1 foot from exterior walls.
6. The room should be serviced by automatic control systems, integrated thermostats, and automatic timing devices for day-night operations.
7. Fully operational heating, ventilation, and air-conditioning systems should be available whenever possible, particularly for those schools and training and conference centers that operate year round.
8. Rooms that employ extensive audiovisual equipment and computer-related equipment should have additional cooling in direct proportion to the heat produced by these media.

36.3.10.5.1. Thermal Limits for Media and Technology. While adhering to the thermal conditions cited in 36.3.10.5 will accommodate both people and audiovisual equipment, in 1970 the Educational Facilities Laboratories issued guidelines in terms of thermal limits for various media. Perhaps the reader will find their inclusion here of some practical value (EFL, 1970):

1. Computer facilities: Constant temperature of 75°F with 50% RH. Operational limits: Dry-bulb temperature of 60–90°F, relative humidity of 20–80%, maximum dry-bulb temperature of 78°F. Recommend 1/4-ton cooling per computer-assisted instruction (CAI) station. (*Author's note:* This last recommendation was based on what constituted a CAI station in 1970; a more accurate assessment can be made today by adding up the total wattage of each component in a VDT workstation, i.e., monitor, CPU, printers, server, etc., and multiply this number by 3.42 to determine the number of BTUs per hour that can be expected from this equipment during operations.)
2. Film projectors (slide, motion picture, etc.): 65–70°F and 25–40% RH.
3. Film storage: Below 80°F and 25–60% RH.
4. Audiotape storage: 60–90°F and 20–80% RH.

36.3.10.6. Air Distribution. The standard air distribution system for most rooms is centralized, with air being supplied from specific locations in the ceiling. This works well for standard workspaces and classrooms but is problematic in open-plan offices and learning resource centers because of the presence of work and study stations with self-standing partitions. Because of these partitions, the room's central air supply is often short circuited across the ceiling, and "still air" pockets are created. In response to such problems, newly designed heat distribution and ventilation systems that operate in a decentralized manner are now available.

One version is a "task-under-floor" ventilation system (TUFV). A study employing this system and involving six facility managers and 151 office workers found that the facility managers recorded fewer complaints about thermal discomfort and ventilation problems than in their previous buildings where a standard system had been employed. And the majority of the 151 office workers said that TUFV improved thermal comfort and perceived air quality, as well as providing good temperature and ventilation conditions, better supporting work productivity, and worker alertness (Hedge et al., 1990).

36.3.10.7. Air Quality

36.3.10.7.1. The Sick Building Syndrome. In considering air quality, it is noted that a growing number of schools and daycare centers and libraries are included in the category of "sick buildings" (Norbock et al., 1990; Yeung et al., 1991). Causes for this are symptoms such as itching skin, eye irritation, headache, nausea, respiratory problems, fatigue, and complaints of odor and disagreeable taste. These complaints center on the concentration of volatile organic hydrocarbons and the presence of wall-to-wall carpet (Noback & Widstrom, 1989). There is growing consensus that these symptoms are related to physical factors such as air temperature, pollutants, and biological factors like pollen and mold, as well as psychological factors (Potter, 1988). Excessive levels of static electricity are also cited as contributory causes of eye and skin irritations (Wedberg, 1987).

The causes of the recent increase in the level of pollutants found in our newly constructed offices and learning environments are attributed to new construction techniques and materials. According to Chant (1986) "new office buildings [and presumably schools] aimed at creating a uniform and perfect environment have been designed largely on the basis of building shape and engineering economics, with cheaper materials and construction shortcuts that have in many cases resulted in dangerous working environments." Commenting on this situation, Parsons (1992) stated that: "new building materials often give off fumes, particularly fumes containing formaldehyde. New office partitions and furniture, especially those made from particle board and other manufactured wood products, contain high concentrations of formaldehyde." Parsons goes on to indicate that formaldehyde can also be released from rugs, drapes, and other textiles. He also adds paints, solvents, wood preservatives, asbestos, glass fibers, cleaning agents, correction fluid, and pesticides to his list of building pollutants.

36.3.10.7.2. Air Quality and Emissions. Classroom and conference room air quality should meet and, where possible, exceed the requirements for office environments as specified in ANSI/ASHRAE 62-1992 standard. This standard stipulates that the maximum emission rate for total volatile organic compounds released in a room should not exceed 0.25 mg/hr/m^3, and carbon dioxide should be kept below 800 ppm.

Other emissions of concern include the electromagnetic emissions that are created by VDTs, building wiring, low-voltage lamps, and other electrical devices (Pool, 1990). Such emissions fall into the primary divisions: ELF, 5 Hz–2 kHz, VLF, 2 kHz–400 kHz, RF, and microwave. At the present time a causal relationship between EMFs and physical discomfort and illness has not been clearly established.

On the other hand, there is considerable scientific evidence that raises concern and promotes continued research on the subject (Burgess, 1992). And, compounding this problem is the cumulative effect likely to be found in the computer laboratory where 20 or more monitors operate simultaneously (Ross & Stewart, 1993; Frost, 1992). Facility planners, architects, and school administrators need to monitor this potential problem and give consideration to relevant research findings.

36.3.11 Display Systems

36.3.11.1. Basic Requirements. One of the most important components of the learning environment, and particularly of spaces used for media presentations, is the display system. Display systems range in sophistication from a basic setup that typically includes a television monitor, a slide projector, and a matte white screen, to highly complex front- and rear-projection multimedia systems. They can be as simple to operate and maintain as an overhead transparency projector or as complex as light-valve television projectors or plasma displays hooked up to an interactive computer program. In all cases they require the same basic considerations if they are to serve the function for which they were designed. It has been long established that display systems in order to be effective should have the following characteristics (Meister et al., 1969):

1. High legibility of individual characters and meaningful groups of symbols and words easily recognizable
2. Easy detectability of weak signals at all display ranges and at long and short viewing distances
3. Comfortable and accurate viewing at any required viewing angle
4. Minimum fall-off in image brightness at all viewing angles
5. Appropriate brightness-contrast, good resolution, and minimal image distortion
6. Qualities that elicit high observer accuracy and response time in performing visual functions
7. No apparent flicker for any of the viewers
8. Effective viewing within entire operating range of ambient illumination
9. Response with minimal equipment delay to user's request for display, as in information retrieval systems
10. Display parameters (brightness and contrast) adjustable by user
11. Audio signals of sufficient strength and fidelity to provide accurate and comfortable hearing for all listeners
12. Sound and image that appear to emanate from same location
13. Properly coded display controls for ease and accuracy of operation
14. Equipment and components that can be maintained by in-house technical staff
15. Adaptability for the inclusion of new presentation devices

36.3.11.2. Front- and Rear-Screen Projection. The two display systems commonly employed in classrooms, auditoria, and technical presentation facilities are front- and rear-screen projection. Each system has its merits and limitations. Consequently, it is not unusual and frequently advisable for a facility to be provided with both systems.

36.3.11.2.1. Front-Screen Projection. In a front-projection system, an image is produced by reflection off an opaque screen. Screen types include matte, ultramatte, beaded, lenticular, and aluminum foil. The standard matte screen is recommended for general applications and wide-angle viewing; the ultramatte should be used for higher image luminance, while still providing wide-angle viewing. Beaded screens are often recommended for rooms with narrow viewing sectors and where higher image luminance is required from standard projection equipment. Fixed, perforated lenticular screens are standard equipment for motion picture theaters, and the aluminum foil screen is used for special situations involving high ambient illumination and low-luminance television projection.

36.3.11.2.2. Rear-Screen Projection. In a rear-projection system, an image is produced by transmission through a translucent vinyl, acrylic, or glass screen. Rear-projection screens have found high acceptance in conference and training centers, where media presentations generally occur in rooms with high ambient illumination (McVey & Powell, 1985). These screens are widely available in a variety of colors and "gain" features.

36.3.11.2.3. Screen Gain. The "gain" of a screen refers to its light distribution characteristics. The most popular are the low-gain (1.2 to 1.8) screens for wide viewing sectors, and the moderately high-gain screens (2.0 to 3.0) for the more narrow viewing sectors or where greater image luminance is required under higher ambient illumination levels. Standard microdiffusion rear-projection screens with higher gains are usually unsatisfactory for general applications since they project noticeable hot spots. But recently a number of manufacturers have developed acrylic screens that employ fresnel lens technology and lenticulation to produce wide-angle viewing and higher gain (principally in the horizontal sector). These screens appear ideally suited for video display but are limited in size (about 12.5 feet diagonal) and cost significantly more than conventional RP screens.

While it has been generally accepted that front projection provides better image quality than rear projection, at least one study found that in terms of rendering print legible, both forms of projection (matte white vs. RP with 2.0 gain) yielded equivalent scores from graduate students, even when using alphanumerics measuring only 10, 8, and 6 subtended arc-minutes (Hamilton, 1983).

36.3.11.2.4. Rear or Front. A survey of the 10 leading conference centers in the United States relative to their existing and desired facilities found that the greatest number of requests by the managers was for fixed rear-projection facilities (McVey & Powell, 1985). Similar responses are now coming from business and higher-education organizations. Information relative to projection systems is continually updated and readily found in the literature (Utz, 1992).

Figure 36-20 shows a marketing/presentation room I recently designed for a computer company, in collaboration with Carl Franceschi of DRA Architects, showing both front- and rear-screen capabilities. This recognizes the fact that each medium has its own special attributes, and that having both provides the users with the capability of modifying their presentation approaches in the future when new technologies may make one of these two display approaches more desirable than the other.

36.3.11.2.5. Coordinating Lighting with Projection. As noted above, rear projection can be more effective in displaying media in conditions where there is more illumination than most front-projection systems can accommodate. Actually, both rear- and front-screen display can be made more effective by controlling the amount of illumination that falls off the display surface from room lighting during projection. The limits of this nonimage illuminance will vary with the light output of the display system and the reflectivity of the screen surface. For decades, the standard in the motion picture industry for nonimage illuminance in theaters has been 0.3 foot-candles (Kloepfel, 1969). My own experiments with conventional media indicate the following relative to currently typical media use in today's educational/training environments. These recommendations for permissible light levels may be modified upward where new developments increase the light output of tomorrow's standard projection equipment:

> Permissible ambient light levels on front projection screens are 0.3 FC with movie and video projection, 1.0 FC with slides and LCD display, and 2.5 FC with overhead projection of high-contrast transparencies. These ambient light levels may be increased significantly with rear-projection display, in direct proportion to the reflectivity of the screen surface. For rear screens having 10% reflectivity, the above levels may be tripled, but for rear screens having a 30% reflectivity, such levels can only be doubled.

36.3.12 Controls

In the learning environment, instructors, presenters, and students are faced on a daily basis with the need to operate various kinds of controls. Some of the controls that the instructor or presenter have to deal with are environmental, and include lighting, window drapery, or shades, and, in some cases, room thermostats. Other controls they operate involve the room's presentation systems, such as projectors, audio- and videotape recorders and players, sound system levels and balance, etc. And others include those that involve the room's security and electrical power systems. The students also are expected to operate many controls. Most of these involve the operation of equipment in their computer workstation, i.e., mouse, joy stick, optical scanner, etc., or portable audiovisual equipment employed in their project activities.

For many years now, one of the byproducts of human factors engineering efforts in the military and space programs was the development of practical and effective guidelines for the control of equipment and building systems by the operator. For example, even at the most general level, ergonomists such as Woodson (1981) offered such guidelines relative to control selection, design, and use (p. 570).

1. Type of control: The control should be chosen as though it were an extension of the operator's limb, i.e., it would be operable in terms of the natural motions of the arm, wrist, finger, leg, ankle, or foot, and it should not require awkward and unnatural positioning, extension, or motion on the part of the operator.
2. Feedback: The control interface and basic controller system should provide feedback so that the operator knows at all times what his or her input is accomplishing.
3. Resistance: There should be sufficient resistance to operator inputs to dampen spurious inputs, but not so much that the operator has to put great force into the control, so that his or her muscles are not quickly fatigued or that the operator has difficulty maintaining the nominal operating position.

Figure 36-20. Marketing/presentation room with both front- and rear-screen projection.

4. Position of the control: Controls should be placed where they do not require the operator to assume awkward body positions or make frequent long-reaching movements. The position should reflect consideration of the excursion requirements of the control system so that there is no chance that the operator will be unable to reach a critical point in the control movement path.
5. Size and shape: The size and shape of control interfaces (handles, knobs, buttons, etc.) should be compatible with the size of the operator's hands, fingers, or feet. The shape of a control should also be compatible with the kind of grip or motion required to operate the control interface.
6. Interface surface: The surface of a control handle should depend on the type of operation required, i.e., it may need serrations or knurling in order to apply a firm grip for maximum force.
7. One-hand versus two-hand operations: Two hands often provide more precision or force.

Today's equipment designers seem, however, to be ignoring the above and other guidelines that have proved so effective in controlling the complex systems found in military and space programs for past 4 decades. Instead they seem to be driven by a misplaced concept of uniformity and symmetry. Andre and Segal (1994) recently studied what happens when designers attempt to design control panels with total symmetry: "Typically these types of layouts do not allow the user to easily differentiate between controls that serve different functions." They go on to cite that they found amplifiers with as many as 28 similar buttons laid out in a symmetrical pattern. They note: ". . . such similarity in form between controls further hinders differentiation and requires the user to adapt to the product." According to these authors, the operators are expected to rely on memory and verbal labels to differentiate among variables that are in essence quite different. And this is where the conflict lies: "Switches on computer monitors, buttons on phones, calculators, etc., all are deliberately made less visible (or are omitted) so as not to detract from the so-called aesthetic quality of the product." The direct consequence of designing for reduced visibility is reduced feedback.

The psychologist Donald A. Norman (1988, p. 3) addressed this problem of reduced feedback through efforts toward design aesthetics via simplicity when he described how he had tried to operate a particular slide projector: "With only one button to control the slide advance, how could one switch from forward to reverse?" When he asked a technician how he could initiate both functions from one button, he was told that a brief push of the button would send the slide forward; a long push and it would reverse itself. However, even after having an explanation of the system's "logic" without the necessary feedback, he was still unable to operate the projector successfully. This motivated Norman to note that there are psychological principles that should be followed in order to make controls understandable: visibility, appropriate clues, and feedback of one's actions, constituting a psychology of how people interact with things and thus how they should be designed.

In designing or selecting a control system for purchase, one needs to be reminded of the "locus of control" theory, which states that a control, system as well as other human-technology interfaces, should permit the user to feel in control of the system, and not vice versa (Robson & Crelin, 1989). If an ergonomist, is to successfully prescribe the learning environment, he or she must direct attention toward the design of all elements in the learning environment, and that includes the systems that control audiovisual presentation systems as well as room features. Figures 36-21a, b, and c show examples of the product for which I was asked to design control systems for room lighting and audiovisual equipment.

The methods employed on the lectern controls systems (Fig. 36-21a) included clustering related controls, color coding, shape coding, and employing knobs for quantitative elements, such as sound levels from both the voice reinforcement and program playback systems, and illuminated feedback switches. The lighting controls (Fig. 36-21b) are set up so that an instructor or presenter simply picks a "scene," i.e., general, vugraph, slides, or video, and in each case the correct light fixtures are left on, with the appropriate number of lamps, for the media to be effectively used and to maximize the available light for the students.

The touch AV control panel (Fig. 36-21c) represents a hybrid of modern LCD selection screens, along with discrete buttons to the side of the touch panel which duplicate some of the most frequently used functions. The reason for this is that many people do not need or want to go sequentially through selecting a menu to control such things as volume level, lights, draper, or a projection screen's descent. Readers should be aware that ample information is available to guide their efforts at developing efficacious control systems. These sources include but are not limited to: Woodson and Conover (1973), Van Cott and Kinkade (1972), and Sanders and McCormick (1987).

36.4 Conclusion

This chapter considered some of the environmental, ergonomic, and display system factors that contribute to the effectiveness of learning environments in general, with particular emphasis on classroom and conference room settings, and workstations where educational media, including VDTs, are used extensively. When such factors are prudently integrated into a learning environment's design, they have gained acceptance and appreciation from both students and faculty (McVey, 1979). Trainers and trainees working in similarly designed environments also recognize and appreciate their features.

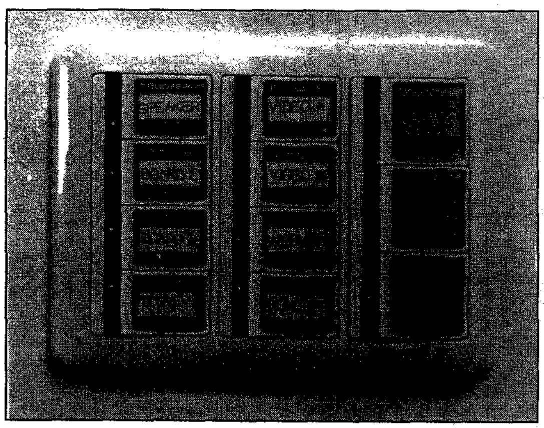
Figure 36-22 is a photograph of an auditorium I recently designed in collaboration with Mark Sweeney of OmniArchitecture Inc., Charlotte, North Carolina. The photograph shows many of the ergonomic features discussed in the preceding pages of this chapter. Such features include the following:

- NASF of 2,928 SF, serving a total of 219 occupants, 28 in movable castered seats behind tables, 189 in fixed seats, plus 3 handicap locations (13.4 SF/occupant) plus a 11' × 42' rear-projection room, a 7' × 20' front-projection room, and a 230 SF enclosure for a chairlift.

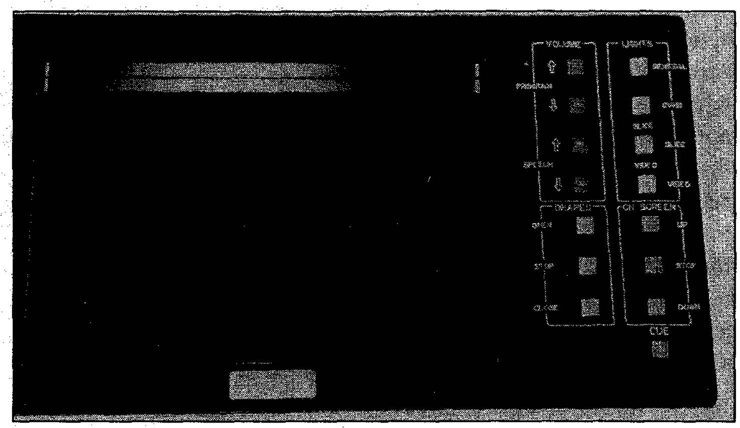
- 189 fixed seats, 12 with regular 21" seat pan widths, and 177 large modules of 22.75–23.50", with side-to-side spacing of 26.5–27.0", true staggered arrangement, on risers spaced 42" apart and with a tablet arm and two arm rests per person. Left-hand tablet arms clustered at desired viewing locations, with a "L" label on the chair back to simplify locating the left-handed seats.
- Ambient noise level equal to PNC 26, with a reverberation time of approximately 1.2". Acoustical gain of voice amplification system 20+ dBA. The physical acoustics of the room make possible two-way communications between presenter and audience without microphones.
- Fluorescent levels for general activities variable by scene selection up to 70 FC, downlighting on dimmer for AV activities = 0–25 FC. Videoconferencing illuminance levels variable by dimmer up to 139 FC.
- Rear-screen image luminances ranged from 28 FL, as seen from audience center, to 5 FL at most angular viewing locations.
- All vertical viewing angles between 25° to top of display and -10° to bottom of display. All horizontal viewing angles within acceptable standards.

Planning and designing ergonomically correct learning environments require a concerted effort to make the proposed facility's educational specifications reflect what we have learned from ergonomic research. It is hoped that readers, whether facility planners, architects, media specialists, or teachers, will adopt the principles and guidelines presented in this paper and make every effort, consistent with their role on a school systems' building committee or on a college or university's planning committee, to see that these principles and guidelines are employed in the planning of their own future facilities.

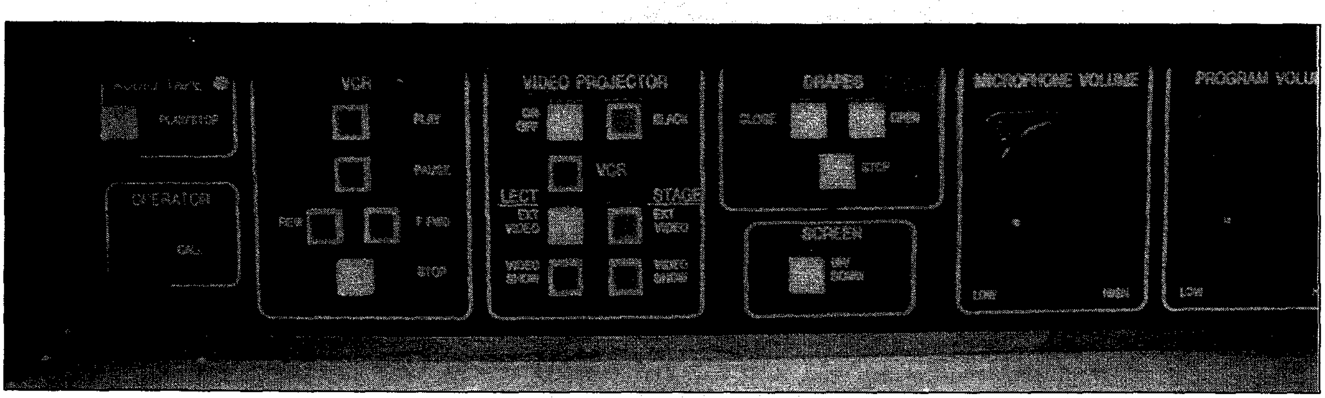
In addition, it is hoped that classroom teachers, college instructors, and high-tech trainers or presenters will, after reading this chapter, have a better understanding of how the physical factors inherent in the design of their spaces affect the comfort, well-being, and task performance of their charges, and aggressively seek ways of employing or modifying elements to achieve their instructional goals in an



a. Scene selection and dimming lighting control.



b. LCD AV touch control panel with supplementary hard-wired controls.



c. Hard-wired AV control panel for lectern.

Figure 36-21a, b, c. Lighting and audiovisual controls designed or specified by author.

Figure 36-22. Photo of Hoechst/Celanese auditorium showing ergonomic features.

ergonomically appropriate manner—and where doing so may not be possible, then guide their charges in adapting teaching activities and materials accordingly.

For educational researchers, it is hoped that this chapter has provided the kind of introduction with appropriate examples that will spur them on to conduct their own ergonomic research. It is hoped that the approximately 200 citations presented in this chapter's reference section can assist in such efforts. It is imperative that we add to our ergonomic knowledge base if our future learning environments are to be developed on the basis of "hard science" with justifiable expectations and not left to the whims of trends and design affectations. Figure 36-23 is a visual summary of many of the design details that affect the comfort, attention, and notetaking effectiveness of students in lecturing environments.

36.4.1 Summarizing Questions

In concluding this chapter, I would like to suggest a series of questions and concerns that I feel need to be addressed each time those involved in planning the learning environment get together to assess the ergonomic needs of the facility's occupants in the process of developing the critical document known as the *educational specifications.* Of course such discussions should not be limited to these questions but also include the many others that relate to the school or training center's mission, demographics, staffing, and so forth. However, since it is usually the ergonomic concerns that seem to get short shrift, and since that is the topic of this chapter, I will focus my coverage on the major ergonomic issues. However, I will also include a couple of related issues that I feel need to be mentioned. These same questions need to be asked at the conclusion of the facility's construction and occupancy in order to help the facility's administration to determine if all of the important considerations have been made or whether physical corrections are already in order. Asking oneself these questions will also alert the teacher or trainer to the need for classroom interventions.

Area. This is the net assignable area allocated to the various spaces in a facility. Will the various space allocations make it possible for a teacher/trainer to set up seating in the patterns they desire, with appropriate viewing distances and viewing angles? Will the space allocations accommodate the easy access and storage of instructional materials and equipment? Is there a need to use a chalk and/or marker board simultaneously with media projection, and if so is the room sufficiently wide enough to permit this side-by-side display arrangement?

HVAC. Has there been an accurate estimate made regarding the anticipated heat that will be produced in the areas by people, activities, technology, lighting, etc.? Have the electrical and HVAC systems been appropriately "sized" to accommodate such estimated full-load amperes (FLA) and British thermal units per hour (BTUH)? Will the thermal environment provide the appropriate amount of air exchange in the spaces, with an appropriate number of fresh-air changes per hour? Will the resultant air velocities at each student location be sufficient to dissipate heat buildup but not cause drafts? Will the spaces' relative humidity be kept within acceptable limits throughout all months of the year for both occupants and sensitive educational technology? Will there be any "off gassing" problems expected from the building materials used in the facilty's construction?

Acoustical factors. Will the spaces have the ambient noise spectra (preferred noise criteria curve) appropriate for the programmed activities. Will the room's walls sufficiently attenuate (sound transmission class) sound in one room from interfering with the activities of an adjacent room? Will the air-handling units create too much background noise for effective speech communication to occur? Will the spaces have reverberation times appropriate for the programmed activities and the needs of special students? Are there any hard parallel walls that should have acoustical treatment in order to avoid excessive reverberation, echoes, flutter, etc.? Will the ballasts used in the lighting systems be appropriately quiet for the spaces intended activities?

Lighting. Will there be sufficient horizontal illuminance for the proposed visual tasks? Will there be sufficient and uniform vertical illuminance to illuminate the chalk and/or marker board areas appropriately? Will the resultant display surfaces have a luminance at least equal to, and preferably a bit greater than, the adjacent wall areas? Can the ambient illuminance in the projection screen area be effectively and easily controlled during projection so that images are not "washed out"? Have all possible sources of glare been considered and eliminated through either design or product selection? Will the luminaires have color temperatures and color rendition indices appropriate for the spaces intended activities? Has daylighting been employed effectively and its control such that solar-heat gain and glare will not be problematic for occupants, and that it will not compromise media projection when in use? Will the pattern of luminances created by lighting and surface finishes be such that they promote visual efficiency, visual comfort, and aesthetic value?

Reflectances. Will the reflectances chosen for the wall and desk finishes be such that they will produce backgrounds for near and distant visual tasks that will promote orientation to the task and in general contribute to a glare-free environment when illuminated by the lighting systems chosen for the spaces? Are the chalkboards and/or marker boards of a reflectance appropriate to display chalk or liquid markers with sufficient contrast for legibility, but not so great as to create contrast ratios that are visually uncomfortable?

Utility factors. Are there sufficient electrical circuits and outlets to support the technology needs of the spaces? Are there sufficient data/voice lines and connections in the spaces for the programmed activities? Will there need to be electrical filtration or transient "spike" suppressions systems? Is water (hot and cold) or compressed air required in any of the spaces?

Seating. Are the chairs ergonomically appropriate for the programmed activities and the physical sizes of the intended user population? Do the chairs have all of the required

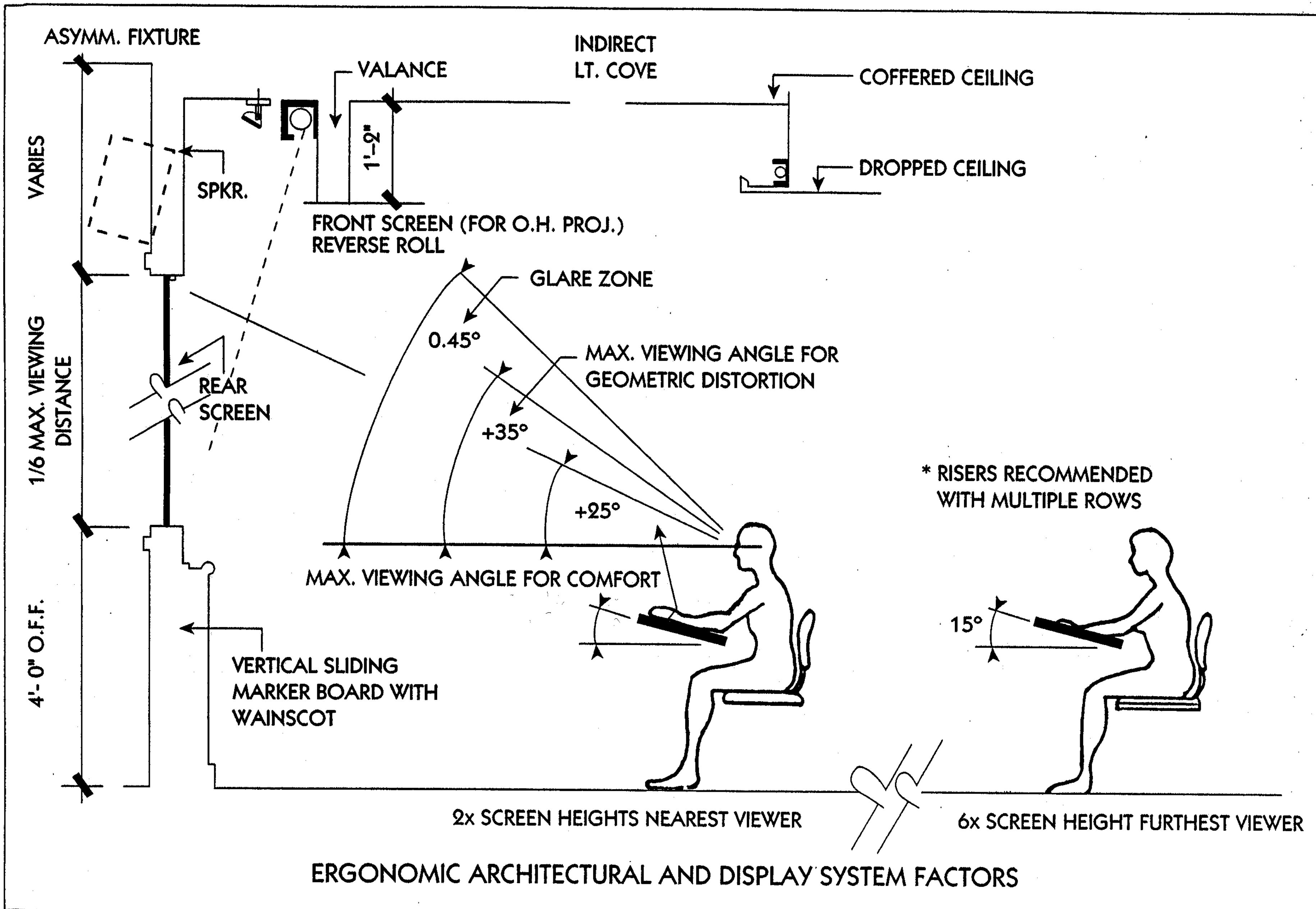


Figure 36-23. Ergonomic design details for lecture environments with media.

adjustment features needed, and, if so, will they be able to be operated easily by an inexperienced occupant? Will the desks be of an appropriate height and provide sufficient surface area for the programmed activities? Will the reading and writing surface have an inclination sufficient to promote the comfortable and effective completion of near visually centered tasks such as taking notes, writing, and reading? Will there be desks or tables available with flat work surfaces for three-dimensional tasks, i.e., assembly work, models, etc.?

Display system factors. Has the most appropriate display system (rear screen or front screen) been selected for each of the spaces where display systems are required? Do the screens have light distribution patterns (gain) appropriate for the intended media and the width of the spaces? Is it possible for simultaneous use of marker board and media display where required? Are horizontal and vertical sight lines to all parts of the screen physically comfortable as well as unobstructed by occupants seated in front of each other? Have the display systems been coordinated with the lighting fixtures (luminaires), dimmers and/or switches, and scene selection "controls" to permit appropriate image/non-image "brightness" ratios?

Audio system factors. Has the most appropriate type(s) of audio system(s) been selected for each of the presentation spaces? Will these systems be capable of producing sound levels to promote orientation and adequate signal-to-noise ratios for effective communications? Is "sound masking" needed in any of the "open" multipurpose spaces?

Safety and security factors. Have all possible egress scenarios been considered and provided for? Have the appropriate fire suppression systems been provided for people and equipment? Are there any electrical or hazardous substance conditions that need to be accommodated? Have medical and first-aid services been considered and provided where a need is anticipated? Have security measures been provided to ensure personal safety and hazard and intrusion avoidance? Are there pockets of invisibility where potential hazards for people are likely to be hidden from view? Is the parking area safe? Are all locks clearly visible so that using one's keys is not problematic at any time of the day or night the facility is in use?

Handicapped/elderly. Have the physical, auditory, and visual needs of the handicapped and elderly learners been accommodated?

Anthropometric factors. Have corridors, door openings, etc., been designed to make passage safe and nonclaustrophobic. Will they accommodate prosthetic devices including wheelchairs? Are all critical controls for environmental and equipment elements within easy reach for all of the intended population? Are all physical clearances into spaces of sufficient height and width to accommodate all of the intended population? Have furnishings been selected on the basis of anthropometric appropriateness and not solely on the owners's aesthetic values or organizational image?

Orientation factors. Is the floor plan logic such that people new to a space will have no difficulty getting to where they want to go? Has sufficient attention been given to space differentiation, and to color and graphic usage, t promote efficient "way finding"? Is the logic such tha there is not excessive transition time from entrances t information sources, i.e., reception desks, the message cente or message monitors?

Proxemics. Have the spaces been designed to provide sense of personal space where desired and the number o socieopital and sociofugal spaces needed to compliment th facility's program? Does the facility convey a sense o openness and/or territoriality where desired?

Aesthetics and interaction. Will the facilty convey a sense of familiarity, cultural identity, and naturalness? Are there sufficient window views and areas that capitalize on natural light? Will the facility provide sensory variation for its occupants that is stimulating but not so distracting that it will interfere with their task performance?

Housekeeping. Have the problems associated with beverages, food use, and smoking been accommodated, through both facility design and the establishment of rules and regulations?

Control systems. Are there control systems for room lighting, drapery, and HVAC? Are these accessible to the appropriate people? Are the media control systems designed in a logical manner so that their operation is self-evident, i.e., one does not need to read a manual in order to use them? Are all operations labels visible and legible given the lighting conditions under which they are expected to be used? Can a student turn on and operate all elements in his or her workstation without needing to involve someone else? Are important operating instructions clearly visible and understandable by all of the intended users? Do all controls provide the operator with feedback, i.e, tactile, kinesthetic, visual, auditory, etc., so that the operator knows immediately the consequence of his or her action?

REFERENCES

Aikman, L. (1994). Personal communication, Newton, MA.

Akerblom, B. (1954). Chairs and sitting. *In* W.F. Floyd & A.T. Welford, eds. *Symposium on Human Factors Design. Proceedings of the Ergonomics Research Society,* Vol. II, 29–35, Loughborough, U.K., Ergonomics Society.

Ali, M.R. (1972). Pattern of EEG recovery under photic stimulation by light of different colors, *Electroencephalography and Clinical Neurophysiology 33,* 332–35.

Allen, W. & Charles, J.G. (1986). The aural environment. *In* R. Lueder, ed. *The ergonomic payoff: designing the electronic office.* New York: Nichols.

Andre, A. & Segal, L. (1994, Oct.). Design functions. *Ergonomics in Design.*

Ankrum, D.R. & Nemeth, K.J. (1995). Posture, comfort, and monitor placement. *Ergonomics in Design,* April, 7–9.

ASHRAE (1992). Thermal environmental conditions for human occupancy. *ANSI/ASHRAE,* 55-1992, Atlanta, GA.

Ary, D., Jacobs, L.C. & Razavieh, A. (1979). *Introduction to research in education.* New York: Holt, Rinehart & Winston.

ASTM (1976). *Acoustical environment in the open-plan office.* Report of ASTM Task Group E33.04C.

Au Yeung, Y.N., et al. (1991). Sick building syndrome—a case study. *Building and Environment 26,* 319–30.

Auliciems, A. (1989). Thermal comfort. *In* N.M. Ruck, ed. *Building design and human performance.* New York: Van Nostrand.

Badolato, M. (1995). An ergonomic analysis and assessment of selected music education classrooms, Doctoral dissertationin progress, Boston University.

Bass, B.H., & Klubeck, S. Effects of seating arrangements on leaderless group discussions. *Journal of Abnormal Social Psychology 47,* 724-27.

Bendix, T. & Hagberg, M. (1984). Trunk posture and load on the trapezius muscle whilst sitting at sloping tables. *Ergonomics 27,* 873–82.

— & Jensen, F. (1986). Wrist support during typing: a controlled electromyographic-graphic study. *Applied Ergonomics 17,* 162–68.

Bennett, C. (1977). *Spaces for people.* Englewood Cliffs, NJ: Prentice Hall.

— (1985). Three comparisons of incandescent and fluorescent: color or luminaire. *Proceedings of the Human Factors Society,* 29th annual meeting.

Bennett, H.E. (1928). *School posture and seating: a manual for teachers, physical directors, and school officials.* Boston, MA: Ginn.

Bethune, J. (1991). A user assessment of selected lecture halls to determine the relative merits of architectural standards and ergonomic guidelines. Doctoral dissertation, Boston University. Ann Arbor, MI: University Microfilms.

BS7179 (1990). *Ergonomics of design and use of visual display terminals (VDTs) in Offices, Parts 1-6.* Milton Keynes, England: British Standards Institute.

Beranek, L., Blazier, W. & Figwer, J. (1971). Preferred noise criterion (PNC) curves and their application to rooms. *Journal of the Acoustical Society of America 50* (5.1), 1223–28.

Birren, F. (1969). *Light, color and environment.* New York: Van Nostrand.

Bobker, S. (1991). Work smart, work safe. *MacUser 7,* (12), 221–23.

BOCA (1990). *The BOCA National Building Code/1990,* 11th ed. International Country Club Hills, IL: Building Officials and Code Administration.

Boray, P.F., et al. (1989). Effects of warm-white, cool-white, or full-spectrum fluorescent lighting on simple cognitive performance, mood, and ratings of others, *Journal of Environmental Psychology 9,* 297–308.

Boubekrl, M., et al. (1991, Jul.). Impact of window size and sunlight penetration on office workers' mood and satisfaction. *Environment and Behavior 23,* (4), 474–93.

Boyce, P.R. (1974, Sep.). User's assessment of a landscaped office. *Journal of Architectural Research 3,* 44–62.

Brainard, G.C. (1994, Oct.). *Special report: impact of light on human health, performance and well-being.* Unpublished Report. Boston, MA: Tradeline Symposium.

Broadbent, D.E. (1957). Effects of noise on behavior. *In* Harris, ed. *Handbook of noise control,* Chap. 10. New York: McGraw-Hill.

Bruner, J. (1961). The cognitive consequences of early sensory deprivation. *In* P. Solomon, ed. *Sensory deprivation.* Cambridge, MA: Harvard University Press.

Bugelski, B.R. (1971). *The psychology of learning applied to teaching.* New York: Bobbs-Merrill.

Burch, L. (1993). Architects and educators: the total is greater than the parts. *The Educational Facility Planner.* CEFPI, 32, No. 3, 5–6.

Burgess, C.G. (1992, Dec.). Electromagnetic fields (EMF) and health hazards. *CSTG Bulletin,* Human Factors and Ergonomics Society.

Burton, Daniel, J. (1980). *Human needs assessment, performance-based programming, construction and user evaluation of a facility for the elderly and the handicapped, utilizing man-environment data.* Doctoral dissertation, School of Education, Boston University. Ann Arbor, MI: University Microfilms.

Cakir, A., et al. (1980). *Visual display terminals.* Chichester, U.K.: Wiley.

Caldwell, B. (1994, Jan.). The learning-friendly classroom. *Ergonomics in Design,* 30–35.

Caldwell, B., et al. (1995, Jan.). Classroom environment analysis and improvement strategies, Proceedings 37th Annual Meeting of the Human Factors and Ergonomics Society.

Campbell, D.T. & Fiske, D.W. (1959). Convergent and discrimination validation by the multitrait-multimethod matrix. *Psychological Bulletin 56,* 81–105.

— & Stanley, J.C. (1963, 1966). Experimental and quasi-experimental designs for research. Chicago, IL: Rand McNally.

Canter, D., ed. (1970). Architectural psychology. Proceedings of the conference held at Dalandhui, University of Strathclyde, Glasgow, Scotland, 28 Feb.–2 Mar., 1969. London: Royal Institute of British Architects.

—(1975). Psychology for architects. New York: Halsted Press, Wiley.

Carnovale, R., et al. (1989). *A guideline on office ergonomics.* CSA Standard CAN/CSA-Z412-M89. Rexdale, Ontario: Canadian Standards Association.

Castaldi, B. (1977). *Educational facilities.* Boston, MA: Allyn & Bacon.

CCSE (1938). *Report of the Consultative Committee on Secondary Education.* London: CCSE, HMSO.

CEFP (1969). *Guide for planning educational facilities.* Columbus, OH: CEFP.

CEQ (1968). *Noise: sound without value.* PB 180299, Committee on Environmental Quality, Federal Council for Science and Technology. Washington, DC: Government Printing Office.

Chant, R. (1986). Air quality. *In* R. Lueder, ed. *The ergonomic payoff: designing the electronic office.* New York: Nichols.

Chapanis, A. (1965). *Research techniques in human engineering.* Baltimore, MD: John Hopkins.

Close. P.D. (1957). *Sound control and thermal insulation of buildings.* New York: Reinhold.

Cohen, A. (1969, Feb.). Effects of noise on psychological state. In *Noise as a public health hazard.* ASHRAE Reports 4, 74–88, Proceedings of the American Speech and Hearing Association, Washington, DC.

Christinaz, D. & Knirk, F. (1987). Environmental requirements for computer-assisted instruction, Proceedings of the Human Factors Society, 31st Annual Meeting, 228–32. Santa Monica, CA.

Davis, G. (1991, May). The electronic office. In *Building Operating Management.* GTE Sylvania.

DeCecco, J.P. (1968). *The psychology of learning and instruction: educational psychology.* Englewood, NJ: Prentice Hall.

DeChiara J. & Callender, J. (1980). *Time saver standards for building types,* 2d ed., New York: McGraw-Hill.

DesRosiers, E. (1976).The effect of image/surround brightness contrast ratios on student preference, attention, visual comfort, and visual fatigue. Doctoral dissertation, Boston University. Ann Arbor, MI: University Microfilms.

Diffrient, N., et al. (1974). *The human scale.* Cambridge, MA: MIT Press.

Doelle, Leslie, L. (1972). *Environmental acoustics.* New York: McGraw-Hill.

Dunn, O. (1964). Multiple comparisons using rank sums. *Technometrics 6,* 241–52.

Eckenrode, A. & Abbot, L. (1959). *In* C.T. Larson, ed. *SER 2,* 1965. Ann Arbor, MI: University of Michigan.

EFL (1970): *Instructional hardware: a guide to architectural requirements,* 66–98. New York: Educational Facilities Laboratories.

Eggleton. E., ed. (1983). *Ergonomic design for people at work, Vol. 1.* Belmont, CA: Lifetime Learning.

Ferris, G. & Moldstad, J. (1961). *Improving the learning environment.* Bloomington, IN: Indiana University.

Francescato, A., et al. (1975). Evaluating residents' satisfaction in housing for low- and moderate-income families: a multimethod approach. *In* C. Lozar, ed. EDRA 5: Sec. 5, methods and measures: 1974. Milwaukee, WI: University of Wisconsin.

Freudenthal, A., et al. (1991, Oct.). The effect on sitting posture of a desk with a ten-degree inclination, using an adjustable chair and table. *Applied Ergonomics,* 329–36.

Frost, M. (1992). Mac LC and IIsi color display systems. *MacUser 8* (2), 157–70.

Fulrath, D. (1976). Some effects of seating arrangement and task duration on fatigue, attention, participation, and preference of individuals engaged in small group media tasks. Doctoral dissertation, Boston University. Ann Arbor, MI: University Microfilms.

Gagné, R. (1965). *Conditions of learning.* New York: Holt, Rinehart & Winston.

Gardner, D.E. (1971). *Guide for planning educational facilities.* Columbus, OH: Council of Educational Facility Planners.

Gerard, R.M (1958). Differential effects of colored lights on psychophysiological functions. Doctoral dissertation, University of California, Ann Arbor, MI: University Microfilms.

Grandjean, E. (1969). *Fitting the task to the man.* New York: Taylor & Francis.

— (1984). VDT workstation settings, body posture and physical impairments. *Applied Ergonomics 15,* 99–104.

— (1987). *Ergonomics in computerized offices.* London: Taylor & Francis.

— (1987a). Design of VDT workstations. *In* G. Salvendy, ed. *Handbook of human factors,* Chap. 11. New York: Taylor & Francis.

— (1988). *Fitting the task to the man,* 4th ed. New York: Taylor & Francis.

— et al. (1983). VDT workstation design: preferred setting and their effects. *Human Factors 25,* 161–76.

Green, A., ed. (1966). *Educational facilities with new media.* Washington, DC: AECT.

Hall, E.T. (1966). *The hidden dimension.* New York: Doubleday.

Hamilton, M. (1983). The accuracy recognition of positive and negative symbols of seven, five, and three minutes of arc on front and rear projection screens under self-selected illumination. Doctoral dissertation, Boston University. Ann Arbor, MI: University Microfilms.

Harmon, D.B. (1951). *The coordinated classroom.* File No. 35-B, Washington, DC: A.I.A.

— (1953). *Controlling the thermal environment of the coordinated classroom.* ERIC ED 033531, Minneapolis, MN: Honeywell.

— (1966). Class lecture notes: environmental design program. Madison, WI: University of Wisconsin.

Harris, C.M. (1957). *Handbook of noise control.* New York: McGraw-Hill.

Hathaway, W. (1988). Educational facilities: designing to enhance learning and human performance. *Education Canada 28,* (4), 28–35.

Haubner, P. & Kokoschka, S. (1983). *Characteristics of performance.* International Commission on Illumination (CIE), 20th Session in Amsterdam, 52 Bd. Malesherbes 75008 Paris, France.

Hawkes, R.J. & Douglas, H. (1970, Nov.). Subjective acoustic experience in concert auditoria. *Architectural Research and Teaching* (2), 34–35.

Hebert, L.A. (1989). *The neck-arm-hand book.* Bangor, ME: IMPACC.

Hedge, A., et al. (1989). Lighting the computerized office: a comparative study of parabolic and lensed indirect office lighting systems. *Proceedings of the Human Factors Society, 33d annual meeting.*

— (1990). Improving thermal comfort of offices: the impact of underfloor task ventilation. *Proceedings of the Human Factors Society, 34th annual meeting.*

Heijs, W. & Stringer, P. (1988). Research on residential thermal comfort: some contributions from environmental psychology. *Journal of Environmental Psychology 8,* 235–47.

HFS (1988). *American National Standards for Human Factors Engineering of Visual Display Terminal Workstations.* ANSI/HFS Standard No. 100-1988. Santa Monica, CA: Human Factors Society.

Hill, S. & Kroemer, E. (1986). Preferred declination of the line of sight. *Human Factors 28* (2) 127–34.

Hocking, W. (1987) Epidemiological aspects of repetition strain injury. *Medical Journal of Australia 147,* 218–22.

Horowitz, J. (1992, Oct.). Crippled by computers. *Time 12,* 70–72.

Howell, D.C. (1982). *Statistical methods for psychology.* Boston, MA: Duxbury.

Hultgren, G., Knave, B. & Werner, M. (1974). Discomfort thru microfilm in different enlargers. *Applied Ergonomics,* 194–210.

Hunt, D.P. & Bernotat, R. (1977). *University curricula in ergonomics.* Forschungsinstitut fur Anthropotechnic, Meckenhim.

IES (1989). IES-RP-24: *VDT lighting.* Washington, DC: Illuminating Engineering Society of North America.

Issac, S. & Michael, W.B. (1981). *Handbook in research and evaluation.* San Diego, CA: Edits Publications.

ISO (1988) Visual display terminals (VDTs) used for one tasks-ergonomic requirements. *International Standard* ISO/DIS 9241-1.

Ittleson, W., Rivlin, L. & Proshansky, H. (1970). The use of behavioral maps. *In* H. Proshansky, W. Ittleson & L. Rivlin, eds. *Environmental psychology.* New York: Holt, Rinehart & Winston.

Jaschinski-Kruza, W. (1988). *Visual strain during VDU work:*

the effect of viewing distance and dark focus. Ergonomics *32* (10), 1449–65.

John, J.E.J. (1960). The efficiency of hearing aids as a function of architectural acoustics. *In* AW. Ewing, ed. *The modern educational treatment of deafness.* Manchester, U.K.: Manchester University Press.

Kaufman, J.E., ed. (1981). 1981 *lighting handbook,* Vols. 1, 2. New York: Illuminating Engineering Society of North America.

Kerlinger, F.N. (1973). *Foundations of behavioral research.* New York: Holt, Reinhart & Winston.

Kjellberg, A. & Skoldstrom, B. (1991). Noise annoyance during the performance of different non-auditory tasks. *Perceptual and Motor Skills 73,* 39–49.

Kloepfel, D.V. (1969). *Motion picture projection and theater presentation manual.* New York: S.M.P.T.E.

Kwallek, N. & Lewis, C.M. (1990). Effects of environmental colour on males and females. *Applied Ergonomics 21* (12), 275–78.

Knirk, F.G. (1992, Sep.). Facility requirements for integrated learning systems. *Educational Technology 33* (9), 26–32.

Kryter, Karl, D. (1970). *The effects of noise on man.* New York: Academic.

LaGuisa, F. & Perney, L. (1973, May). Effects of brightness variation on attention span in a learning environment. *Lighting Design and Application* (3) 6, 28–29.

— (1974) Further studies on effects of brightness variations on attention spans. *Journal of the Illuminating Engineering Society 3,* 249–52.

Lam, W. (1977). *Perception and lighting as formgivers for architecture.* New York: McGraw-Hill.

Lane, K.E. & Richardson, M.D (1993). Human factors engineering and school furniture: a circular odyssey. *The Educational Facility Planner,* CEFPI 31, No. 3, 22–23.

Larson, C.T. (1965). SER 1, 2, 3, school environment project. Ann Arbor, MI: University of Michigan.

Leavitt, H.J. (1951, Jan.). Some effects of certain communication patterns on group performance. *Journal of Abnormal Social Psychology 46,* 38–50.

Lee, S.A. (1973). Environmental perception, preferences and the designer. *In* R. Kuller, ed. *Architectural Psychology, Proceedings of the Lund Conference.* Stroudsburg, PA: Dowden, Hutchinson & Ross.

Leed, S. & Leed, J. (1987). *Building for adult learning.* Cincinnati, OH: LDA.

Levy-Leboyer, C. (1982). *Psychology and environment.* Beverly Hills, CA: Sage.

Lexan, H. (1969, May). The noise is killing us. *St. Anthony Messenger 76,* 12–17.

Markus, T. (1974, May). The why and how of research into 'real building.' *Journal of Architectural Research* (2), 19–23.

McVey, G.F. (1969). An analysis, synthesis, and application of selected research findings to visual design and presentation by the visual specialist. Doctoral dissertation, University of Wisconsin-Madison. Ann Arbor, MI: University Microfilms.

— (1971). *Sensory factors in the classroom learning environment.* Washington, DC: NEA.

— (1979, Summer) User assessment of media presentation rooms. *Educational Communication and Technology Journal, 27* (2), 121–47.

— (1985). The learning environment. In *The international encyclopedia of education.* New York: Pergamon.

— (1991, Jul.). Twelve ergonomic guidelines for integrating AV into conference room design. *Facility Planning News.*

— (1992). In search of equitable learning environments: the acoustics of classrooms used in mainstreaming hearing-disadvantaged students. *Proceedings of EDRA/23.* Environmental Design Research Association, Apr. 9–12, Boulder, CO.

— & Bethune, J. (1992). User assessment of selected lecture halls and the relative merits of architectural standards and ergonomic guidelines. *Proceedings of the Human Factors Society,* Oct. 12–16.

— & Powell, J. (1985, Aug.). *An audiovisual facility and production status study of selected national conference centers.* Cambridge, MA: B & M Technologies.

Mehrabian, A. & Russell, J. (1974). *An approach to environmental psychology.* Cambridge, MA: MIT Press.

Meister, D., et al. (1969, Aug. 30). *Guide to human engineering design for visual displays.* Canoga Park, CA: Bunker-Ramo.

Menell, J. (1976). Training facilities and equipment. *In* American Society for Training and Development. *Training and development handbook: a guide to human resource development,* 2d ed. New York: McGraw-Hill.

Mikellides, B. (1990, Spring). Color and physiological arousal. *Journal of Architectural and Planning Research 7* (1), 13–19.

Miller, J.D. (1971). Noise and performance. In *Effects of noise on people,* 118–21. NTID 300 7. Washington, DC: Environmental Protection Agency.

Moon, P. (1961). *The scientific basis of illuminating engineering.* New York: Dover.

Nakaseko, P. (1982). History of occupational cervicobrachial disorders in Japan. *Journal of Human Ergology 11,* 7–16.

Niemoeller, A.F. (1968). Acoustical design of classrooms for the deaf. *American Annals of the Deaf 113,* 1040–45.

NIOSH, (1991). *The occupational safety and health office of communication workers of America: a survey.* Washington, DC: NIOSH.

Norback, D., et al. (1990). Volatile organic compounds, respirable dust, and personal factors related to prevalence and incidence of sick-building syndrome in primary schools. *British Journal of Industrial Medicine 47,* 733–41.

Norman, Donald A. (1988). *The design of everyday things.* New York: Doubleday.

NRC (1987). *Work, aging, and vision: report of a conference.* Washington, DC: National Academy Press.

NSWI (1992, Jun. 15). *The healthy office report.* Chicago, IL: National Safe Workplace Institute.

Packard, R., ed. (1988). *Ramsey and Sleeper architectural graphic standards,* 8th ed., New York: Wiley.

Parsons, H.M. (1992). Human factors/ergonomics in office design and automation. *Proceedings: 1982 Meeting of the American Psychological Association.*

Partridge, R.C. & MacLean, D.L. (1935). Determination of the comfort zone for school children. *Journal Industrial Hygiene 17,* 66–71.

Patterson, A.H. & Passini, R. (1974). The evaluation of physical setting: to measure attitudes, behavior, or both? EDRA 5: Proceedings. Milwaukee, WI: University of Wisconsin.

Pearson, R. (1956). The development and evaluation of a checklist for measuring subjective fatigue, USAF No. 56-115. Randolf AFB, TX.

Pekkarinen, E. & Viluanen, V. (1990). Effect of sound-absorbing treatment in speech discrimination in rooms. *Audiology 29*, 219–27.

Pool, R. (1990, Sep. 21). Electromagnetic fields: the biological evidence. *Science 249*, 1378–81.

Porter, J.M., et al. (1992). An evaluation of a tilting computer desk. *In* E.J. Lovesey, ed. *Contemporary ergonomics.* London, U.K.: Taylor & Francis.

Potter, I.N. (1988). The sick building syndrome: symptoms, risk factors and practical design. BSRIA Technical Note 4/88.

Preiser, W. (1970). Behavioral design criteria in student housing. *In* H. Sanoff & S. Cohn, eds. *EDRA 1: Proceedings.* Raleigh, NC: North Carolina State University.

Proshansky, E., Ittleson, W. & Rivlin, L., eds. (1970). *Environmental psychology.: man and his physical setting.* New York: Holt, Rinehart & Winston.

Propst R. (1968). *The office: a facility based on change.* Zeeland, MI: Herman Miller.

Rea, M.S. (1991). Technics: solving the problem of VDT reflections. *Progressive Architecture 10.*

Ripple, P.H. (1952). Variation of accommodation in vertical directions of gaze. *American Journal of Ophthalmology 35*, 1630–34.;

Rosenthal, N.E. (1984). Seasonal affective disorder: a description of the syndrome and preliminary findings with light therapy. *Archives of General Psychiatry 42*, 72–80.

Ross, M. (1972). Classroom acoustics and speech intelligibility. *In* J. Katz, ed. *Handbook of clinical audiology*, 756–71. Baltimore, MD: Williams & Wilkins.

Ross, T.W. & Steward, G.K. (1993). Facility planning for technology implementation. *The Educational Facility Planner*, CEFPI, 31, No. 3, 9–12.

Sanders, M.S. & McCormick, E.J. (1987). *Human factors in engineering and design*, 6th ed., New York: McGraw-Hill.

Sauter, S. & Schlufir, L. (1991). Work posture, workstation design, and musculoskeletal discomfort in a VDT data entry task. *Human Factors 33* (2) 151–67.

Sommer, R. (1959). Studies in personal space. *Sociometry 22*, 247–60.

— (1965). Further studies of small group ecology. *Sociometry 28*, 337–48.

— (1967). Small group ecology. *Psychological Bulletin 67*, (2) 145–50.

— (1968). *The ecology of study areas.* University of California Cooperative Research Project No. 6-1121., U.S. Office of Education, Washington, DC.

— (1969). *Personal space: the behavioral basis of design.* Englewood Cliffs, NJ: Prentice Hall.

— (1974). *Tight spaces: hard architecture and how to humanize it.* Englewood Cliffs, NJ: Prentice Hall.

— (1970). Studies of small group ecology. *In* R.S. Cathcart & L.A. Samovar, eds. *Small group communication.* Dubuque, IA: Wm. C. Brown.

— & Becker, F.D. (1971, Dec. 2). Room density and user satisfaction. *Environment and Behavior* (4), 412–17.

Spencer, D.E. (1954). Comparative analysis of comfort and glare. *Illuminating Engineering 49*, 39–49.

Steinzor, B. (1950, Jul.). The spatial factor in face to face discussion groups. *Journal of Abnormal Social Psychology 45*, 552–55.

Tannenbaum, P.H. (1957). *In* C.E. Osgood, G.J. Sochi & P.H Tannenbaum. *The measurement of meaning.* Urbana, IL: University of Illinois Press.

Terlaga, K.L. (1990) *Training room solutions.* Howe Furniture.

Tessmer, M. (1994). Personal communication.

— & Harris, D. (1992). *Analyzing the instructional setting.* London, U.K.: Kogan Page.

Tichauer, E.R. (1978). *The biomechanical basis of ergonomics: anatomy applied to the design of workstations.* New York: Wiley.

Tuckerman, B.W. (1972). *Conducting educational research.* New York: Harcourt, Brace.

Utz, P. (1992, Oct.). Video projector ergonomics: the basics of screen and audience placement. *AV Video*, 70–88.

Van Cott, D. & Kinkade, R. (1972). *Human engineering guide to equipment design.* New York: McGraw-Hill.

Veitch, J.A. (1990). Office noise and illumination effects on reading comprehension. *Journal of Environmental Psychology 10*, 209–17.

deWall, M., et al. (1991). The effect on sitting posture of a desk with a 10° inclination for reading and writing. *Ergonomics 34* (5), 575–85.

Wadsworth, R. (1983). *Basics of audio visual systems design.* Indianapolis, IN: Sams.

Wedberg, W. (1987). Facial particle exposure in the VDU environment: the role of static electricity. *In* B. Knave & P.G. Wideback, eds. *Work with display units.* New York: Elsevier.

Weinstein, C. (1979). The physical environment of the school. *Review of Educational Research 49* (4), 577–610.

Woodson, W.E. (1987). *Human factors design handbook.* New York: McGraw-Hill.

— (1992). *Human factors design handbook: information and guidelines for the design of systems, facilities, equipment, and products for human use*, 2d ed. New York: McGraw-Hill.

— & D. Conover, (1973). *Human engineering guide for equipment designers.* Berkeley, CA: University of California Press.

Wools, R. (1970). The assessment of room friendliness. *Architectural Psychology: Proceedings of the Conference at Dalandhui.* University of Strathclyde, Glasgow, Scotland, 28 Feb.-2 Mar. 1969. London: Royal Institute of British Architects.

Wysotsky, M.Z. (1971). Wide-Screen Cinema and Stereophonic Sound. New York: Communication Arts Books.

Yerges, L. (1978). *Sound, noise and vibration control.* New York: Van Nostrand.

Zental, S.S. Color stimulation on performance and activity of hyperactive and non-hyperactive children. *Journal of Educational Psychology 78* (2), 159–65.

Zipp, P., et al. (1983). Keyboard design through physiological strain measurements. *Applied Ergonomics 14*, 117–22.

Zmirak, J.P. (1993). Workplace utopia. *Success 40* (2), 35–40.