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IN-CITIES PROGRAM DOCUMENT

NATIONAL BUREAU OF STANDARDS REPORT

VOLUME ONE

THE PERFORMANCE CONCEPT:

A STUDY OF ITS APPLICATION TO HOUSING

prepared by

The Institute for Applied Technology

for the

Department of Housing and Urban Development

NBS

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

REPORT NUMBER 9849

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D. C., 20234.

[2] Located at Boulder, Colorado, 80302.

[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT

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NBS REPORT

9849

THE PERFORMANCE CONCEPT

A Study of Its Application in Housing

VOLUME I

Prepared

by

THE INSTITUTE FOR APPLIED TECHNOLOGY

For the

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

WASHINGTON, D. C.

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

May 31, 1968

IN REPLY REFER TO:
421.00

Mr. Thomas F. Rogers
Director, Office of Urban
Technology and Research
Department of Housing and
Urban Development
1626 K Street, N. W.
Washington, D. C. 20410

Dear Tom:

In the next few pages of this report you will find a summary of what the National Bureau of Standards and its consultants have done as a result of our joint efforts with HUD in studying the availability of adequate performance standards for housing for low-income families. This summary reflects the central thrust of our response to the work statement which accompanied your memorandum of agreement, the conclusions we have reached, and our recommendations for further research. Some of the thinking presented in the main body of our report, the technical appendices and the supplementary documents is complex enough that it will require a more thorough reading than can be gained from the summary. I have attempted, therefore, to key the summary to other portions of these documents in order that you, and others who will read this report, can find your way into the larger body of the report.

Five xerox copies of the final report (Volume I) are transmitted herewith in compliance with the June 3, 1968 deadline. As per our agreement an additional 25 copies, reproduced by a more suitable means, will be furnished to you in approximately one week. The Appendices will be furnished shortly thereafter as Volume II, and will contain:

Appendix A. Needs of the Rural Poor in Low-Cost Housing
Appendix B. Housing of Indians on Reservations and of Alaskan Natives
Appendix C. Conceptual Structure of Low Cost/Low Income Housing
Appendix D. Nature of the Problem
Appendix E. Performance Concept and Building Code Implementation

A final volume (III) made up of supplementary documents from contractors will be transmitted prior to the June 30th termination date of our agreement. This volume will contain:

1. The American Housing Production System
2. Performance-Based Space Criteria for Low-Cost Housing
3. The Role of Social Needs of the Urban Poor in Formulating Performance Standards
4. A Pilot Study of the Economies of Scale Related to Residential Construction

We believe we have made a constructive beginning and that in some cases we are presenting reports and ideas not previously available. We appreciate the support of HUD in this important undertaking.

Sincerely yours,

John P. Eberhard
National Bureau of Standards

C. CONTENTS OF VOLUMES II AND III

The main body of this study of performance standards for low-income housing is contained in Volume I. However, two more volumes (Appendices and Supplementary Documents) complete this study. Their contents are as follows:

Volume II - Appendices

A. Needs of the Rural Poor in Low-cost Housing
B. Housing of Indians on Reservations and of Alaskan Natives
C. Conceptual Structure of Low Cost/Low Income Housing
D. Nature of the Problem
E. Performance Concept and Building Code Implementation

Volume III - Supplementary Documents

1. The American Housing Production System
2. Performance-Based Space Criteria for Low-Cost Housing
3. The Role of Social Needs of the Urban Poor in Formulating Performance Standards
4. A Pilot Study of the Economies of Scale Related to Residential Construction

AN EXECUTIVE SUMMARY

A. Background

Performance standards are not a substitute for sound judgment, but a guide and supplement to such judgment. They therefore require a context of reasonable and intelligent men, backed by institutional means which adapt to their use, for their efficacy. Performance standards can provide a basis for making sound decisions on research directed at new product development; they can be used in codified form to provide for public health, safety and other environmental requirements; and they can assure the nation that the quality of its future housing inventory is worthy of a great nation. But they provide no magic formula that will surely and of themselves unleash the innovative forces of society to solve the problems of housing for low-income families. They can provide a means of removing one of the major constraints identified by all with whom we spoke--narrowly drawn building codes, regulations or specifications. We have found insufficient evidence to warrant optimism in our ability to produce a comprehensive performance document for housing for low-income families. Those documents which have been prepared in the recent past based on the performance concept fall short of the mark, not because their writers were insincere, but because the sum of knowledge now available is not sufficient for the task.

The nation will continue to invest in new housing and in the rehabilitation of existing housing in ever greater numbers. This administration has promised to provide six million housing units for low-income families in the next decade. This enormous task is always publicly acknowledged as one of providing adequate housing--not just cheap housing. This commitment, therefore, implies an intention to measure the adequacy of such housing by standards of performance which do not sacrifice housing features necessary to the preservation of health, the provision of a safe environment and providing for the housing users' needs. There is also the need to assure ourselves that this investment is a prudent use of our resources, so that we invest no more in the cost of providing such housing than is commensurate with the benefits to be gained. This ratio of costs to benefits is an extremely complex one, which we explore in more detail in Section B.5 of this report. It is clear that in housing a penny saved is not always a penny earned, however it is not always clear where the trade-offs are best made.

We believe that it is also important that all concerned understand that the nature of the "problem" to which we address ourselves is capable of being understood at various levels of definition. In Section A of the report we develop our line of reasoning in some detail:

- The problem in its simplest form states that the goal is to reduce the costs of dwelling units (including their operating and maintenance costs) to bring them within the affordable range of low-income families.

- The next level of complexity says that the costs cannot be lowered sufficiently to bring them within the income range of poor families, so that some adjustment in the transaction mechanisms (like rent subsidy or low interest, long term loans) is required.

- We may then complicate the goal by desiring better housing generally (a quality concern) as measured by benefit returned per unit of investment. This deals with more clearly articulated user requirements which in turn concerns the material and manufacturing factors involved in housing.

- The goals would also be seen differently if it was clear that low-income families in fact have special needs that aren't normally considered in performance requirements for housing (for instance they might want to provide space for indigent relatives as well as the nuclear family)--mostly we lack the data to support these needs.

- Our goals become elevated if we say that even if we were able to find a fit between the needs of low-income families and the cost of housing we should not be satisfied with the system for producing housing in this country. Systems improvements in the production of housing could go beyond the immediate problems to providing an opportunity for more effective resource utilization or increased performance of the total urban environment for all of us--including low-income families.

- Finally we might want to be cautious about solving the problems of housing alone (a sub-optimization) if by doing so we were to cause dislocations in other urban systems. This has certainly been the case in our past attempts at solving urban traffic problems by plunging highways right through our housing inventory with little or no concern for the social impact of the decisions.

The work statement which accompanied the agreement between the Department of Housing and Urban Development (HUD) and the National Bureau of Standards (NBS) which initiated this study contained the following hypothesis:

> "It is hypothesized that, if adequate performance standards for low-cost housing could be developed; and if they were broadly used, an important and fundamental way could have been opened to accommodate the introduction of cost-reducing innovations into the design of low-cost housing."

We have found that this hypothesis is true on its face, but subject to careful evaluation in terms of its implications. In the main body of the report we deal with some of these implications and respond to the five specific objectives of our agreement. The summary which follows deals with each of these objectives in the order of their appearance in the agreement. The reader will find a fuller discussion of them in the main body of the report. The response to these five objectives has been handled within the dictates of the scope of the work as prescribed in the agreement--namely:

> 'Within the constraints of available time and funding, and with recognition that the goal of this agreement is one of assessment and definition of needed future research to test the hypothesis that emphasizes low-cost housing, the broadest professional view should be adopted. The major emphasis will be on scientific knowledge and technology availability and the resultant effect of their application on cost reduction; however, administrative, social financial, legal, employment, transportation, production, and human factors will be identified to the extent that they appear to apply in an important way to the goal of using performance standards to reduce the cost of housing for low-income families."

B. Response to Objectives of Study

B-1. "To document in very brief narrative form a description and definition of the performance concept and the hierarchy of performance statements as related to low-cost housing and the social needs of low-income families, using examples and references."

The performance concept is an organized procedure or framework within which it is possible to state the desired attributes of a material, component or system in order to fulfill the requirements of the intended user without regard to the specific means to be employed in achieving the results. In this report we are concerned with the performance concept as it relates to the housing needs of low-income families that live in urban areas. We refer in Appendix A (Volume II) to a brief review of the needs of low-income families in rural areas (a potentially larger need, but not as politically visible or organized) and in Appendix B (Volume II) to the needs of low-income families who live on Indian reservations.

The performance considerations with which we deal flow from two directions of emphasis:

- The performance of housing components, equipment and systems in terms of those properties which affect their safety durability, operating efficiency, maintainability and quality.

- The performance expected of housing in order to respond to the reasonably intended use of the housing units by families to carry out such activities as eating, sleeping, playing, entertaining, etc.

These two directions are not mutually exclusive, but in fact are interdependent. They have not historically received equal attention by the research community nor have their interdependencies been well established in practice. We attempt in Section B.2 to trace their relationships.

The performance concept consists of a hierarchical set of statements which are more or less sequentially developed and which normally become more rigorous at each stage of their development. These statements, in order of their development are:

Performance requirements
Performance criteria
Evaluative techniques
Performance specifications
Performance standards
Performance codes

Each of these terms is defined more fully in the main body of the report and an example is given of the application of this hierarchy to the area of waste disposal needs of families. The dominant current technological solution in this area is plumbing and Section B.3 contains a detailed analysis of the current availability of performance statements for plumbing systems.

We also want to emphasize the value of the performance concept to another important intellectual tool--the systems approach. The systems approach depends on a statement of objectives in performance language in order that alternative solutions can be rationally compared. The systems approach enables us then to trace out the effects of any set of choices and decisions. The use of the performance concept for such systems studies as those envisioned under the HUD (RFP 22-68) _'In-City' Experimental Housing Research and Development Program_ is of obvious utility.

B-2. "To delineate the important performance requirements that relate to such goals as health, safety, and low costs for the dwelling and the site and off-site improvements."

It is important to recognize that this objective refers to performance requirements, not specifications or standards. At the fundamental level such requirements are derived from the characteristics of users which housing can effect such as:

Physiological needs--the life processes
Psychological needs--the mental processes
Sociological needs--the interactions between people and groups and the effects of commonly held beliefs.

Needs are not dependent on particular materials, devices or systems, it is the other way around. Housing components are developed in response to the needs of the user. Once such components for a house have been developed in response to needs we also require that they serve us well over time. We are therefore concerned with the structural soundness of housing components, their durability to withstand wear and weather, and their ability to continue to operate with a minimum of maintenance.

Since the housing users needs become the guiding force to requirements, we need first to examine the range of potential users. We find four characteristics useful in defining the USER:

1. RESOURCES: income, level of ownership
2. CULTURE: Spanish, Negro, Asian, Indian, etc.
3. LOCATION: urban, rural, etc.
4. UNIT SIZE: individuals, couples, families, communities.

For the development of the total range of performance requirements for housing, it is acknowledged that for each function and activity, requirements must be described for each user. We have attempted to illustrate only one function FOOD PREPARATION and the physiological needs associated with it for families. The full range of functions would include entertaining, playing, studying, sleeping, etc. These functions in turn would have requirements developed from the needs of the various kinds of users. The needs of the low-income urban poor have not been studied sufficiently to identify potentially unique requirements. What evidence there is would suggest that their rising expectations would cause them to resent any statement of their unique requirements as being less than middle-income families.

In order for houses to reasonably accommodate such activities as sleeping and food preparation the interior environment of the house needs:

conditioned air, adequate illumination, controlled acoustical properties, stability and strength, protection against dangers to health or safety, adequate space to allow activity to occur (in three dimensions), an orderly arrangement of such spaces, an acceptable esthetic content, and a capability of being reasonably maintained.

These interior spaces need to be enclosed within a shell which:

. provides adequate protection against climatic conditions, and reasonable protection against unusual but possible catastrophes such as hail, earthquakes, fires in adjacent buildings, baseballs, etc.

. provides visual access from the interior spaces to the exterior in reasonable amounts

. provides acoustical privacy from adjacent dwelling units

. is esthetically acceptable

. has surface properties which are capable of easy maintenance over the life of the building

B-3. "To determine what performance specifications are satisfactorily in hand to meet the performance requirements identified in Item B.2."

The largest part of our effort has been devoted to this objective. We have used consultants in some areas, we have studied existing "performance type" codes and specifications, we have looked at the FHA Minimum Property Standards, and we have looked at what is being done in other countries. Our general conclusion is that we are a long way from having adequate performance specifications. The obvious needs of individuals and families that live in houses have not been explicitly stated or systematically identified. The art of planning houses for meeting humans' physiological, psychological and sociological needs is largely one of intuition and perpetuation of existing solution patterns which have apparently been satisfactory. This apparent satisfaction has resulted in a lack of motivation to support research which made these needs more explicit (hence the so-called social sciences are not very well equipped to provide measurement techniques) and has tended to concentrate measurement techniques and specifications on the physical properties of housing elements. This concentration on physical properties has been further narrowed by competitive interests in the producer sector of the industry in order to protect the market position of particular materials and products. A heavy orientation toward assuring the financial community that houses were a sound investment has further concentrated specifications and codes on the performance of the house as a product to be preserved against the forces of nature and the deterioration from use by humans.

One illustration of this disparity exists in the provision of fire safety codes for houses. The emphasis in such documents is in the specification of the fire resistance of the materials and components rather than provision of safety for the occupants. They are not independent variables, but one's view of the need for performance standards will cause a bias in one direction or the other. Under recent legislation the National Bureau of Standards is authorized to mount a major national fire research program. We do not anticipate financial support from HUD at this time in this program area.

Another example is in the area of the visual environment (or illumination). Our consultant, Mr. William Lam, reports:

> "None of the nineteen existing industry or national standards, Federal or other published specifications, or foreign standards, that were examined have any useful performance tests for existing natural or artificial lighting systems pertinent to recommendations for use in low-cost housing.
>
> Among building codes in the U.S., those that have daylight requirements (some do not) express them in terms of window area, rather than performance with regard to view or light. The objectives of the requirements are not described. For artificial lighting the range is from no requirements at all to describing what rooms should have lighting; a few list quantity requirements. None of these provide useful guidance as to the purpose and qualitative aspects of the requirements."

The state-of-the-art of specifications and standards in the structural field after some three thousand years of building technology is in relatively good shape, as would be expected. However, the documents used in this area are filled with specifications that describe specific design parameters for known structural systems and materials (like steel beams) rather than performance statements of what is expected. The performance requirements which exist are often outdated (the loads imposed on apartment floors by furniture and people are probably overstated in terms of today's styles, for example) and sometimes based on rules of thumb which have not be scientifically examined. The National Swedish Institute for Building Research, as an example, reports:

> "According to Swedish building norms (standards) the snow load on roofs with an incline of 45° is half as great as the load on flat roofs. Recordings made by the Institute for Building Research during two winters just past show that the situation is more or less the opposite."
>
> (performance requirements were 100% in error because they were based on a rule of thumb, rather than scientific investigation.)

When new structural concepts are introduced (such as the Mitchell system proposed for the Phoenix Project in Detroit) existing measurement techniques are inadequate to recognize the performance potential. New innovations can thus be stifled even in an area which has a long history of research. We propose as one method of helping to ease the transition to performance specifications during the next few years, that ad hoc test development programs to measure the performance of specific innovations be implemented, just as we have done on the Phoenix project.

There are some areas of performance requirements related to safety that are essentially ignored by existing codes, probably because they are not related directly to any specific product attribute. One of these areas is the provision of protection against accidental falls. Falls constitute the single greatest life hazard in the home, causing about 40 percent of the fatalities, and also contributing about a third of the accidental injuries. The annual toll of casualties resulting from all home accidents is 28 to 30 thousand fatalities and 4 to 21 million serious injuries (depending on definition). Congress has seen fit to require safety requirements of automobile manufacturers, but in the area of housing there is no single industry on whom to place the responsibility. It would appear, therefore, that the performance of the house as a total system designed to help prevent accidents is a governmental concern. We recommend the development of a better accident data base through HEW and the development of performance standards in this area by HUD as a model for state and local governments.

Durability is the time dimension of performance. It describes the ability of a material, component or system to resist deterioration and destruction for a "normal" period of time, with "normal" usage. The key measurement parameter is a definition of "normal." Because of the competitive nature of the industry a large amount of information is available on the requirements for materials and products on an individual basis. In spite of this wealth of information, few, if any, test methods or specifications exist that will predict accurately, at the time of construction, the useful life or rate of deterioration of building materials.

One special provision of durability is the controlled transmission of air, moisture and water through the exterior of the building including the components such as doors and windows.

The provision of a controlled acoustical environment may be thought to be a luxury and therefore not appropriate for low-cost housing. This is one of our areas of sociological and psychological ignorance, however, since we have no evidence of the impact on families and individuals of poor acoustics in housing. We do know that poor acoustical control has been a factor in the turn-over of apartments designed to be rented to families whose income gives them some discretion. There is also evidence that a suitably comfortable acoustical environment can be obtained at little, or no, additional construction cost if acoustical performance is incorporated initially as part of the total housing performance concept.

The presence of clean air and the absence of odors in a building are dependent, among other things, on the equipment available, the size of the building, the occupancy, and the ventilation. The problem is therefore complex. Presently available air-cleaning equipment includes mechanical types, composed of air filter devices, and electrostatic types. Odor removal devices are presently limited to adsorption devices such as activated charcoal panels. The performance of this equipment is reasonably well understood, and it is probable that the same equipment, or variations of the same will be used for the next 25 years. A new approach should be taken that emphasizes air cleanliness in the occupied space and its effect on health (bronchial ailments) and cost of maintenance caused by soiling. The inter-relationship between the size of the building, the number of occupants and the ventilation is not so well understood, however, and a careful appraisal of the performance requirements and necessary research in this direction is needed. We include work in this area under our program for psycho-physical measurement. The ability to measure the thermal response of buildings to exterior climatic variations is reasonably well established. There are major systems trade-offs however between first cost and operating costs of buildings that are not adequately covered by existing specifications. If a building provides good thermal insulation for the interior against differing outside temperatures, the size, the initial costs and operating expenses of heating or cooling systems can be considerably reduced, and the satisfaction of the user needs may be accomplished more effectively at lower long-term cost. We include this area in our psycho-physical program.

The standards and codes currently available for plumbing systems, components and fixtures are largely specification-type. Even those aspects which are performance related are useful only for comparing similar products like bathtubs or pipes independent of their materials. We lack any body of knowledge that would enable us to evaluate completely new concepts of providing for human cleansing and waste disposal functions. Because plumbing is such a major portion of the cost of present high-rise dwelling units (estimated to be about 18 percent of the cost), and because the field is presently very competitive due to an attempt to market components made of plastics, we recommend an effort be undertaken to develop performance criteria and evaluative techniques for plumbing systems which are independent of the materials used.

The performance requirements for individual food service facilities such as cooking facilities, food preparation surfaces, storage of utensils, food storage, etc., are considered under a sub-section of the report entitled Food Services. These requirements relate directly to the more general user needs identified under the example of physiological requirements--food preparation of Section B-2. Our study indicates that practically no realistic performance requirements for these necessary facilities exist, with the exception of limited information on preferred space arrangements.

We have a natural tendency to think of sources of energy like gas, oil, electricity, solar energy, etc., as equal alternatives to be evaluated exclusively on the basis of costs. The costs per unit of energy however are meaningless unless we properly measure the performance of conversion devices utilized to convert the energy into useful purposes for peoples' needs. In addition questions of safety, controllability, cleanliness, etc., are requirements to be satisfied. Only a few specifications currently in hand relate directly to the energy source or form. Research is needed to help establish optimum usage based on total energy needs of multi-story buildings like apartments.

Because electricity is the most widely used source of energy in housing, and because it represents a complex sub-system of the house we made a special study of performance specifications in this field. The National Electrical Code provides an almost universally adopted instrument which helps by providing the benefits of mass production through interchangeable standardized parts, but which inhibits major new innovations which would not be compatible with its standards. The increased use of electricity and the proliferation of electrically-powered equipment in the home pose new questions regarding diversity of loads within buildings and among buildings, as well as a reexamination of the most effective system for convenience outlets and other distribution components.

Mechanical systems are, per se, solutions for user needs, but the performance requirements usually described for such systems do not, in fact, relate directly to the primary user need but instead relate directly to some selected solution. For example the requirement that a heating system have a capacity of x BTU per hour, is a specification based on some previous determination that x BTU per hour is needed to provide a "comfortable" environment for the occupant. We can measure the BTU capacity accurately, but we are not very good at measuring "comfort." This is an example of the tendency to measure what it is possible to measure when it is too difficult to measure what is desired. Performance standards should be developed which would enable us to relate mechanical systems performance directly to user satisfactions. Work in this field, however, can be accelerated greatly by the further development of criteria of human comfort.

Building transportation systems permit the movement of people and objects into and within buildings. They are of two basic types:

a. systems which are static but permit the movement of people and objects along them (entrances, halls and stairs).

b. systems which are dynamic and thus transport people and objects (elevators, escalators). These systems can represent 15 to 20 percent of the cost of a high-rise building.

Performance requirements for such systems like their ability to evacuate occupants in emergencies, their size in order to provide for normally used objects (like refrigerators), their adaptation to handicapped and elderly people, their protection against vandalism, etc., appear to be conspicuous by their absense in existing codes and standards. Research on user needs might well reveal ways to modify the performance of such systems, and would certainly be needed for evaluating new innovations related to vertical transportation in tall buildings.

This section of the report contains almost two hundred pages of useful information to other organizations who might be exploring the current availability of performance based specifications and standards. It is suggested for example that HUD might wish to make it immediately available to the firms who are working with them in various experimental housing programs. We also believe much of the information could be used to convert sections of the FHA MPS document to performance language.

B-4. "To estimate the costs and time to develop those performance specifications that do not now exist in order to meet the spectrum of performance requirements identified in Item B.2."

It should be clear to the reader by this time that the vacuum in this field is so enormous that this objective is like asking in 1958 how much will it take to get a man to the moon. Estimates were made then which subsequently turned out to be orders of magnitude off. In many ways the problem of getting a man to the moon was easier to estimate, because there were few sociological or institutional constraints. We believe the cost will be closer to multi-hundred million dollars than it will be to multi-millions if we are to develop all of the fundamental information which will eventually be needed to relate man's needs to his built environment. Whole new sciences, new kinds of research personnel who practice within the science, and new institutions to utilize their talents will be required. The National Bureau of Standards is not the only institution to which HUD will have to turn for this major effort. We would recommend that NBS be asked to manage and coordinate all research in this area.

What we are proposing is an approach to this area which provides HUD with a series of phased steps that will move us in the right direction. We have suggested some specific research programs to be undertaken in the next six months, and some indication of how they fit into a longer term phased program. We believe a phased program offers the opportunity for a rational approach in the absence of sufficient time or sufficient funds to make a more detailed analysis. We also believe a phased program will provide us with a broader base of intelligence with regard to the utility of longer term research programs and will be more adaptable to changing policies at the national level regarding the goals of HUD's programs.

We are recommending a total research effort of $1,425,000 in this area for fiscal year 1969. Some of this work would be contracted out to other organizations, but all of it would be managed by NBS in HUD's behalf. The nine programs we are recommending develop from four different kinds of emphasis:

-Our programs on Psycho-physical Criteria and A Framework For User Needs are designed to open areas of exploration which are now limited by usable concepts and only a few professional workers. Psycho-physical studies relate man to his surroundings inside a building by his senses of vision, hearing, smell and touch through such physical effects as vibration, temperature, noise, humidity, and air motion. The program on users needs will expand in the preliminary work of Section B.2:3 and 4 of this report to develop a full framework for identifying those "satisfactions" the user needs from housing.

-Our programs on Structural Design Requirements, Performance Specifications for Plumbing Systems, and Safety Requirements for Housing are designed to fill in the gaps in knowledge and test methods in these three important areas of housing systems performance. Our discussion with the professional community have identified these three areas as ones of high priority.

-Our programs in a Continuing Service for Evaluating Housing Innovations and Performance Specifications from Existing Information are both designed to produce immediate results and to translate them into acceptable forms for the current programs of HUD. The work which we have done with HUD on project Phoenix serves as a model.

-Our recommended development of a Technical Information Network is intended to provide a special tool for the research community who address themselves to the development of the performance concept for buildings. This is a more limited service than the larger program HUD is planning for those working in the "urban" area. It is proposed that this be a joint effort by all Federal Agencies supporting research in building performance concepts.

B-5. "To rank order those performance standards to be developed in terms of their impact upon construction."

We understand the intent of this objective, but we wish to point out that the rank-ordering techniques used by both HUD and NBS perhaps should not be limited to this statement. We suggest in this section that there are at least five primary techniques:

1. Ranked in order of IMPORTANCE TO SOCIETY
2. Ranked in order of MAXIMUM COST-REDUCTION OPPORTUNITY
3. Ranked in order of MAXIMUM INCREASED BENEFITS TO USERS (low-income urban consumers)
4. Ranked in order of SOCIO-POLITICAL VISIBILITY
5. Ranked in order of SMOOTHNESS OF TRANSITION (from one system of procuring residential environment to another)

and that each of the techniques is in turn capable of being evaluated against the costs of doing and applying the research; the feasibility of doing the research, finding the personnel needed, and applying the results; and the time required to complete the research and apply it. It would be desirable for any rank-ordering technique we used to reflect all of these considerations. However, the problems and limitations associated with each possible technique limit us at the present to a decision of priorities based on professional judgment and the available capabilities of research institutions.

We include in this section of our report a discussion of techniques for measuring the costs and benefits of using the performance concept, but we have not been able to quantify this analysis. The logic of our discussion may be summarized as follows:

- The specification of the performance expected of an object (like a door or a bathtub) allows the procurement potential of a larger number of alternatives than specifying a particular object. This opens the possibility of receiving a solution which is more efficient or lower in cost.

- If this kind of performance statement is linked to a systems approach some evaluation of the overall efficiency of the object as a part of a larger context can be made. Larger benefits may accrue thereby, since systems costs are known not just object costs. An additional benefit may come because the performance specification suggests new ideas and concepts that would have been overlooked, e.g., the trade off between exit requirements and fire detection equipment.

- If performance specifications are developed for functional spaces like bedrooms (as is done in FHA Minimum Property Standards) a larger number of alternatives can be evaluated, but the limitation is still the accepted pattern of houses, so that it is most desirable (will produce the most benefits for the least cost), but also most difficult, to specify the users needs independent of any form of solution.

- If benefits and costs associated with rank-ordering objectives were clear it would be possible to evaluate alternative sets of performance specifications, even before evaluating the products which result from their use.

- Perhaps most democratic of all, and hence most beneficial, would be a mechanism for choosing goals that allowed users to make their own needs statements and evaluate alternatives for themselves. Some of the attempts now going on at advocacy planning are testing this possiblity.

- Because we have not yet learned to "model" in appropriately complex terms (simplicity is not a virtue here) the relationships between man and his environment, we are not yet in a position to measure the true costs to individuals or societies of our alternatives nor to indicate in a positive way the benefits which would derive from our investments.

We hope that the Urban Institute will devote a major share of its resources to this.

A. BACKGROUND OF THE STUDY

A.1. THE NATURE OF THE REQUEST

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
Washington, D. C. 20410

Office of the Assistant Secretary
For Administration

In Reply Refer To:
ASA-1
No. IAA-H-14-68

February 23, 1968
(as revised April 4, 1968)

U. S. Department of Commerce
National Bureau of Standards
Institute of Applied Technology
Washington, D. C. 20234

Attention: Mr. John P. Eberhard

Gentlemen:

Subject : Memorandum of Agreement IAA-H-14-68
"Study of Improved Performance
Standards for Low-Cost Housing"

In accordance with discussions and understandings of our respective staffs, this Memorandum of Agreement, including Attachment A, Statement of Work and Special Conditions, provides for the participation of the Department of Housing and Urban Development (HUD) with the National Bureau of Standards, Institute of Applied Technology (NBS-IAT), in the subject project to be conducted by NBS-IAT in accordance with more specific agreements between the Technical Representatives designated under Clause II, Attachment A.

It is estimated that the total cost of the project to NBS-IAT and to HUD will not exceed $170,000. The fiscal obligation of HUD for all work performed under this Memorandum of Agreement shall be limited to $120,000. The NBS-IAT shall provide $50,000 in support of this project.

The NBS-IAT will inform HUD if and when the total cost of the project approaches the total estimated cost of $170,000; in such event HUD will have the choice of having the work hereunder cease on behalf of HUD, or of amending this Memorandum of Agreement to increase the HUD maximum obligation of $120,000 to participate with NBS-IAT in payment for continued performance of the work.

NBS-IAT will bill HUD for advance of funds on Standard Form 1080 in the amount of $120,000, citing agreement IAA-H-14-68 appropriation 86x4070.

The work to be performed for HUD is in furtherance of technical studies under 12 U. S. C. 1701 et. seq., and section 502(1)(2) of the Housing Act of 1948, as amended (12 U. S. C. 1701c(b)(2)), and is payable out of appropriation available to the Federal Housing Administration under P.L. 90-121.

If you accept this Memorandum of Agreement please indicate your acceptance below and on two copies enclosed, and return to the Department of Housing and Urban Development, Contracts and Agreements Division, 1626 K Street, N. W., Washington, D. C. 20410. For accounting purposes, please cite Memorandum of Agreement No. IAA-H-14-68.

Sincerely yours,

W. J. Prime, Director
Contracts and Agreements Division
(Contracting Officer)

Enclosure

Attachment A to
IAA-H-14-68

I. STATEMENT OF WORK AND SPECIAL CONDITIONS

A. BACKGROUND: It is now reasonably clear that the nation is about to undertake the enormous task of providing adequate housing, at a relatively early moment, for those millions of families who are now poorly housed. This implies a truly enormous Federal expenditure. It is of great importance, therefore, that without sacrificing housing features necessary to health, safety and other important social goals, this housing must be produced at the lowest possible cost.

It is hypothesized that, if adequate performance standards for low-cost housing could be developed, and if they were broadly used, an important and fundamental way would have been opened to accommodate the introduction of cost-reducing innovations into the design of low-cost housing.

Effective application of performance standards for low-cost housing will occur, however, only if (a) the standards are practical, (b) they reduce design and construction costs, (c) they provide an expeditious, practical and impartial basis for determining the relative acceptability of innovative designs, (d) they provide adequate health and safety protection, and (e) they assist in meeting the important social needs of low-income families.

B. OBJECTIVE: The objective of this study is to examine, in an organized and comprehensive way, the adequacy of presently available performance standards, to estimate the time and cost of developing the additional standards required, and to rank order those that need to be developed in terms of their impact upon construction costs of low-cost housing.

Specifically this agreement will seek:

1. To document in very brief narrative form a description and definition of the performance concept and the hierarchy of performance statements as related to low-cost housing and the social needs of low-income families, using examples and references.

2. To delineate the important performance requirements that relate to such goals as health, safety, and low-costs for the dwelling and the site and off-site improvements.

3. To determine what performance specifications are satisfactorily in hand to meet the performance requirements identified in Item B.2.

4. To estimate the costs and time to develop those performance specifications that do not now exist in order to meet the spectrum of performance requirements identified in Item B.2.

5. To rank order those performance standards to be developed in terms of their impact upon construction.

C. SCOPE: Within the constraints of available time and funding, and with recognition that the goal of this agreement is one of assessment and definition of needed future research to test the hypothesis that emphasizes low-cost housing, the broadest professional view should be adopted. The major emphasis will be on scientific knowledge and technology availability and the resultant effect of their application on cost reduction; however, administrative, social financial, legal, employment, transportation, production, and human factors will be identified to the extent that they appear to apply in an important way to the goal of using performance standards to reduce the cost of housing for low-income families.

In the study, emphasis will be placed on identifying potential cost-saving features that show promise of being implemented, in a practical way in the next year or two on the basis of performance, by taking an integrated systems view for supplying low-cost housing for low-income consumer groups including site and off-site improvements.

The five specific items to be sought in this study are given in the Objective, and they will be emphasized. They may be reordered or modified as the study progresses by arrangement between HUD, and the Institute for Applied Technology of the National Bureau of Standards of the Department of Commerce.

The professional workers conducting this study are expected to draw upon not only the full experience of both Departments, but relevant experience in other Federal Departments and Agencies, the nation's universities, and in the housing construction industry as well. The broadest national base of data, information, experience and judgment will be sought from within and without the Government.

D. REPORTING REQUIREMENTS: The first phase of the project will begin on February 1, 1968, and a first draft of a final report will be submitted by May 1, 1968, with a final report to be submitted on June 3, 1968. Progress review meetings will be held on or about March 1, April 1, May 1 and June 1, 1968, final review of the results will be held soon after June 3, 1968.

E. EFFORT: The effort shall include at least seven full time staff members of the Institute of Applied Technology, and such other NBS staff, outside consultants, and subcontracting assistance as needed.

II. PERIOD OF AGREEMENT

All work hereunder will be completed by June 30, 1968.

III. TECHNICAL REPRESENTATIVES

A. The Technical Representative for liaison with the Bureau as to the conduct of work hereunder shall be designated by letter; at a later date, from the HUD Contracting Officer.

B. The Project Director for the National Bureau of Standards, Institute of Applied Technology shall be Mr. John Eberhard.

IV. PUBLICATION

The Department of Housing and Urban Development will make the results of the study conducted under this agreement available to the public by means of joint releases as mutually agreed upon. Any other Bureau publication of the results of the study conducted under this agreement shall carry the notation "Data from a special study jointly financed by the Department of Housing and Urban Development, and the National Bureau of Standards, Institute of Applied Technology."

The Department of Housing and Urban Development shall have the full right to publish and disseminate all or part of the data collected hereunder after initial joint release. If the National Bureau of Standards, Institute of Applied Technology in its transmission of reports to the Department qualifies identified data, the Department in any publication it may make of the identified data will include such NBS-IAT qualification or will agree with NBS-IAT on a substitute statement qualifying the identified data.

A.2 THE NATURE OF THE PROBLEM

In order to know whether or not the development of performance statements are capable of helping to solve the "problem" of low-cost housing, we need to be clear on what we mean by the "problem." Problem solving efforts generally suffer from an inaccurate, unclear, or overly simplistic view of the problem itself. Therefore, the nature of the "Problem" should be a key element for discussion.

Since housing itself occurs within the context of complex relationships, it should be no surprise that the system for providing it is also a complex and complicated one, and that some clear and reasonably simple views of the problem may, in fact, be misleading.

We feel that it is possible to lay out the complex relationships within the housing system and to work fruitfully at resolving various system dis-functions. Presented on the following pages is a description of linked (not alternative) problem statements and our beliefs about how understanding these statements can help structure our longer term efforts with the Department of Housing and Urban Development.

STUDY PROCEDURE:

In developing these problem statements, we established certain Operating Rules to help us focus on central issues (rather than ancillary ones) and to ensure a certain level of clarity and rigor to the process of development. These are:

SIX OPERATING RULES FOR RESEARCH STUDY

Rule 1. The various aspects of the "housing problem" should be fully stated prior to selecting specific research directions. Problem definition should not be artificially limited by current administrative limits of responsibility, though it will be useful at a later stage to select specific research projects which do reflect such divisions of responsibility.

Rule 2. In a problem context where so much is unknown, we feel it is a valid technique simply to identify fundamental questions which need to be answered: whether or not such answers are known to be presently available.

Rule 3. There are three distinct categories into which issues can fall:

- technical - whether some course of action is possible
- operational - whether it is practical and feasable
- "political" - whether it is acceptable from the point-of-view of policy

We will examine these three categories on their own merits and not, for example, limit in advance a technical discussion by a presently existing operational constraint.

Rule 4. The controlling purpose of study and research efforts will be firmly to qualify or dis-qualify various possible responses to the problems and issues that are identified. Accordingly it will be perfectly acceptable to arrive at "not possible" or "no fit" answers provided that such answers are well documented.

Rule 5. (a) At certain points some form of technical "solution" may be made mandatory to prove the incompatibility between a specific technical resolution and realistic, "real-world" action. These cases will be indicated by "re-cycle" loops within the program. (b) We wish to resolve the various issues that are identified. Therefore, solutions at the operational and political levels are equally as desirable as technical level solutions. We shall proceed as conventionally as possible in order to resolve the issues. Faced with an impasse we will proceed from the least objectionable concepts towards the least acceptable, making only the minimum changes necessary to meet solution criteria.

Rule 6. In this program maximum use will be made of available information and research. Additional research should be generated (a) only when needed answers are not otherwise obtainable and (b) only in relation to the overall structure produced in response to Rule 1.

These principles should guide not only the initial generation of the problem model, but the way it is used operationally, i.e., in the process of specifying and carrying out needed research. This use will become increasingly apparent as specific research tasks are developed.

In view of Rule No. 1 all possible points of view have been called out first before any particular direction is fixed. This leads to "structural" comparisons. We have described four of these:

1. Starting with the fact that there is a gap between what housing costs and what some people can afford to pay for it, one can either (1) seek to lower the cost of housing or (2) improve the consumer's capacity to pay for it. Although the specific research activity may be quite different (and may involve entirely different types of research teams) the basic objective is the same in both cases: to improve the consumer's position relative to the cost of the housing he needs.

2. In another approach it is possible to deal either (1) with the house as a physical "thing" (2) with the factors or processes which produce the "thing." If (1) is the PRODUCT then (2) is the production PROCESS which "makes" the product, but conceived more broadly than merely manufacturing or construction processes.

3. A third contrast involves the basic premises of alternative housing studies. The housing problem can be approached either (1) by looking at the house as a physical thing, as an agglomeration of building materials which is part of larger community systems that are also physical in nature or (2) by looking first at people who, as residents have a series of needs, some of which are met in the home, others of which are met elsewhere. In the one case success is measured by the efficiency with which physical materials are combined with one another, in the other, by the efficiency by which the total needs of residents are met. (Since this third pair of contrasts raises such intricate issues, it is useful here to point out that no value judgements about

actual research are being made by this listing. This is simply an attempt to get the range of considerations before us. A rational selection process can come only after this groundwork has been laid.)

4. Finally there is the basic contrast between (1) a specifically problem-oriented approach to housing and (2) the commitment to working out positive performance of the housing system on a continuing basis. The first is essentially limited in time, associated with particular dis-functions, and is designed to go out of existence with the resolution of the particular problems at issue. The second is certainly involved with various current problems but within the context of future-oriented "preventive maintenance" for the housing system.

These four sets of contrasts are not mutually exclusive. They have inter-relationships.

SIX ASPECTS OF PROBLEM MODEL

By applying the six "Operating Rules" to the structure of contrasting issues we can generate a workable and practicable problem model. In order, this model would contain the six aspects shown in Figure 0.

To convert this basic problem definition model into a structure that is directly useful for research involves careful study and decisions. Rarely before has there been an opportunity to give this link in the problem-solving process the attention it deserves. We felt it was extremely important to do exactly this.

Accordingly the problem model was followed into its next several levels of detail.

A. PHYSICAL APPROACH

LOWEST COST HOUSING is really the physical approach to the problem of housing. It states, in effect, that for some people there is a gap between the resources they have and the cost of the housing they need. The response to this situation is to attack the "house" side of the problem.

Various kinds of research have been done on the problem of housing costs. Some research is actually re-examining the basic relationships in housing that have gained traditional acceptance, while there is a body of research along

Definition of what type of housing has the lowest absolute costs

Identification of how housing can be afforded by those who need it

Identification of what technical methods it is possible to use in order to obtain generally better housing per unit of investment

Definition of the characteristics of housing for low income people

Identification of what procedures can be used actually to provide the kind of housing that is needed to those who need it

Given the fact that housing is only one among many inter-related parts of the fully functioning community, identification of what requirements this interdependence may exert on housing per se

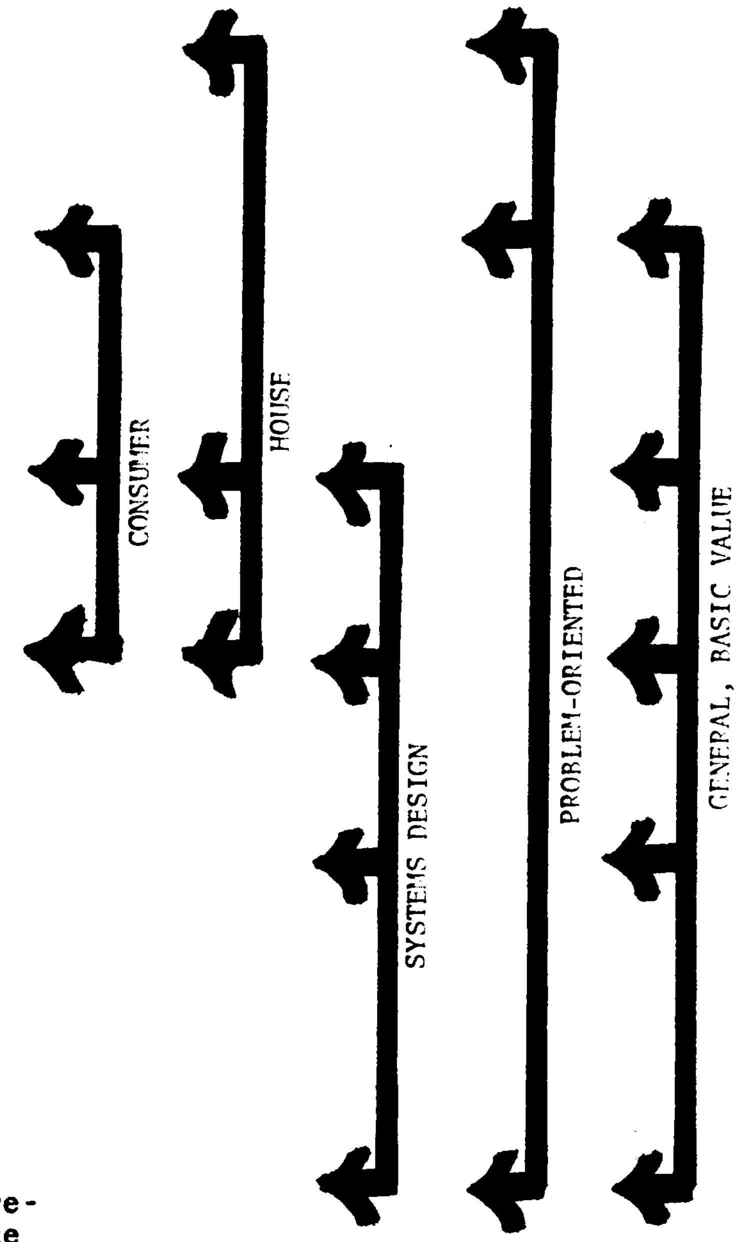


FIGURE a. SIMILAR CONTRASTING ELEMENTS IN SIX ASPECTS OF PROBLEM MODEL close-to-conventional lines that attempts to rid the house of superfluous and unnecessary costs through more complete knowledge of actual engineering requirements. The physical approach asks to what extent output from this research can help resolve the problem now identified.

B. ECONOMIC/FINANCIAL APPROACH

An effort directed to enable people to afford the housing they need is, in effect, an economic or financial approach to the same problem. Cost-effective research on the physical aspects of housing may not be able to produce savings sufficient to remove the gap between consumer resources and housing costs. In fact, one housing economist has made the point that even if the costs of the physical house itself could be reduced to zero, the overall reduction in cost to the consumer would still not be enough to make housing truly affordable.

It would be a liability, then, for a realistic effort at solving the housing problem to rely solely on identifying physical cost savings. There are a number of different strategies that could be investigated in order to solve the problem from the consumer's point of view. It is useful to identify the possibilities even if some of them, for one reason or another, do not fall within the mandate of the present problem-solving effort.

C. PERFORMANCE DESIGN APPROACH

A concern with achieving better housing generally (measured by the benefit returned per unit of investment) is a concern that goes beyond particular problem areas. The performance design approach deals with all the user, material, and manufacturing factors that are involved in housing. Using this approach, various competing constraints and benefits can be measured not simply against one another but against a standard for overall performance and service in meeting the valid needs of housing consumers.

Even though the terms are often used interchangeably "housing for low income people" may be quite a different thing from "low cost housing." There are several factors that make it relevant to raise this question. Two of these are immediately obvious; the first is that the needs of low-income groups are so different (for whatever reasons) that to approach the problem of getting them low cost housing in the conventional sense will not at all solve their housing problem. The second possibility is that conventional measures of "lowest cost" are not very well related to the problem of housing cost that various low income groups have. It is conceivable, certainly, that the cost of housing should not be measured by physical costs alone. It is also conceivable that it is not possible to measure the true cost of housing at the point of "consumption" alone. If there is a single strong point that stands out from systems analysis techniques it is that the most significant indicators of system performance and cost are overall measures (assuming all components perform at or above threshold levels of value satisfaction). But to take measures of component performance as proxies for the service of the larger system is clearly misleading.

D. SOCIAL APPROACH

The challenge to define "housing for low income people," then, is basically a social approach to the problem of housing. But it is a social approach that is based in the rational accounting procedure of performance design. This elevates what has become a more-or-less popular concern with the social role of housing to an entirely different plane of discussion. At this level competing and conflicting social values can be compared and resolved on the basis of their actual influence on a total concept of performance.

E. DEVELOPMENT PROCESS APPROACH

This aspect implies that it is not enough to identify the kind of housing that best reflects valid performance concepts. It is still necessary to consider how such housing can actually be made available to those who need it. As a result, the question is raised about alternative ways of organizing the entire process that generates residential environment. Are there alternative ways it could be organized which would effect significant cost savings or make for a better application of investment in housing?

F. OPERATIONAL APPROACH

This final aspect is specifically concerned with the functional connection between housing and the other operating parts or sub-systems of a community, and is evolved through the following questions:

IF the physical costs of housing were minimized. . .

and IF economic and financial factors were adjusted to aid the housing consumer. . .

and IF general benefits from various levels of investment in housing were maximized. . .

and IF the special needs of particular consumers <u>were reflected</u> fully in design requirements for housing. . .

and IF the process which generates residential environment <u>were coordinated</u> for maximum efficiency and cost savings. . .

<u>one relationship critical to the solution of the housing problem would still remain to be examined</u>.

Clearly the implementation of research based on the approaches (A through E) of the problem model will affect either or both

(1) physical housing conditions considered to be a problem

(2) low income people needing adequate housing

and <u>other parts of any given community</u> as well. It is necessary to ask what the effect would be of completely "solving" the housing problem.

Some urban analysts feel that the use of recommendations suggested by these approaches (A through E) would actually occasion additional, perhaps still more severe problems in the community. A system responds systematically to change introduced at any point within it and transmits that change throughout all connections within the system. This holds true for that especially complex organism, the community, as well as for other systems whose workings are better understood.

The sub-system for "housing" is one sub-system among many in the overall community system. It is mandatory to know how this larger system will react in the face of what will be major and significant changes in the housing component of that system. We know now only that this larger system is not particularly well organized to mend the massive dis-function that we call the housing problem. On this basis alone we should expect that solution of the "housing problem" will precipitate the potential for other changes. In order actually to solve the housing problem, it seems of the highest importance to know the nature, direction, and magnitude of these related changes.

This is the general domain for each of the six inter-related approaches to the problem. The next step is to determine how this conceptual organization can be translated into an operational structure for research.

USE OF PROBLEM DEFINITIONS

The problem structure is to be used not simply for making decisions about research (the most immediate need) but is to be used as well for evaluating and later applying workable research output. This extended application is derived from incorporating not one or two approaches to the housing problem but the six most fundamental aspects which adequately define the total scope of concern.

DESCRIPTION OF BASIC RESEARCH STRUCTURE

The six aspects in the problem model are given in the left column below as they were originally stated. Paired with them in the right column is the "short-hand" term which will now be used to represent these aspects.

Definition of what type of housing has the lowest aboslute costs	PHYSICAL APPROACH
Identification of how housing can be afforded by those who need it	ECONOMIC/FINANCIAL APPROACH
Identification of what technical methods it is possible to use in order to obtain generally better housing per unit of investment	PERFORMANCE DESIGN APPROACH
Definition of the characteristics of housing for low income people	SOCIAL APPROACH
Identification of what procedures can be used actually to provide the kind of housing that is needed to those who need it	DEVELOPMENT PROCESS APPROACH
Given the fact that housing is only one among many inter-related parts of the fully functioning community, identification of what requirements this interdependence may exert on housing per se	FUNCTIONAL OR OPERATIONAL APPROACH

Figure 1 depicts the most basic operational relationships that link our concern to actual areas of application using this program structure.

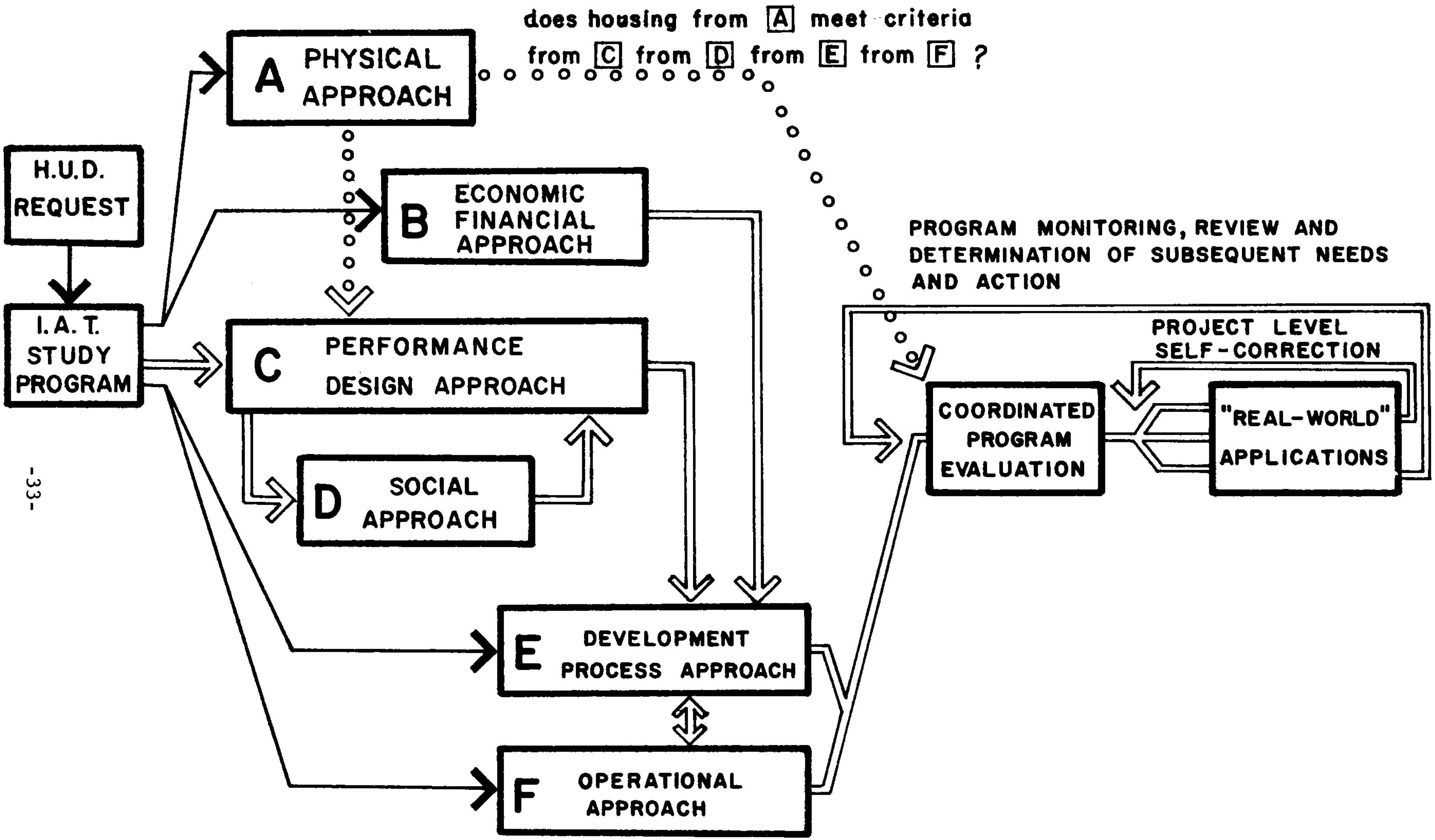

H.U.D. REQUEST
I.A.T. STUDY PROGRAM
A PHYSICAL APPROACH
B ECONOMIC FINANCIAL APPROACH
C PERFORMANCE DESIGN APPROACH
D SOCIAL APPROACH
E DEVELOPMENT PROCESS APPROACH
F OPERATIONAL APPROACH
does housing from A meet criteria from C from D from E from F ?
PROGRAM MONITORING, REVIEW AND DETERMINATION OF SUBSEQUENT NEEDS AND ACTION
PROJECT LEVEL SELF-CORRECTION
COORDINATED PROGRAM EVALUATION
"REAL-WORLD" APPLICATIONS

FIGURE 1.

ANALYSIS OF RELATIONSHIPS WITHIN PROBLEM

The next step in moving toward actual research efforts is to determine how issues are actually related to one another within each of these six aspects. What are the major "blocks" of considerations? For example there are many detailed questions about the use of different materials, yet all of these tend to be grouped together in relation to other major blocks - for instance, "user requirements" or "environmental factos" or "locational characteristics of the housing problem." If these major blocks can be identified and related properly to one another, then we can feel confident about the various detailed issues and questions on which our judgements about research will be based.

Figure 2 (A through E) presents these major blocks for the six aspects of the program structures.

As we noted above, the next step in the sequence is to expand these major blocks into the fully developed program structure. This next level of detail has been completed and is contained in Volume 2 of this study. This Volume 2 contains the Appendices. . .work commissioned and completed for this study, but deemed either too bulky, too unwieldy, or too detailed for inclusion in Volume 1.

There are already answers for some of the questions raised in this series--some available from previous research, others from practical experience. For certain other questions, specific studies were undertaken where they fell within the six problem definitions and the requirements of this study. They are referenced here:

PHYSICAL APPROACH: Available performance specifications (B.3:1 through B.3:5) are tools to reduce costs of housing through the involvement of industry who can develop innovative hardware responses to such specifications. Performance Requirements for Housing (Section B.2) is a framework for making changes in the "conventional" house while still maintaining acceptable levels of health, safety and social welfare.

ECONOMIC/FINANCIAL APPROACH: The Measurement of Costs and Benefits (Section B.5:2) links the resources of the consumer to the "thing" consumed-housing in this case. In general many questions raised here were outside the scope of the original request for the study and are not developed here.

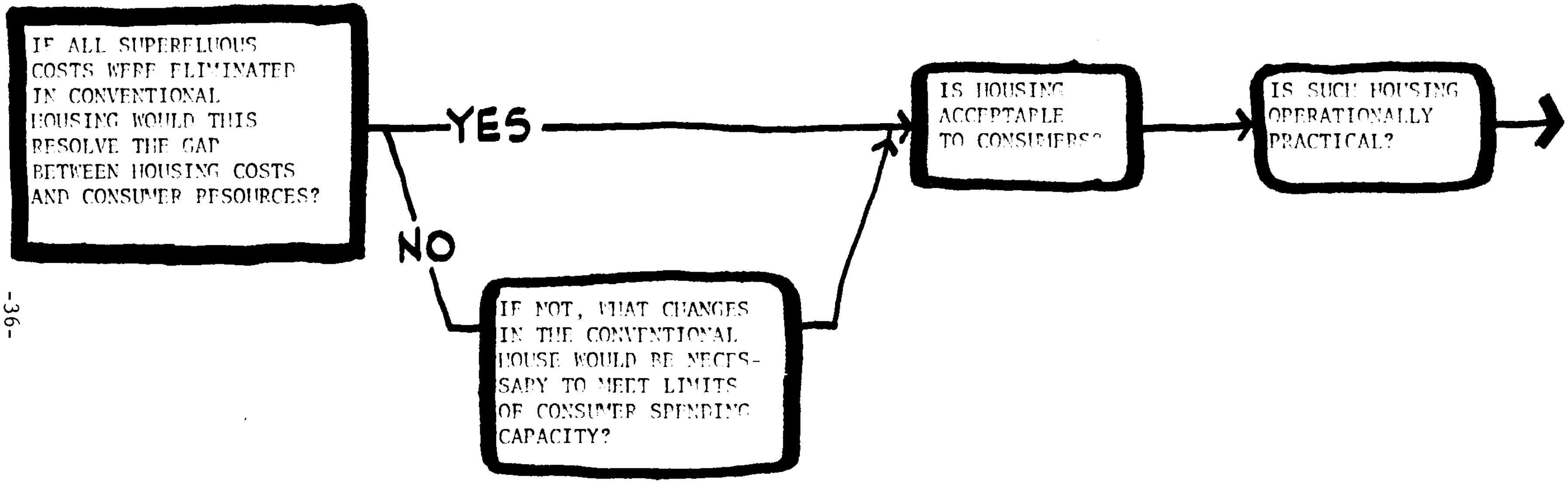
PERFORMANCE DESIGN APPROACH: The Performance Concept (Section B.1) is a direct response to the first question. The Performance Requirements for Housing (Section B.2) explores user influences on performance, while Available Performance Specifications (Section B.3) are in most cases directly concerned with the environmental influences on Performance. The User Needs (Section B.3:0) describes the availability of such work in the development of this approach.

SOCIAL APPROACH: This is an area deliberately eschewed in our study for two reasons: the compressed time frame for the study precluded it. . .and the exceedingly complex competing social "visions" of the problem. A separate study was commissioned for this topic area and will be available as a supplementary document (Volume III).

DEVELOPMENT PROCESS APPROACH: A discussion of how costs are accrued in this process is in The Measurement of Costs and Benefits (Section B.5:2). A study of how scale alters costs in this process was commissioned and is referred to in the Executive Summary.

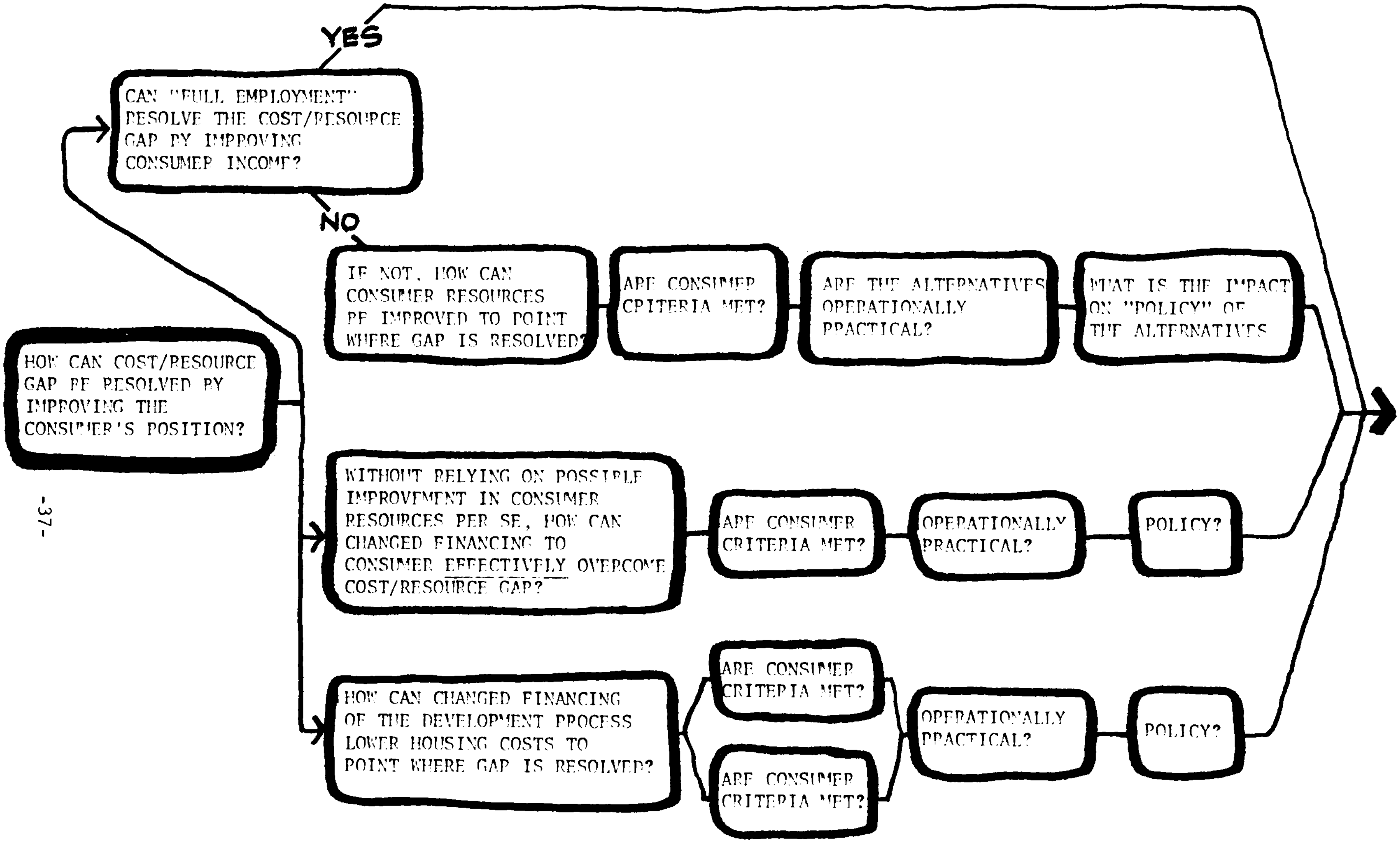
FUNCTIONAL OR OPERATIONAL APPROACH: Since this approach deals with the links between other operating subsystems of the community (transportation, education, waste removal, food supply, etc.) and housing, it is outside the scope of the immediate study. Techniques for Rank-Ordering (Section B.5:1) and Measurement of Costs and Benefits (Section B.5:3) are both concerned with how we can make decisions within such a complex approach.

We have addressed ourselves to certain elements within these six problem definitions in the study which follows. Obviously, not all of the problems have been explored and remain as the basis for further research.



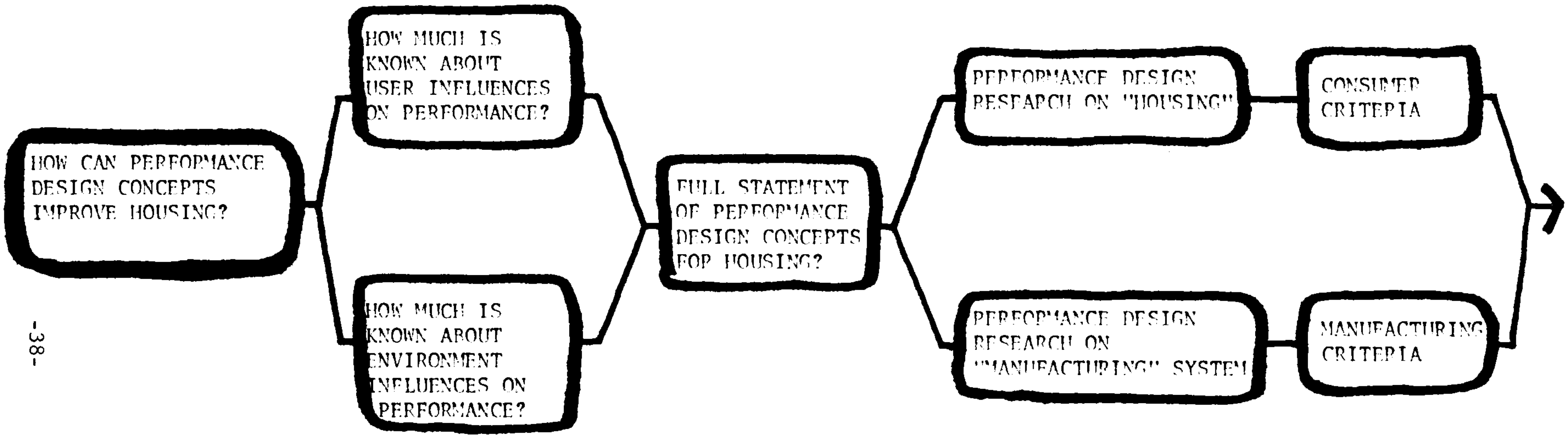
PHYSICAL APPROACH

FIG. 2 A

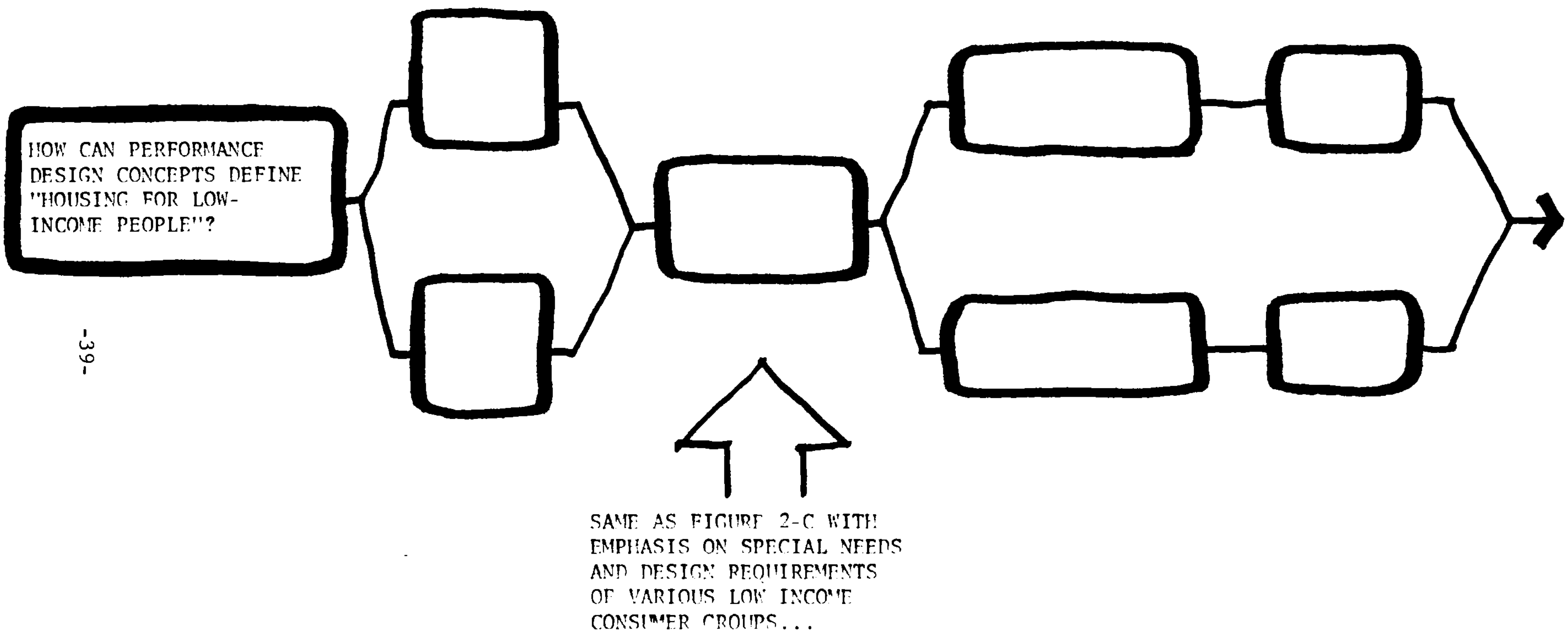


ECONOMIC/FINANCIAL APPROACH

FIG. 2 B

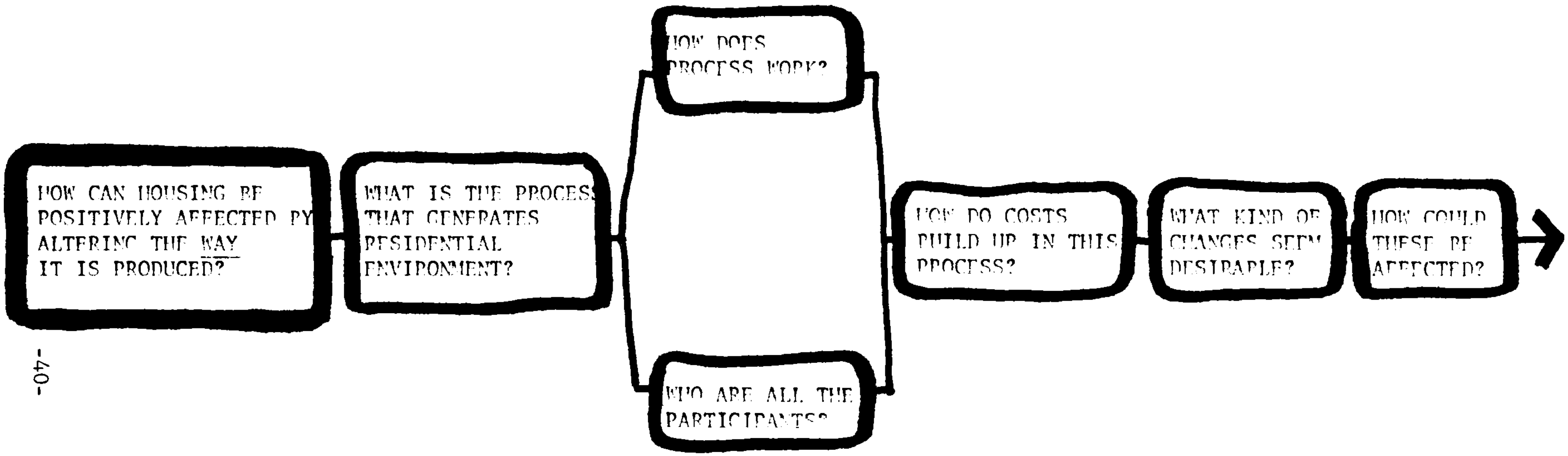


PERFORMANCE DESIGN APPROACH FIG. 2 C

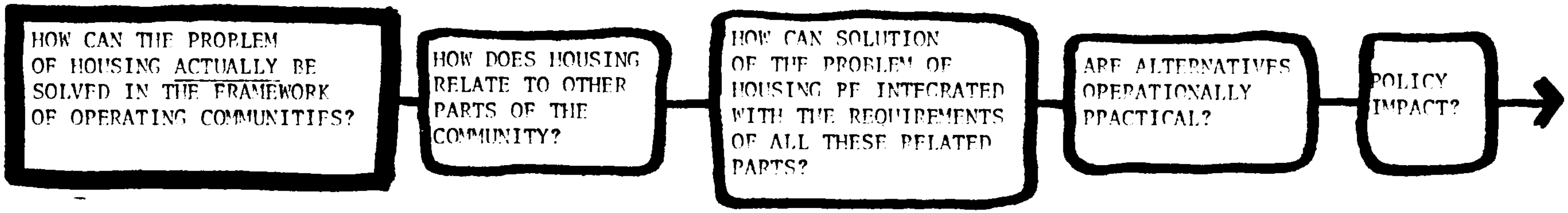


SOCIAL APPROACH

FIG. 2 D



DEVELOPMENT PROCESS APPROACH FIG. 2 E



OPERATIONAL APPROACH

FIG. 2 F

3. HOW THE STUDY WAS ORGANIZED

The study was organized to respond to the questions:

1. What is the Performance Concept?
2. What Performance-based information is available for use, or could easily be made available?
3. How much time and money would it take to research and develop "the rest"?
4. How can we establish priorities for such research and development?

The basic definition of the performance concept yielded a framework in which to develop answers to these questions.

> "The performance concept is an organized procedure or framework within which it is possible to state the desired attributes of a material, component or system in order to fulfill the requirements of the intended user without regard to the specific means to be employed in achieving the results."

From the questions and the definition, the study was then structured in three major sections:

1. Data Gathering

2. Concepts, Costs, and Tactics

3. State-of-the-Art

Data Gathering gave support to answers to questions 2, 3, and 4 and included such activities as:

1. Contact and liaison with university and non-profit research community for (1) reports of available research, (2) areas of research related to performance requirements and test methods they have interest in exploring because they have special skills or facilities.

2. Liaison and contact with professional societies and standards and test methods in the housing field.

3. Contact with foreign countries that already employ the performance concept.

Concepts, Costs, and Tactics was responsible for the development of the User-based Performance Requirements, the discussion of the Problem's complexity, and the rank-ordering techniques in an attempt to address questions 3 and 4.

Studies were also made of Space Requirements, the effects of construction scale on costs, costs in general, and the Social needs of low-income housing users.

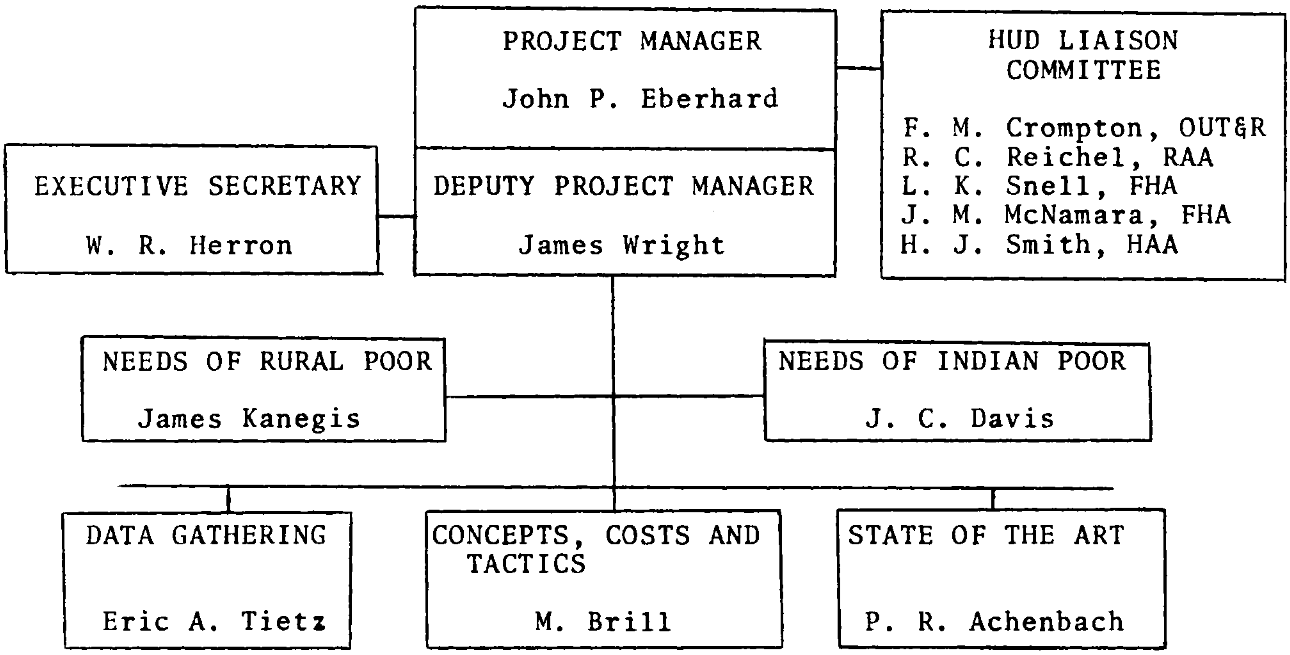
State-of-the-Art dealt mainly with performance requirements that currently can be measured in varying degrees by scientific and engineering methods. Major subject areas included were:

1. Structural
2. Safety
3. Durability
4. Environmental characteristics
5. Service systems

These studies were a direct response to question 2, and the research proposals in Section B.4. (Research Recommendations) respond to question 3 and 4.

Individual analysts addressed the problems of the American Indian Poor and the Rural Poor. The major emphasis elsewhere was on the urban poor.

The study was deemed important by both the Department of Housing and Urban Development and the National Bureau of Standards and therefore financed jointly. HUD was responsible for 12/17 of the costs and NBS for 5/17.


PROJECT MANAGER
John P. Eberhard
HUD LIAISON COMMITTEE
F. M. Crompton, OUT&R
R. C. Reichel, RAA
L. K. Snell, FHA
J. M. McNamara, FHA
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B.2. Performance Requirements for Housing--Mike Brill, H.Z. Rabinowitz

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B.3.2 Safety--Harry Shoub, Daniel Gross, A.F. Robertson, A. Hockman, P.T. Howard, P.G. Campbell

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B.3.4 Characteristics of Internal Environment--George Winzer, J.C. Davis, H.E. Robinson, W.M.C. Lam

B.3.5 Service Systems in Housing--R.S. Wyly, C.W. Phillips, W.J. Meese, G.C. Sherlin Jr.

B.4. Research Recommendations--J.P. Eberhard, J.R. Wright, P.R. Achenbach, Mike Brill

B.5. Rank Ordering of Performance Standards--Mike Brill, R. Krauss

Appendix A. Needs of the Rural Poor in Low Cost Housing--James Kanegis

Appendix B. Housing of Indians on Reservations and of Alaskan Natives--J.C. Davis

Appendix C. Conceptual Structure of Low Cost/Low Income Housing--George Birrell

Appendix D. Nature of the Problem--Terry Collison, Mike Brill

Appendix E. Performance Concept and Building Code Implementation--R. Smith

Consultants Discipline or Speciality	Supplementary Document in Volume III
Drayton Bryant Industrial Capacity and Techniques	"THE AMERICAN HOUSING PRODUCTION SYSTEM: An Exploration of Inhibitions and corrections, Lines of Research and Use of Performance Standards"
Small Homes Council Space Requirements	"PERFORMANCE-BASED SPACE CRITERIA FOR LOW-COST HOUSING"
Serendipity Association Presentation Techniques	None
John Mascioni Architect	"THE ROLE OF SOCIAL NEEDS OF THE URBAN POOR IN FORMULATING PERFORMANCE STANDARDS FOR HOUSING"
William A. Allen Architect	None
Terry Collison City Planning	None
National Association of Home Home Builders Home Building Costs	"A PILOT STUDY OF THE ECONOMIES OF SCALE RELATED TO RESIDENTIAL CONSTRUCTION"

B. THE SPECIFIC OBJECTIVES OF THE STUDY AND THE RESULTANT CONCLUSIONS AND RECOMMENDATIONS

B.1. THE PERFORMANCE CONCEPT

1. WHAT IS THE PERFORMANCE CONCEPT

The performance concept is an organized procedure or framework within which it is possible to state the desired attributes of a material, component or system in order to fulfill the requirements of the intended user without regard to the specific means to be employed in achieving the results. This is true of any product or system produced for use by humans from shelter to weapons. We are concerned in this report with the development of performance statements for the systems and sub-systems of a house, a dwelling unit, a collection of dwelling units in a high rise building, or a community of units in low rise buildings, but not with systems of the city or beyond the concerns of a community development. We are concerned with community systems and services (only as they interact with our prime considerations listed above.

We are not directly concerned with measuring or specifying the performance of those engaged in the processes of designing, making, conveying or removing houses except as these are necessary to consider in allocating financial resources.

We are not directly concerned in this report with devices or materials in terms of their performance when divorced from their contribution to user based systems performance. (Although NBS is involved in other research related to such concerns.)

> e.g., we are not concerned with plastics or even plastic pipe, but with the performance of plumbing systems without regard to the materials of which they are made.

Within the range of our performance considerations we are interested in those performance requirements related to reasonably intended use.

> e.g., - a screwdriver may be used as a doorstop, but that is not a "reasonably intended use."
>
> - the thermal properties of exterior walls are important, but may not be for interior walls.

The range of our performance considerations grow out of the activities for which a dwelling unit is intended. These include:

entry, reception and delivery

social entertaining and entertainment

play

communications

learning and study

business

    sleeping

    sex

    dressing

storage

    grooming

    washing

    bathing

metabolic

    food preparation and storage

eating and drinking

    an unusual event

maintenance, cleaning and renewal

The interior environment in which these activities occur needs the following:

> conditoned air, adequate illumination, controlled acoustical properties, stability and strength, protection against dangers to health or safety, adequate space to allow activity to occur (in three dimensions), an orderly arrangement of such spaces, an acceptable esthetic content, and a capability of being reasonably maintained.

These interior spaces need to be enclosed within a shell which:

> .provides adequate protection against climatic conditions, and reasonable protection against unusual but possible catastrophes such as hail, earthquakes, fires in adjacent buildings, baseballs, etc.

> .provides visual access from the interior spaces to the exterior in reasonable amounts

.provides acoustical privacy from adjacent dwelling units

.is esthetically acceptable

.has surface properties which are capable of easy maintenance over the life of the building

.acts to selectively filter and modify the external climate

These functions and attributes of a house are related to the needs of the user. The user, however, is capable of being defined by four characteristics (any and all of which may effect his needs), these are:

a. Resources

   income, level of ownership

b. Culture

   Spanish, Southern White, Negro, Indian, etc.

c. Location

   urban, rural, other

d. Module/Role

   1. individual: infant
      child
      teen-ager
      adult
      guest

   2. a couple

   3. nuclear family

   4. extended family

   5. the neighbors

   6. nodding acquaintances

   7. the community

We have in this report concentrated our efforts on studies related to the needs of urban low-income families, and we have assumed their concentration to be in high-rise housing. (In Appendices A and B we have provided some insights into current thinking on the needs of the rural poor and the low-income Indian population.)

The Performance Heirarchy

The performance concept consists of a set of elements which are more or less sequentially developed and which normally become more rigorous at each stage of their development. This range of elements is shown on the following chart, and the following pages describe the terms used.

Performance Requirements: (see Part B.2)

At the fundamental level these are derived from the characteristics of users which the physical environment can affect such as:

a. Physiological needs - the life processes
b. Psychological needs - the mental processes
c. Sociological needs - the interactions between people and groups and the effects of commonly held beliefs.

Needs are not dependent on particular materials, devices or systems but derived from the following questions:

- What is the use of function being considered?

- For whom is the requirement posed?

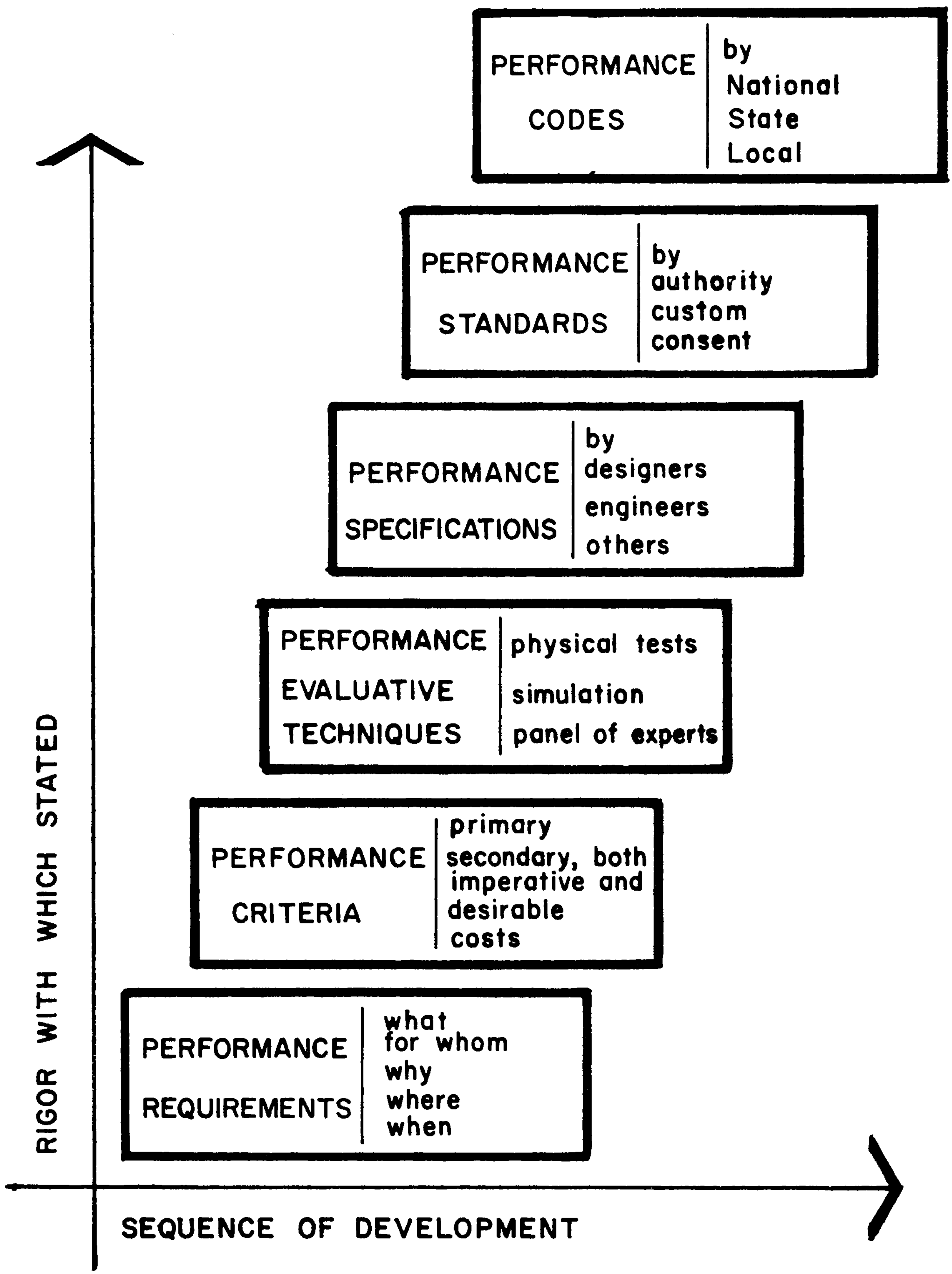
- Why is there a need? This helps explain the background considerations out of which the need has grown, and will assist in determining the anticipated benefits.

- Where will the needs exist, or what are the limits and context of the needs?

- When will the needs exist and for how long?

Performance Criteria

Attributes or characteristics which are to be used in evaluating whether or not the requirements are being met. They may or may not be measurable in any rigorous way, but can be evaluated by some appropriate method. There are secondary but imperative criteria with respect to public health and safety that may be present because of the context of the requirements. There are secondary but desirable criteria related to the interface between solutions and the larger sub-systems or systems of which they will be a part. Criteria related to costs of alternative solutions will enter into the evaluation of performance potential versus benefits.



THE PERFORMANCE HIERARCHY

Performance Evaluative Techniques:

Once criteria are identified there is a need to develop some method of evaluating solutions advanced to meet the requirements against such criteria. The most reproducible evaluative techniques are those based on physical tests. But some criteria do not lend themselves to numerical evaluation so that simulation techniques will have to be utilized to answer simply if the solution is satisfactory or unsatisfactory. In other cases the judgement of experts may be the only evaluation possible.

Performance Specifications

Statements which are rigorous enough to indicate which criteria are to be considered and how they are to be measured. Upper or lower limits, established according to the selected measurement technique, are used to indicate the range of values of the criteria which are considered acceptable or unacceptable. They may be used or required by owners or their agents, including architects and engineers.

Performance Standards:

If the measurement techniques are reproducible, and the requirements are reasonably common ones, a duly constituted (authoritative) body may issue the specifications as a standard to be referenced by others, or it may become a de facto standard by common usage.

Performance Code:

A collection of specifications and standards, which have been adopted by a process of law and which can be enforced by the police power power of a government. Codes are promulgated by National model code groups, state and local governments. A code is usually intended for impartial regulation of an area of activity, the purpose which is the protection of the safety, health and general welfare of the public.

2. EXAMPLES OF PERFORMANCE SPECIFICATIONS

As an example of the range of the performance concept from the most basic statement of user needs all the way along the scale to present code requirements, let us examine the general area of waste disposal:

a. This need is derived from the basic user need for providing systems which meet the physiological requirements of humans. (see Part B.2)

b. A sub-category of this requirement in terms of the operational needs of the user is provision for the maintenance of health, which may be still further subdivided into a set of requirements of the user related to protection from contamination injurious to health.

c. In developing the performance requirements within this area of concern we would ask ourselves the following questions:

1. What? - To provide for the disposal of those waste products which result from:

   a. human digestive processes

   b. human cleansing needs

   c. clothing cleansing needs

   d. food preparation and consumption

   e. large amounts of discarded paper and paper products

   f. other discarded items

2. Why? - In our present style of urban life people produce large amounts of discarded or waste products in addition to their human waste. In crowded cities the means of disposing of these wastes is of major importance since an accumulation can be dangerous to safety and health. There are many current problems associated with pollution caused by various methods of disposing of wastes.

3. Where? - These requirements exist in any dwelling unit, whether inhabited by one person or many. In high-rise buildings the need may exist high in the air (on the 30th floor) as well as near the ground, so that systems which attach to the ground will have to make provisions for access from all points above the ground.

4. When? - While some of the disposal requirements can be scheduled, most of them need to be available 24 hours a day and every day. The requirement will continue for the useful life of the dwelling.

d. If we select within this set of requirements the need to "provide for the disposal of waste from human digestive processes," then the primary criteria related to such systems include:

1. Available at all times.

2. Afford reasonable privacy to the user.

3. Be capable of being kept easily in a sanitary condition.

4. Provide a reasonable means of controlling associated odors.

5. Any parts of the system which come into contact with the human body should be capable of reasonable thermal control and have acceptable textural qualities.

6. Adaptable to the variations in the anthropometric fit of humans such as height, weight and muscle tone.

7. The system shall be made of durable materials.

- The secondary, but imperative criteria include:

1. The system should not endanger the health or safety of the occupants of the dwelling in any way.

- The secondary, but desirable criteria include:

1. Acoustical privacy as well as visual privacy should be available to the user.

2. The system should be modular in order that it can be coordinated with other building systems.

3. Any visible parts of the system should be attractive in appearance.

e. Performance specifications, standards and codes which are derived from these requirements and criteria are presently related to plumbing systems since that is the predominently available systems solution. If in the future new concepts were to be developed they would have to have new specifications developed for their use, again derived from the fundamental requirements. It is conceivable that such solutions would be capable of providing for a larger spectrum of waste disposal needs.

The performance criteria, test methods, specifications and standards for plumbing systems will be found in Part B.3.5.1, page 258. This develops the current state-of-the-art with respect to specifying plumbing systems.

3. ARGUMENT FOR THE USE OF THE CONCEPT

The use of the performance concept provides for the rational evaluation of technological alternatives thus paving the way for innovation. By avoiding the specification of how a house is to be built, but rather opening the way to new ideas through stating the performance to be met by any solution, conditions are created for achieving more cost-effective solutions. A more efficient solution can often result in producing a lower first cost as well as reduced life-costs. To the extent our current knowledge will permit, the use of performance standards makes it possible for industry to bring the production costs of their products within the demand capability of the market. To the extent that dislocations will still exist between low-income families housing needs and the lowest costs capable of being produced by industry the difference will have to be made up by some form of subsidy or by more technological innovations. Performance standards cannot produce any magic which will fill the gap between technological capability and low-income families, it can only help to make the direction of innovation more free of constraints.

Without a well developed set of performance requirements and performance evaluation techniques a good deal of research and development by industry may be wasted in exploring non-relevant directions. Thus the presence of developed performance concepts helps to more effectively link the research base of industry to the needs of all of us--not just the poor. The opportunity to enhance the lives of every citizen through improved housing performance should certainly be one of HUD's goals.

4. RELATIONSHIP OF SYSTEMS APPROACH TO PERFORMANCE CONCEPT

The most striking recent technological advances, although made "visible" by their physical machinery, owe their genesis to a non-physical "intellectual technology" - the application of the new intellectual techniques of systems analysis, simulation, and operations research to problem solving: the Systems Approach.

The systems approach has been applied previously in the development of military projects and space problems. It appears to be applicable to urban problems (particularly urban housing) since these, like large-scale space and weapons projects, are complex, require a multidisciplinary approach and involve the organization of technological or quantitative factors.

The approach has two main features. First, objectives are stated clearly in performance terms rather than in particular technologies or pre-existing models. The advantage of specifying objectives in systems terms is that it forces decision makers to cast the problem in terms so that a rational comparison of alternative solutions is possible.

The second feature of the systems approach is its emphasis upon the inter-relations within a system. The pre-systems method was to divide a problem into more manageable sub-problems, thereby losing those factors which were relationship-based or dynamic. The comprehensive view of the systems approach enables us to trace out the effects of any set of choices and decisions upon all other relevant decisions.

B.2 PERFORMANCE REQUIREMENTS FOR HOUSING

1. REASONS FOR DEVELOPMENT

There are two methods for developing performance requirements for housing. The first is to develop statements of USERS NEEDS--those "satisfactions" the user desires or needs from housing. The second method is to use existing hardware configurations (or systems) as models, and to abstract from these their important and desired performance characteristics. Both methods can be developed into performance specifications used to procure housing. The first method is more difficult, implying evaluative techniques not completely available now. It does offer a wider range of alternative responses to user needs as the statements are essentially cast in terms of the user, and not the hardware. The second method offers, in a number of cases, an easier transition to the performance "way" of designing and procuring housing as the evaluative techniques are relatively well developed. These are discussed in B.3, "Availability of Performance Specifications."

In this section we will attempt to develop the first method. Very little work has, to our knowledge, been completed in any formal, rigorous manner for housing. That which has been done, we discuss in B.3.:0, "USER NEEDS."

2. UNDERLYING ASSUMPTIONS AND RATIONALE OF ANALYSIS

For the purposes of developing a Methodology to generate Performance Requirements from User Needs we have made certain assumptions which we make explicit here:

The Place

We assume the physical context to be urban areas. The attributes common to these areas will guide the development of the Performance Statements . . . high density, good access to transport and modes of travel, availability of services and utilities, and systems support of many kinds normally found in such areas.

THE USER is the basis for performance

It is user satisfaction which is being procured through performance and what costs will be measured against.

Any USER can be defined, for our purposes, by four characteristics:

a. RESOURCES

   income, level of ownership

b. CULTURE

   Spanish, Negro, Asian, Indian, other

c. LOCATION

   urban, rural, other

d. UNIT SIZE

   1. individual: infant
child
teen-ager
adult
elder
guest

   2. a couple

   3. nuclear family

   4. extended family

   5. the neighbors

   6. nodding acquaintances

   7. the community

for this project, the development of Performance Requirements for housing, we have assumed OUR USER to be:

a. resources: LOW-INCOME

b. cultures: NEGRO, HISPANIC, CAUCASIAN

c. locations: URBAN & URBAN BLIGHTED CORE

d. unit size: ALL SIZES, BUT GENERALLY STATED

For the development of the total set of Performance Statements for housing, it is acknowledged that for each function and activity, criteria must be described for each user. There are many users. Further, users change over time, as individuals, families, and communities grow and modify each other and the environment. However, to cope with this complexity within the time constraints, we have aggregated all users into a generic "USER."

AFFECTABLE CHARACTERISTICS OF THE USER

We assume that the characteristics of users which the physical environment can affect are:

a. Physiology - the life process

b. Psychology - the mental processes

c. Sociology - the interactions between people and groups and the effects of commonly held beliefs.

We wish to describe the environment as a function of these characteristics, and to develop NEEDS statements based on them as the NEEDS should determine the qualities of the environment. We will not develop performance requirements for the Psychology and Sociology of our generic "User." The time frame and the state-of-the-art preclude it. By developing Physiology only, we can develop generic statements for all users . . . for factors like gravity, illumination, and health and safety requirements will not vary to any discernible degree for any users, while privacy, personalization, and aspirations will, and to a marked degree for different users and user groups.

NOTE:

For the Systems Approach to yield maximum benefits, the full set of Performance Requirements for PSYCHOLOGY and SOCIOLOGY must be developed.

REASONABLY INTENDED USES OF HOUSING

We assume that housing will be asked to perform those functions, and for those users, that have historically been called the REASONABLY INTENDED USES OF HOUSING. We are not expanding the uses of housing in this development of Performance Requirements.

For example, a possible social teen-age use of housing might be as rehearsal space for a fledgling band and would require special acoustic considerations. We will not develop criteria for these considerations, as they do not stem from the Reasonably Intended Use of Housing. However, the party wall between families in high-rise housing must have sufficient sound-attenuating characteristics to prevent the radio or TV of one family from disturbing the peace of another in normal use. This is a Reasonably Intended Use of Housing, and one for which performance criteria must be established. The criteria for the teen-age band and the radio might be the same, but we concern ourselves only with those criteria of normal, historically REASONABLY INTENDED USE.

3. GENERIC PERFORMANCE REQUIREMENTS FOR HOUSING

The "reasonably intended uses" of housing affect the Body, Mind, and Social Interactions of its inhabitants. These are the basic AFFECTABLE CHARACTERISTICS of human users:

1. Physiology

2. Psychology

3. Sociology

Performance statements may be developed to assure that the needs related to, or generated by these AFFECTABLE CHARACTERISTICS are satisfied through housing, to the extent that housing can, in fact, satisfy these needs.

The development of these statements is based on the following rationale:

Performance (or "needs") statements occur at many levels of differentiation. When they are very specific, they tend to be solution (or "means") oriented, are measurable with existing techniques and permit some limited innovations in satisfying the stated Need. As the statements become broader and more generic, measurement techniques become more complex and less available, but allow a very wide range of innovation solutions to meet needs.

As developed here, ESSENTIAL NEEDS OF THE USER is the most generic statement and ENVIRONMENTAL SYSTEMS SUPPORT the most specific. The diminishing sequence ESSENTIAL NEEDS... OPERATIONAL NEEDS...REQUIREMENTS...is related to the user, is a measure of his needs, and gets more specific left to right. ENVIRONMENTAL ATTRIBUTES is the "bridge" between the User and the Environmental System of Housing. This statement describes the Attributes (qualities) the Environment must possess or generate in order that the Users Requirement can be met. For example, in order to read, the user must see the book. The Environmental Attribute is light--not lighting fixtures. The SYSTEMS RESPONSE may be lighting fixtures, or a window, or luminescent panels or some source of light not yet invented. The Environmental Attribute is what is supplied, the Systems Response is how it is supplied.

Environmental Systems Support describes one or all of the following:

a. energy sources -- i.e., electricity for the light fixtures

b. spatial and structural support -- i.e., enough space and strength in the ceiling to house and support the fixtures

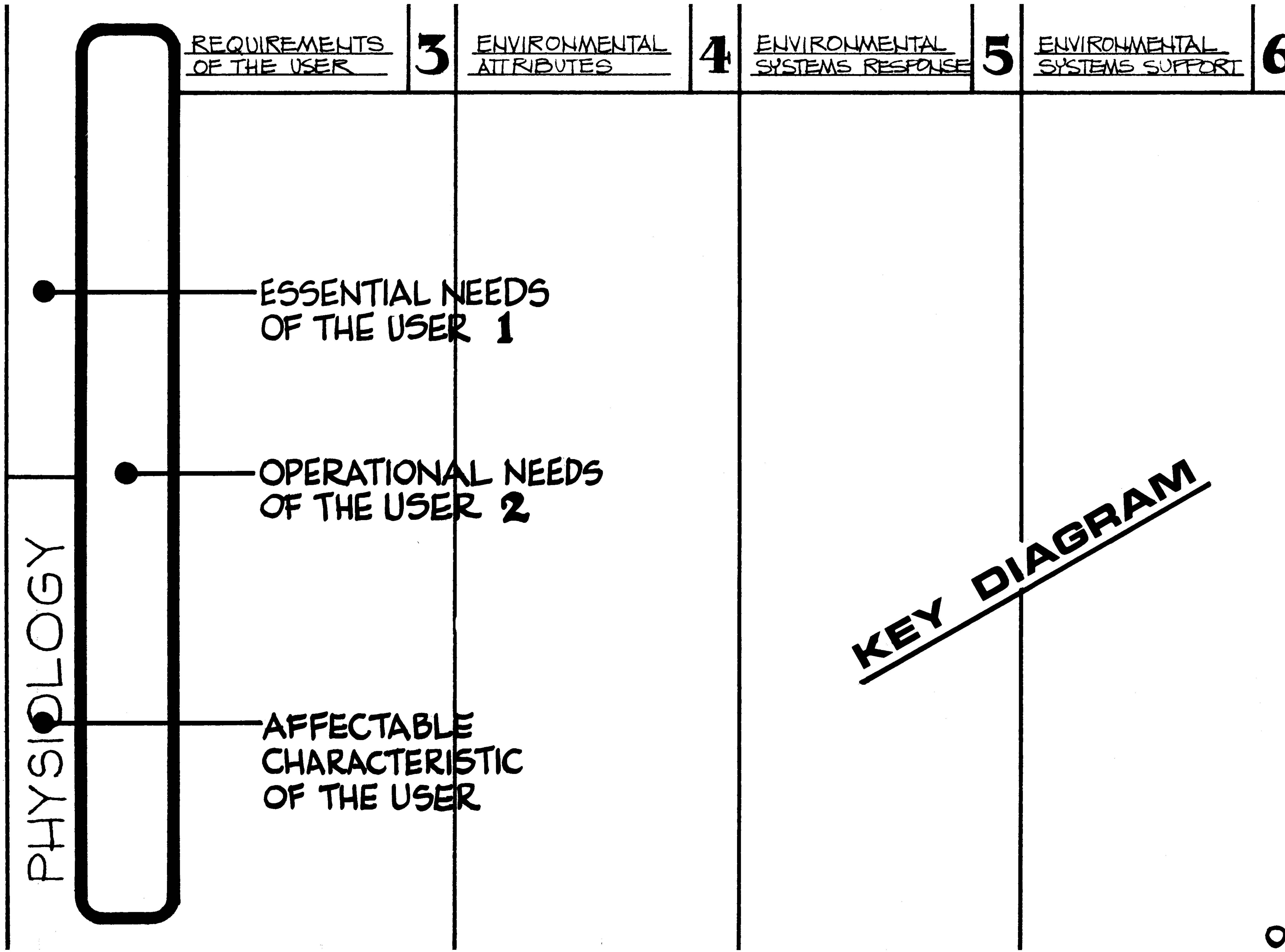
c. non-physical support -- i.e., spare parts supply, maintenace manuals, personnel and schedule

d. removal of unwanted output -- i.e., heat generated by lights is used to heat the building or compensated for by air-conditioning

The development of performance statements for every "level" allows us to indicate needs and to trace possible responses to these needs.

This generation of alternative responses widens the range of problem resolution.

The following chart shows these relationships graphically.


REQUIREMENTS OF THE USER
3
ENVIRONMENTAL ATTRIBUTES
4
ENVIRONMENTAL SYSTEMS RESPONSE
5
ENVIRONMENTAL SYSTEMS SUPPORT
6
PHYSIOLOGY
ESSENTIAL NEEDS OF THE USER 1
OPERATIONAL NEEDS OF THE USER 2
AFFECTABLE CHARACTERISTIC OF THE USER
KEY DIAGRAM
o

PHYSIOLOGY

ACTIVITY SUPPORT

PERMIT (OR ENHANCE) THE OCCURRENCE OF ACTIVITIES AND FUNCTIONS

REQUIREMENTS OF THE USER 3	ENVIRONMENTAL ATTRIBUTES 4	ENVIRONMENTAL SYSTEMS RESPONSE 5	ENVIRONMENTAL SYSTEMS SUPPORT 6
"PROPER" SENSORY ENVIRONMENT FOR FUNCTION MUST BE PRESENT DURING THAT FUNCTION	Provide proper thermal environment for user engaged in food preparation - Conduction - Convection - Radiation reference: B.3:4.3	- Supply System - Control System - Removal System for unwanted output	
	Provide proper illumination for food preparation: - Light levels appropriate to tasks, e.g.: reading, cutting - Color Fidelity - Direction of light to task areas - Controlled Contrast - Controlled Glare reference: B.3:4.4	- Supply System - Control System - Directional Controls - Surfaces to achieve such illumination needs	
	Provide proper acoustical environment, for food preparation - Ambient Noise e.g., equipment, mechanical - Low transmitted sound from adjacent spaces - Low reverberation in food preparation space - "Signals" audible to the user to aid food preparation reference: B.3:4.1	- Absorptive or non-reverberant surfaces in use contact with "hard" objects - Adequate sound attenuation with adjacent space	
	Provide proper tactile environment for activity Textures for use during function 1. With attention to rate of activity and position of user during activity	- Surfaces which are comfortable to the touch and permit food preparation and related activities - Information transmitted by texture, e.g., surfaces which should be used for cutting, etc.	
	Provide proper esthetic environment, i.e., one which clarifies and enhances use	Surfaces, edges, shapes and organizing principles, which - Perception of food preparation activities and clarity - Information transmittal e.g., hot surface - Focus on activity	
	Provide consistancy of sensory environment		

PHYSIOLOGY — ACTIVITY SUPPORT

PERMIT (OR ENHANCE) THE OCCURRENCE OF ACTIVITIES AND FUNCTIONS

REQUIREMENTS OF THE USER 3	ENVIRONMENTAL ATTRIBUTES 4	ENVIRONMENTAL SYSTEMS RESPONSE 5	ENVIRONMENTAL SYSTEMS SUPPORT 6
PROVIDE NECESSARY PHYSICAL EQUILIBRIUM DURING FUNCTION For activity support we are only concerned with the physical equilibrium during that activity as general physical equilibrium is a requirement of safety.	Stability of environment during food preparation reference: B.3:5.2	- Physical environment shall "resist" activity generated loads both static and dynamic, e.g., chopping	
	Constancy of environment during function	- Continuity of organization and placement	
	Durability of environment during food preparation reference: B.3:3.1&2 B.3:5.2	- Surfaces and materials - Resistance to: fading, stain impacts, cutting, washing, etc, on those surfaces receiving abuse - Resist discoloration, decomposition	
	Maintainability of environmental attributes necessary for food preparation reference: B.3:3.1&2 B.3:5.2	- Cleanability, e.g.: stains, dust, food particles, spillage - Access for cleaning, repair and replacement - Ability to repair by user or repairman - Replaceability of components or entire units	
SUFFICIENT SPACE AND "FIT" FOR FUNCTION AND FOR FURNITURE, EQUIPMENT AND ACCESSORIES	Access to food preparation area by users, furniture, equipment and accessories Unavailability for non-users Access to food serving area	- Storage of furniture, equipt, accessories, and utensils - Clear movement patterns to and within food preparation area - Ingress for users - Separation of non-users from users	
	Size appropriate to accommodate food preparation activities and related storage and activities	- Dimensions for number of users storage movement equipment, etc. - Modification, e.g.: for new equipment	
	Shape to permit most comfortable performance of activity including user, movement, objects, storage	- Geometry of space related to food preparation - Planning, sequence and relationships of activities and equipment	
	Clear relationships of food preparation elements - Movement - Planning	- Efficient sequence of movement - Proper sequence of preparation activities and therefore equipment and storage - Flexibility to accommodate new relationships and elements	

SAFETY

PHYSIOLOGY

PROTECTION FROM UNCONTROLLABLE ENERGY SOURCES

REQUIREMENTS OF THE USER 3	ENVIRONMENTAL ATTRIBUTES 4	ENVIRONMENTAL SYSTEMS RESPONSE 5	ENVIRONMENTAL SYSTEMS SUPPORT 6
MINIMIZE INJURY, LOSS OF LIFE AND PROPERTY FROM..... .....ATMOSPHERIC DISTURBANCES	Limited occurrence and scale of failure due to atmospheric disturbances reference: B.3:1 B.3:3.2	- Reliability of environment (food preparation area) to withstand failure due to atmospheric disturbance e.g., protection from leaking, wind blown objects, etc.	
.....GRAVITATIONAL FORCES	Limited occurrence and scale of failure	- Reliability (e.g., of structure)	
	Separation of users from imminent or actual failure	- Information on imminent or actual failure - Removal of users from failure - Isolation of users from failure	
	Control of failure: Limited rate and size of propagation of of such failure reference: B.3:1	- Slow "collapse"	
.....GEOLOGICAL DISTURBANCES	Limited occurrence and scale of failure reference: B.3:1	- Reliability	

PHYSIOLOGY / SAFETY / PROTECTION FROM PHYSICAL SYSTEMS HAZARDS	REQUIREMENTS OF THE USER 3	ENVIRONMENTAL ATTRIBUTES 4	ENVIRONMENTAL SYSTEMS RESPONSE 5	ENVIRONMENTAL SYSTEMS SUPPORT 6
	MAXIMIZE ANTHROPOMETRIC FIT I.E., PREVENT ACCIDENTS It is assumed here that all personal accidents are caused by a lack of "fit" between the physical environment and the humans active within it. Example: Stair accidents are caused by a lack of "fit" be between the shape of a stair and the stride and activities of a user. Slipping is caused by a lack of "fit" (caused by reduced friction or overbalance) between a floor surface and human stride movements during an activity	Maximized anthropometric fit of food preparation area and its subelements and processes to the user. reference: B.3:2.2&3 B.3:5.2	- Information system indicating anthropometric fit or misfit of food preparation area to user e.g., hot stove or implements "signalled". - Design which maximizes anthropometic fit related to activities, equipment and user - Dimensions - Position - Surface - Edge - Configuration - Organizing Principles - Surface friction on altered to unsafe levels by grease and water, with increased possibility of "slip" - Equipment and space designed for movement reducing hazard from sharp corners, protrusions, etc. - Equipment and space designed for multiple-users at the same time - Equipment and space designed to protect children not engaged in food preparation	
		Reliability of anthropomentric fit reference: B.3:3.1&2 B.3:5.2	- Durability-limited change overtime - Consistancy of design and flow in food preparation area, and between areas serving the same function, e.g., food preparation areas in the same building	

PHYSIOLOGY

SAFETY

PROTECTION FROM PHYSICAL SYSTEMS HAZARDS

REQUIREMENTS OF THE USER 3	ENVIRONMENTAL ATTRIBUTES 4	ENVIRONMENTAL SYSTEMS RESPONSE 5	ENVIRONMENTAL SYSTEMS SUPPORT 6
MINIMIZE INJURY, LOSS OF LIFE AND PROPERTY THRU FIRE	Limited occurrence and scale of fire in food preparation area reference: B.3:2.1	- Low fuel load in food preparation area - Control and safety of equipment which produces heat - Isolation of food preparation equipment using heat and high fuel load sources - Isolation and removal of volatile substance	
	Separation of users and property from fire present in food preparation area reference: B.3:2.1	- Barriers between potential fire sources and adjacent property and users - Information: Detection and communication of imminent or actual fire - Removal of users and property from fire	
	Limited rate of propagation and size of fire reference: B.3:2.1	- Protection (insulation) - Limited flame spread - Isolation of potential sources of fuel	
	Elimination of existing fire situations in food preparation areas reference: B.3:2.1	- Supply extinguishers to user to: a. Lower temperature b. Remove air c. Remove fuel - Access to fire situation by users, and if necessary, professional fire fighters - Automatic extinguishers when user cannot use extinguisher e.g., not present at time of fire	

PHYSIOLOGY / SAFETY / PROTECTION FROM PHYSICAL SYSTEMS HAZARDS	REQUIREMENTS OF THE USER 3	ENVIRONMENTAL ATTRIBUTES 4	ENVIRONMENTAL SYSTEMS RESPONSE 5	ENVIRONMENTAL SYSTEMS SUPPORT 6
	MAXIMIZE MECHANICAL SUBSYSTEM SAFETY TO USER	Limited occurrence of mechanical subsystems failure affecting food preparation area reference: B.3:5.2&3&4	- Reliability of mechanical subsystems for food preparation activities - Self corrective systems - "Fool-proof" controls on dangerous equipment	
		Separation of user from mechanical subsystem failure	- Information systems for detection and communication - Isolation of users - Removal of users	
		Limited rate of propagation and size of mechanical subsystem disfunction reference: B.3:5.2	- Relief system, e.g., pressure relief valve - Limited spread, e.g. flame spread - Barrier system	
		Elimination of existing dangerous failure reference: B.3:5.2	- Extinguish. e.g., self destruction or other methods - Access to point of failure by user or professional hazard "fighter" - Available extinguishers or corrective procedures for probable hazards	

PHYSIOLOGY

SAFETY

PROTECTION FROM PHYSICAL SYSTEMS HAZARDS (Top)

PROTECTION FROM HAZARDS CAUSED BY SOCIETY (Bottom)

REQUIREMENTS OF THE USER 3	ENVIRONMENTAL ATTRIBUTES 4	ENVIRONMENTAL SYSTEMS RESPONSE 5	ENVIRONMENTAL SYSTEMS SUPPORT 6
MINIMIZE INJURY AND LOSS OF LIFE DUE TO AIRBORNE TOXICITY	Prevent presence of air containing unacceptable amounts of toxic materials in food preparation area reference: B.3:2.3 B.3:4.2	- Reliability on such event not occurring - Use of materials and processes which will not be a source of toxicity	
	If toxicity does occur separation of users from such toxicity reference: B.3:5.5	- Information systems for - Detection - Communication - Isolation of toxicity or of users - Existing systems	
	Limited rate of propagation of toxicity and limited size of occurrence	- Limited toxic potential of materials - Absorption of toxicity e.g., filters - System for evacuation of existing toxicity - Barrier systems	
	Elimination of existing toxicity in food preparation area reference: B.3:4.2	- Air removal system - Selective removal of toxicity e.g., filters	
MINIMIZE INJURY, LOSS OF LIFE AND PROPERTY FROM SOCIAL SYSTEMS DISFUNCTIONS, E.G., CRIME	Separation of users from social systems disfunctions thru or in food preparation area e.g., crime, burglary reference: B.3:2.3	- Barrier systems-through configuration of space and design elements - Security systems e.g., locks, alarms - Surveilance systems - Scanning e.g., electronic	

PHYSIOLOGY

HEALTH

PROVIDE A CONTROLLED HEALTH-ENHANCING ENVIRONMENT "BUILDING CLIMATE"

REQUIREMENTS OF THE USER 3	ENVIRONMENTAL ATTRIBUTES 4	ENVIRONMENTAL SYSTEMS RESPONSE 5	ENVIRONMENTAL SYSTEMS SUPPORT 6
SUFFICIENT QUANTITY OF SUPPLIED "CLIMATE"	Sunlight supplied to food preparation area, e.g., for sun-ripening of food reference: B.3:4.4	- Aperture to outdoors source of: Infrared Ultraviolet Radiation - Control System	
	Provide thermal climate appropriate for food preparation activities reference: B.3:4.3	- Supply System - Control System - Removal of activity generated unwanted heat	
	Humidity appropriate for food preparation activities reference: B.3:3.2 B.3:4.2 B.3:5.5	- Supply - Control - Removal of activity generated unwanted humidity ie.g., steam	
	Air supply and air movement to support and enhance food preparation activities reference: B.3:4.2 B.3:5.5	- Air supply system - Air control system Velocity Direction	
	Limit occurrence of pollution from food preparation activity e.g., clean processes, materials reference: B.3:5.5 B.3:4.2	- Removal systems e.g., ventilation - Filtering systems - Clean supply systems e.g., water, fuel, air	
	- Separation of users from existing pollution - Isolation of pollution sources in and out of activity reference: B.3:5.1	- "Barrier" systems	

PHYSIOLOGY / HEALTH	PROTECTION FROM CONTAMINATION INJURIOUS TO HEALTH	REQUIREMENTS OF THE USER 3	ENVIRONMENTAL ATTRIBUTES 4	ENVIRONMENTAL SYSTEMS RESPONSE 5	ENVIRONMENTAL SYSTEMS SUPPORT 6
		MINIMIZE HEALTH HAZARDS DUE TO GASEOUS, LIQUID AND SOLID WASTES Pertains to both activity generated (food, trash) wastes and metabolic wastes (human excreta, etc.)	Separation of users from wastes which are potential or actual sources of contamination reference: B.3:4.2 B.3:5.1&2&5&6	- Barrier system for wastes associated with food preparation activities e.g., containers - Removal of wastes from food activity area. e.g,. garbage and trash disposal - Wastes removed from space in process of food preparation	
			Limited growth and spread of contamination in food preparation area reference: B.3:3.1 B.3:5.2	- Remove nutrient and/or provide "easy" maintenance through the proper design and placement of permanent equipment to protect against rodents or vermin: 1. Prohibit growth through limited space in which growth can occur 2. Prohibit growth through allowing clearnances to permit maintenance - Design of space and equipment to permit (or motivate) easy maintenance by users. No spaces unreachable in normal maintenance, either through design or movability	
			Elimination of existing contamination of wastes present in food preparation area reference: B.3:3.1 B.3:5.5	- Destruction system e.g., incineration - Access for "cleaning" e.g., disinfection, antiseptic methods	

This chart, fully completed, would still not yield information about how the environment must respond to the activities or functions of users. Many activities demand different ENVIRONMENTAL ATTRIBUTES in order that the activities may take place. Sleeping and food preparation require specialized environmental attributes, and these activities themselves modify the environment. The magnitude of specialization for different activities is a gage of compatibility. For example, sleeping and food preparation cannot take place in the same space at the same time and it is not for lack of space, but for lack of ATTRIBUTE compatibility.

To clarify which activities associated with housing are compatible, and to describe the attributes necessary for these activities to take place, the chart is added to in the following manner:

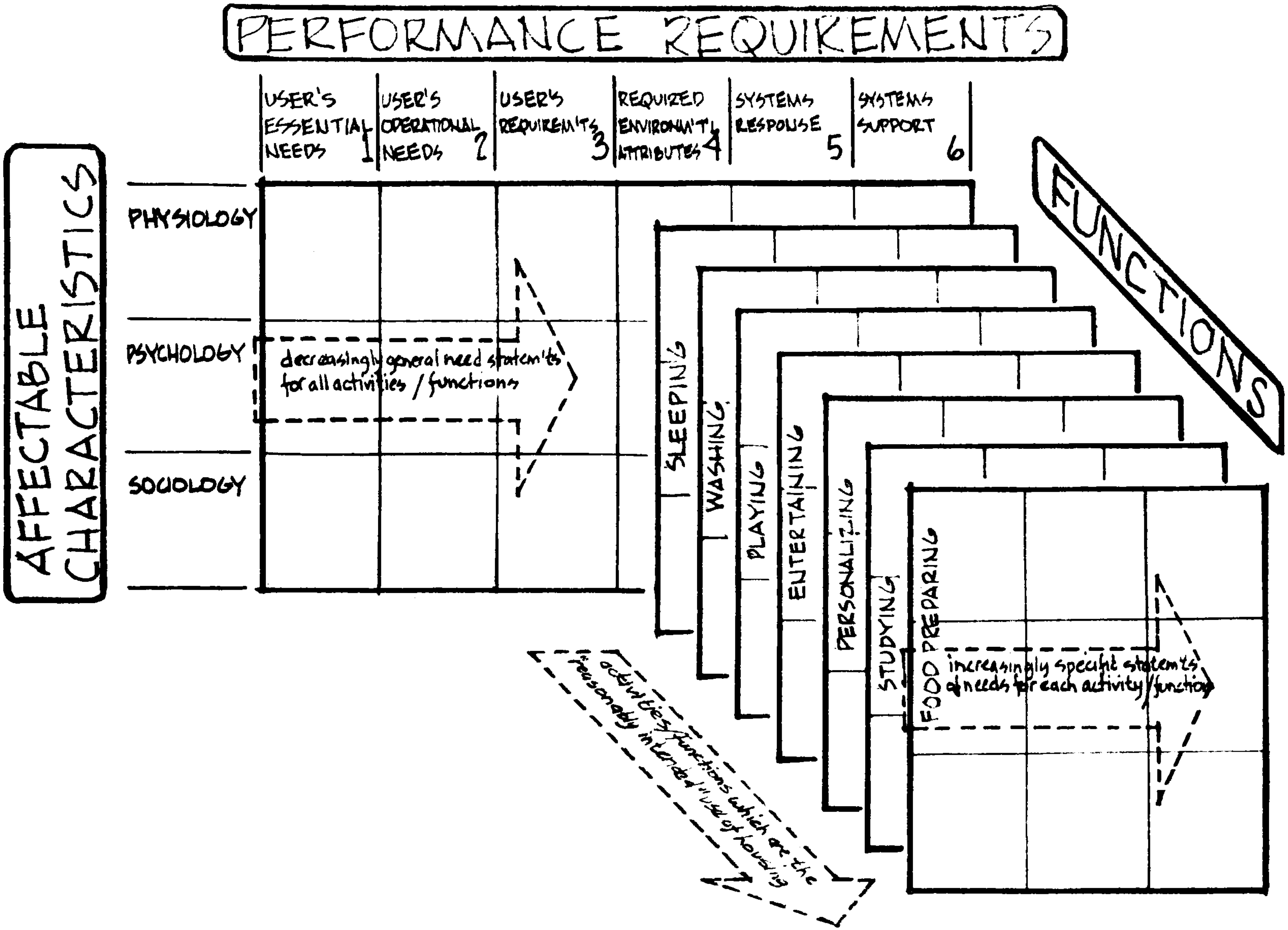
As activities change, the ENVIRONMENTAL ATTRIBUTES must be modified (light, air, acoustics), and the SYSTEMS RESPONSES (lamps, ventilating systems, walls) must be structured to make these changes. The SYSTEMS SUPPORT must, in turn, support the ability of the system to change.

These three elements are the "variables" for activites, and activities charts form overlays on the original chart. See the following chart.

"Looking through" the third dimension (the layers of activities), we can compare ENVIRONMENTAL ATTRIBUTES criteria for compatibility and for ascertaining the design range required for satisfying activity needs. Some of the activities for which environmental criteria must be established are described here, and are listed with the understanding that such a list will change as it is developed further.

ACTIVITIES OR FUNCTIONS:

1. entry, reception and delivery
2. social entertaining and entertainment
3. play
4. communications
5. study
6. business



performance requirements development methodology

4. A SPECIFIC EXAMPLE OF PERFORMANCE REQUIREMENTS

The following example demonstrates how the Generic Performance Requirements for housing may be developed for specific activities or functions into clear statements of user requirements, environmental attributes and systems response. Such statements, with criteria and evaluative techniques added, form the base for Performance Specifications or may be the Specifications themselves.

The Activity chosen as an example is the sum of those functions referred to as food preparation. [See B.3:5.2 for the availability of actual criteria for this topic] Realizing that there are other options available to provide prepared food to housing residents, we have nevertheless assumed the historical posture that such an activity is centered within the individual dwelling unit, and is designed to serve the immediate family and occasional guests. Further, the true systems approach would also examine those functions and spaces affecting or linked to Food Preparation such as the way such food is brought to the dwelling unit, its inventory and storage, the serving, cleaning and waste functions, and secondary uses of such spaces in terms of the cyclic nature of the activity. These are alluded to, but not developed.

We will develop those statements linked to the physiological factors of Food Preparation, starting with the Essential Needs of the User and going from columns 1 through 6, ending with Environmental Systems Support. We will not develop Psychological or Sociological Performance Requirements, but state that such research and development is imperative to fully display alternative systems approaches, and to enable us to make cost-reducing tradeoffs from these alternatives.

Our considerations are:

1. Cooking facilities

2. Food preparation surfaces

3. Basic utensils

4. Water supply

5. Food storage

6. Food serving, dispensing and dining facilities

7. Cleaning facilities

B.3 AVAILABILITY OF PERFORMANCE SPECIFICATIONS

B.3:0 USER NEEDS, PERFORMANCE SPECIFICATIONS, STANDARDS & CODES

A. User Needs

1. Rationale: The basis for the development of performance specifications for procuring housing is the ultimate consumer of such housing, called the USER. Satisfaction of his NEEDS is the most basic goal of housing. The ability to state clearly his own needs is generally not a skill the users possess. Therefore, the bulk of such study and articulation has been carried out by professionals skilled at such work.

2. Existing statements of User Needs:

   The following lists those documents which, in whole or in part, have gone back to the user to develop needs statements for housing.

   There is additional work which has been done on user needs, but for other kinds of man-made structures ranging from office buildings to submarines. In most cases, this other work does not explore psychological and sociological aspects of the users needs.

   The listing is for housing only:

   a. FINAL REPORT: RESEARCH AND DEVELOPMENT MILITARY FAMILY HOUSING
   prepared for Department of Defense--Family Housing
   Contract DACH 15-68-00158
   prepared by General Electric:
   Missile and Space Division & Community Development Division. 1967.

   b. HUMAN NEEDS FOR HABITAT
   A study of the sociological, psychological, and physiological needs of the American nuclear family, to establish performance requirements for industrially produced habitats.
   Unpublished
   by Walter M. Kroner
   Arlington, Mass.
   1966-67.

   c. HOUSING FOR THE ELDERLY COMMUNITY
   A study of basic needs of the aging individual in relation to their housing requirements.
   Unpublished
   William F. Winslow
   1966
   at Rensselaer Polytechnic Institute
   Troy, New York

d. PERFORMANCE-BASED SPACE CRITERIA FOR LOW-COST HOUSING
by Small Homes Council-Building Research Council
University of Illinois at Urbana-Champaign
Mr. Rudard A. Jones, A. I. A., Director and
Mr. William H. Lapple, A. I. A.
prepared for Institute for Applied Technology, 1968.

e. USER REQUIREMENTS FOR SITE PLANNING
unpublished
by Michael Brill
1967-1968

f. USER REQUIREMENTS FOR NEWARK HUMAN RENEWAL CORPORATION
preliminary draft
by Research Center for Urban and Environmental Planning
at Princeton School of Architecture, Princeton University.
Bernard S. Spring, Director
1967

g. PATTERNS & PATTERN LANGUAGE
from Center for Environmental Structure
2701 Shasta Road, Bèrkeley, California 94708
by Christopher Alexander
Sara Ishikawa
Roslyn Lindheim
Murray Silverstein
Sim Van Der Ryan
1967

h. THE BATHROOM-CRITERIA AND DESIGN
by Alexander Kira
for Cornell University and Bantam Book Co.
Ithaca, New York
1967

i. AN INVESTIGATION OF THE SMALL HOUSE
Pratt Institute
School of Architecture
Brooklyn, New York

j. CONSIDERATIONS FOR ENVIRONMENTAL RESEARCH IN HUMAN FACTORS
by Frederick H. Rohles, Jr.
for Institute of Environmental Research
Kansas Engineering Experiment Station
Kansas State University
1965

k. DEVELOPMENT AND EVALUATION OF NEW BUILDING PRODUCTS
by George Christensen and Klaus Blach
for Danish Building Research Institute
Statens Byggeforskningsinstitut
SBI Reprint #171 english translation
1967

l. COMMUNITY AND PRIVACY
by Serge Chermayeff and Christopher Alexander
Doubleday & Co., New York
1965

m. CRITERIA FOR MASS HOUSING
by Alison & Peter Smithson for Team X.
Architectural Design, London W.C1, U.K.
1957-1959

n. PERFORMANCE REQUIREMENTS FOR HOUSING - [Section B.2 of this document]
for Joint project for Department of Housing and Urban Development and Institute for Applied Technology

o. MINIMUM PROPERTY STANDARDS FOR MULTI-FAMILY HOUSING
by Federal Housing Administration FHA #2600

Comment: This document goes beyond User Needs into actual prescription specifications, but chapters are introduced with "general objectives" which are User Needs stated in specific language.

p. BASIC REQUIREMENTS FOR BUILDING CODE
by Joseph Weiler
for Building Code Advisory Review Board
Department of Industry, Labor, and Human Relations
State of Wisconsin, Madison, Wisconsin
1968

q. MEASUREMENTS OF MAN
by Henry Dreyfuss

Comment: Anthropometric data which could be developed into needs.

3. Evaluation: In general, there are NO FULLY DEVELOPED USER NEEDS FOR HOUSING FOR LOW-INCOME CONSUMERS IN URBAN AREAS. A portion of the work done has as its context the detached, or low-density, or non-urban dwelling unit life style. The urban context would alter these User Needs statements, especially those factors of privacy, security, social interaction, personalization, and maintenance responsibility.

The user has been quite thoroughly described in Physiological terms, but very little performance-based language has been developed to make a "bridge" between this information and the physical environment.

A great deal of the work has been done in an academic atmosphere, often without testing. The statements are expressions by extremely capable people working in a very new, very unexplored field, and often attempts to link the criteria-rich "hard" sciences with the measurements-poor "soft" sciences are not successful.

It is a field of very great opportunity for an organized research program whose goal might be: the Development of User Needs for housing. Low-income consumer groups are a special case, and policy decisions would be required to mount research in this specific area. The framework to carry out such work is proposed in section B.4:3 of the Research Recommendations.

B. Performance Specifications for Procurement of Buildings

In this country and Canada there is continuing work whose goal is the procurement of buildings from performance specifications. One group of projects (based on one specification) has been completed, one is under construction, one is being bid and some half dozen are in the process of being developed.

They have as a typical procedure the organization of a large "market" through which they attempt to spur the creative ability of manufacturers to develop innovative responses to performance specifications.

All of the buildings are highly specialized and most are for Educational purposes--they are for schools, laboratories, Federal Office Buildings and college dormitories. None of them are for housing, and are not adaptable for housing in any reasonable manner for reasons in the discussion which follows:

Certain specifications for subcomponents may be adaptable to housing use, but generally the requirements for housing and the uses to which these buildings are to be put are quite disparate.

Certain criteria (temperature, for example) may be the same as that desired for housing but these criteria would be in a range typical for all buildings. The critical criteria are generated from the building's intended use, and it is this difference which prevents the use of these performance specifications for housing.

Further, not one of the performance specification projects has, or is attempting to procure a whole, functioning building. Most of them, for instance do not develop criteria and specifications for external walls, plumbing systems, stairs or elevators.

In the chart which follows, we delineate for each project its status, its intended use, its height and area range, and how much of the building is being procured through the use of performance specifications.

SUMMARY OF PERFORMANCE SPECIFICATIONS FOR PROCUREMENT OF BUILDINGS

PROJECTS COMPLETED

S.C.S.D. (School Construction Systems Development)*

Intended Use:	Schools
Height (max.):	2 Stories
Intended Size:	2.2 million sq. ft.
In-Systems :	Structure
	Lighting/Ceiling
	Partitions
	HVAC
Out-of-System:	Exterior Wall
	Floor Elect.
	Bathrooms
	Plumbing

PROJECTS UNDER CONSTRUCTION

Florida S.S.P. I. (Special Schools Project)

Intended Use:	Schools
Height (max.):	2 Stories
Intended Size:	
In-Systems :	Structure
	Lighting/Ceiling
	Partitions
	HVAC
Out-of-System:	Same as above

PROJECTS UNDER BIDDING NOW

U.R.B.S. (University Residential Building Systems)

Intended Use:	University Dormitories
Height (max.):	13 Floors
Intended Size:	1.6 to 3.2 million sq. ft.
In-System :	Structure/Ceiling
	HVAC
	Bathrooms
	Partitions
	Furnishings
Out-of-System:	Exterior Wall
	Plumbing
	Elevators
	Communication
	Electrical

* A much larger amount of non-SCSD buildings were built using the winning system.

PROJECTS OUT FOR BIDS

Montreal Catholic Schools

Intended Use:	Schools	
Height (max.):	4 Floors	
Intended Size:		
In-Systems :	Structure HVAC Partitions Lighting/Ceiling Electronics	
Out-of-System:	Exterior Walls	

PROJECTS IN SPECIFICATION WRITING

Metropolitan Toronto School Board

Intended Use:	Schools	
Height (max.):	5 Floors	
Intended Size:	1.5 million sq. ft. - 1970 $1/2 billion/10 yrs.	
In-Systems :	Structure Atmosphere Lighting/Ceiling Int. Space Divider Casework	External Skin Plumbing Electricity Roofing Int. Finishes
Out-of-System:		

Public Buildings Service

Intended Use:	Office Buildings	
Height (max.):	N.A.	
Intended Size:	1 million sq. ft.	
In-Systems :	Structure HVAC Utilities Luminaires Floor	Ceiling Space Dividers
Out-of-System:	Core Elements Exterior Wall Perimeter HVAC	

PROJECTS UNDER RESEARCH

A.B.S. (Academic Building Systems)

Intended Use:	Academic Buildings
Height (max.):	Under Research
Intended Size:	Under Research
In-Systems :	Under Research
Out-of-System:	Under Research

Florida S.S.P. II. (Special Schools Project)

Intended Use:	Schools
Height (max.):	Under Research
Intended Size:	Under Research
In-Systems :	Under Research
Out-of-System:	Under Research

SPECIAL PERFORMANCE PROJECTS

Pittsburgh Great Schools
Binghamton Laboratories (S.U.N.Y.)
S.U.N.Y. Performance Research

Projects not done for "bidding" purposes, rather to set performance standards for the Architectural design of buildings

C. Current Application of Performance in Specifications, Standards and Codes

In considering the application of performance requirements, criteria, specifications, and standards to housing and the impact of this procedure on innovation, it was necessary to develop a set of generalized performance requirements for each of the major components or subsystems in a dwelling that was independent of the materials and arrangement used. Then, to assess the degree of use of performance language in the design and construction of present-day housing, it was necessary to focus those generalized performance requirements on the solutions, specifications, and standards now in effect. Finally, the analysis, test development, and standards production required to attain a satisfactory future position in the application of the performance concept to low-income housing was summarized.

This analysis is presented under the five main sections and 16 subsections identified in the following outline. The discussion is related to the performance of a single building and does not deal with community interactions. Although, each of the 16 sub-elements is treated separately, there is recognition and discussion of the fact that no sub-element of a dwelling functions independently of the others, and that laboratory and field research on performance must provide for system evaluation and the simultaneous measurement of more than one characteristic at a time.

Many of the better known building codes, building regulations, and so-called "performance specifications" generated in recent years for procuring various types of buildings were examined for performance requirements, criteria, test methods, and specifications that might be directly or indirectly applicable to low-income housing. The results of these examinations are included in the discussion of the 16 sub-elements which follows, and the subsections where this discussion may be found is summarized in table 1. A great many additional test methods, standards, specifications, and codes were studied for the various sub-elements of a dwelling, and the provisions of these publications are also discussed in the following textual material.

Table 1

Subsection Identification of Discussion on Performance Requirements for Various Regulations and Specifications

Specification, Code, Standard, or Other Building Regulation	Structural Systems	Fire Protection	Falls	General Safety	Durability, Time Dimension of Perf.	Air, Moisture, Water Penetration	Acoustics	Air Cleaning and Odor Control	Thermal Environment	Visual Environment	Plumbing	Food Services	Energy Sources	Electrical Systems	Mechanical Systems	Transportation
Sch. Constr. Systems Development (SCSD)	B.3.1.0	Principal Sources: ASTM and NFPA			Principal Sources: ASTM, USASI, Fed. Stds.	B.3.2.0	B.3.4.1		B.3.4.3							
Univ. Residential Building Systems (URBS)	B.3.1.0					B.3.2.0	B.3.4.1				B.3.5.1					
FHA Min. Prop. Stds.	B.3.1.0						B.3.4.1	B.3.4.2	B.3.4.3	B.3.4.4		B.3.5.2		B.3.5.4	B.3.5.5	B.3.5.6
N. Y. State Building Code	B.3.1.4 Table II						B.3.4.1	B.3.4.2	B.3.4.3		B.3.5.1					
Canadian Building Code	B.3.1.4 Table II								B.3.4.3	B.3.4.4						
European Agrément Syst.						B.3.2.0					B.3.5.1					
N. Y. City Bldg. Code	B.3.1.0						B.3.4.1		B.3.4.3							
Uniform Building Code	B.3.1.4 Table II									B.3.4.4						
BOCA Building Code	B.3.1.4 Table II									B.3.4.4						
Southern Building Code	B.3.1.4 Table II									B.3.4.4						
National Building Code	B.3.1.4 Table II															
Chicago Building Code	B.3.1.4 Table II															
Natl. Building Regs. (England and Scotland)	B.3.1.4 Table II						B.3.4.1		B.3.4.3		B.3.5.1					
ISO Recommendations							B.3.4.1									

Outline of Discussion of Performance Characteristics and the State-of-the Art

1. Structural Systems

2. Safety

   2.1 Fire Protection
   2.2 Falls
   2.3 General Safety

3. Durability

   3.1 Durability, as the Time Dimension of Performance
   3.2 Air, Moisture, and Water Penetration

4. Environmental Characteristics

   4.1 Acoustical Environment
   4.2 Air Cleaning and Odor Control
   4.3 Thermal Environment
   4.4 Visual Environment

5. Service Systems within Housing

   5.1 Plumbing
   5.2 Food Services
   5.3 Energy Sources
   5.4 Electrical Systems
   5.5 Mechanical Systems
   5.6 Transportation

1. STRUCTURAL SYSTEMS

1.0 Executive Summary

Several attempts have been made in the past to introduce performance specifications for buildings (S.C.S.D., U.R.B.S., Apartments in Harlow Urban district, Britain). In all these cases performance is defined sufficiently to enable private industry to devise creative solutions by their own initiative. In none of these cases is the concept of performance developed in all areas of building technology (or rather user requirements) and the solutions will consequently conform to traditional standards wherever performance is not specified.

A much more thorough and also a much bolder approach will have to be taken in order to bring about creative innovations by private industry in all areas of building technology. A major long term effort in this field is therefore justified. However, such a long term effort does not and should not preclude the rapid introduction, through a short term project, of performance specifications into the field of low income housing. Although such a short term project will not lead to the ultimate in performance specifications, it will set the stage for the development of true user-related performance standards. Such a move would be important and highly desirable, since no amount of research will bring about the perfection of performance specifications without the feedback from actual project experience.

In the structural field no performance specifications, other than those contained in already existing building codes, have been introduced in the SCSD, URBS, and Harlow projects. Structural performance specifications and appropriate test methods, which could be used in an actual project, could be developed in a 6 to 8 month effort. The feedback from projects combined with a more extensive research effort could lead to a more advanced document at a later stage and eventually to the development of true performance codes.

The following effort is proposed in order to develop the first set of structural performance specifications.

1.0.1 General Policy:

Structural performance will be defined in terms of strength, static deflections, dynamic deflections, and settlements.

1.0.2 Loads:

Wind Load: USASI A58 Subcommittee Report on Wind Loads (Unpublished)
Snow Loads: "Design Snow Loads for Contiguous United States" (Ref. 32, Unpublished).
Seismic Loads: USASI A58 Subcommittee Report on Seismic Loads [21]* (Unpublished) or SEAOC Code [22].
Live Loads: USASI A58, 1955 [12] or FHA - M.P.S.
Dead Loads: USASI A58, 1955. [12].
Combined Loads: AISC Code, ACI Code, ASA A58, 1955.
Soil, Hydrostatic and Thermal Loads: Development of criteria based on established engineering practice.
Sonic Boom: 6 - 8 month effort will probably not be sufficient to develop criteria.

* Numbers in brackets identify references at end of Sec. 1, STRUCTURAL SYSTEMS.

The above criteria will be modified and expanded by the following research efforts: See Section 1.5, Parts 1.5.1, 1.5.2, 1.5.3, 1.5.4, (may not yield results in short effort), 1.5.5 and 1.5.6.

1.0.3 Strength:

Determine collapse loads and loads causing inelastic deformations by recognized engineering principles. Specify test methods. Research. See Section 1.5, Part 1.5.11.

1.0.4 Static Deflections:

F.H.A. - Minimum Property Standards, expand and devise test methods. Research Section 1.5, Part 1.5.9.

1.0.5 Vibrations:

Attempt to establish criteria by references [44], [45], [47], and Research Section 1.5, Part 1.5.10. (6-8 months effort may not be successful).

1.0.6 Settlements:

New York City Code for foundations, Research Section 1.5, Part 1.5.12.

Structural performance specifications and criteria as outlined in Sections 1.3.5 and 1.3.6, will be quantitatively developed and ready for implementation at the end of the proposed short term effort. In all areas where criteria cannot be developed in the proposed period of time, traditional code provisions will be adopted and perhaps slightly modified to supplement the performance specifications.

This first effort should proceed simultaneously with other research efforts which will not yield results at the end of a 6 - 8 month period.

1.1 Introduction

The rapid development of modern technology has had only limited impact on residential housing. This is due to the restraining effect of modern building codes as well as the inertia inherent in the use of criteria which are responsive only to conventional systems and materials.

Performance specifications for low income housing will define performance in terms of occupant requirements. This will enable private industry to develop solutions which are responsive to these requirements, provided that restrictive code provisions essentially based on past experience with conventional systems can be relaxed. The introduction of performance specifications will thus encourage progress by:

1) replacing restrictive code provisions,
2) developing criteria related to user requirements rather than to existing hardware systems, and
3) providing to industry an incentive for innovation.

In order to develop performance specifications, user needs must be identified and user requirements must be developed from user needs, taking into account financial and other constraints. System response to user requirements must be defined in terms of performance criteria which are quantitative definitions of response to user requirements. Tests and/or analytical methods must be developed to determine compliance with performance criteria.

Structural performance is part of the total performance of the system which comprises a multi-family dwelling. It will define performance of supporting structural elements which comprise a subsystem that supports all loads caused by the system and acting on the system, as well as structural performance of all other elements of the system.

The purpose of this study is:

1) Identification of qualitative structural performance criteria.
2) Identification of research necessary to develop quantitative structural performance criteria.
3) Identification of research necessary to develop the test methods, testing equipment and analytical methods necessary for the determination of compliance with structural performance criteria.
4) Identification of research which will advance the state of the art to permit formulation of performance criteria which cannot be implemented at the present time.

The results of this study are presented herein.

1.2 Summary

At the present time, structural performance criteria which are directly related to user requirements and not to specific systems and materials are in many cases nonexistent or poorly defined. Further study and research are therefore needed in order to define performance requirements and ultimately to create a performance code.

Occupant requirements that must be satisfied by structural performance of housing are safety, task support, comfort, esthetics, maintenance, and durability.

Structural performance must be defined in terms of system reliability, where structural subsystems are considered as part of the entire system.

Performance criteria must be developed which will enable the measurement of structural performance in terms of user requirements.

Structural performance will be stated in terms of strength, static deflections and dynamic deflections.

The performance of structural supports (foundations) will be stated in terms of strength, static deflections, dynamic deflections, and settlements.

The introduction of the concept of reliability will require probabilistic determination of loads.

Test methods and/or acceptable analytical methods must be available for quantitative determination of compliance with performance criteria.

1.2.1 Currently existing structural performance specifications:

Currently existing structural performance specifications are either related to user requirements or to existing systems. Those related to user requirements are definitions of design loads and strength. Those related to existing systems are static deflections, dynamic deflections due to earthquakes, and specifications for structural supports. No performance specifications exist for dynamic deflections due to vibrations.

Specifications for performance testing of materials and structural assemblies for strength and static deflections are in existence, but they are mostly related to conventional systems and materials. No specifications exist for performance testing of structural assemblies integrated with other subsystems and for testing of dynamic deflections.

Few of the existing user-related performance specifications can be directly applied to the HUD project without modifications. Most specifications must be restated to meet required performance criteria.

1.2.2 Research leading to development of structural performance specifications

The following research will lead directly to the development of structural performance specifications:

1) Development of a comprehensive testing program, including assemblies combining different subsystems and full-scale tests on structures.
2) Probabilistic definition of atmospheric loads.
3) Definition of performance criteria for static deflections.
4) Definition of performance criteria for structural supports.
5) Definition of ductility as related to earthquake loads.

1.2.3 Research to advance state-of-the-art and add or improve performance performance specifications

The following research will advance the state-of-the-art and lead to additional or improved performance specifications:

1) Development of methods for full-scale test of structures and use of scale models to predict full-scale structural behavior.
2) Observation of wind loads on prototype structures and correlation with wind tunnel studies.
3) Research on the actual occupancy loads in buildings.
4) Test methods and performance criteria for dynamic deflections.
5) Earthquake loads as related to surficial geology.
6) Snow gaging by weight.
7) Development of small-scale model testing.
8) Structural testing and performance criteria under fire conditions.
9) Development of criteria for response to sonic boom.

1.2.4 Generalized structural performance specifications

Under any combination of environmental loads, building loads and man-made loads (either static or dynamic) likely to occur at any time, the structure as a whole, the structural support, and any supporting or non-supporting element thereof shall have acceptable levels of reliability of structural performance against:

1) Total collapse,
2) Damaging stresses,
3) Structural collapse and disruption of vital services by excessive deflections during a fire,
4) Static or dynamic deformations and settlements which would
   a) Impair the usefulness, reduce the durability or unduly increase the maintenance of any structural or other subsystem element.
   b) Cause distress and separation of building fabric or finishes.
   c) Cause distress to or interference with the proper functioning of mechanical and service systems.
   d) Interfere with the proper functioning of windows, doors, or other openings.
   e) Interfere with the connections to utilities outside the

building and disrupt access facilities.
f) Create safety hazards.
g) Have undesirable esthetic effects.
h) Cause excessive noise, discomfortable vibrations, or cause any structural element to vibrate at resonant frequency under anticipated excitation.
i) Cause discomfort, anxiety or nuisance to the occupant.

5) Damage to adjacent properties caused by forces exerted by the structure on supporting soil and rock formations.

1.3 Qualitative Statement of Performance Criteria and Specifications

1.3.1 User Requirements

The purpose of a human dwelling is to fulfill certain needs of its occupants. A multi-family dwelling is therefore a system which responds to human needs. No system will satisfy all the needs that occupants may desire it to satisfy. User requirements must be developed which will account for constraints imposed by financial limitations and other causes.

The following user requirements must be satisfied by structural performance:

1) Safety
2) Task support
3) Comfort
4) Esthetics
5) Maintenance
6) Durability

Maintenance and durability have been included since, from the point of view of structural performance, cost is not only a constraint on user needs to be satisfied, but also a first-order occupant requirement.

Durability requirements should be set with technological and social obsolescence in mind.

1.3.2 Trade-offs

Low income housing will never satisfy all user needs because of the diversity of these needs and the constraints imposed on engineering solutions. In this case the most important constraint is obviously financial.

System-oriented performance specifications permit us to evaluate each component of the system in terms of occupant needs. Performance specifications should provide the flexibility to sacrifice the quality of the response to one need in favor of the response to some other need which we deem to be more important. For instance, some discomfort caused by vibrations in stairways and corridors may be tolerated in favor of improved comfort in the living room.

These adjustments, which should be made during the development stage of a project, will hereafter be defined as "tradeoffs."

1.3.3 Interfaces

Structural elements of a building interact with several other subsystems:

1) The infrastructure.
2) The site.
3) The external environment.
4) Supporting or abutting soil.
5) Mechanical and service systems.
6) Windows, doors, or equivalent.
7) Surface covers and finishes.

On each of these interfaces the structural elements must satisfy interaction requirements in a manner consistent with occupant needs.

1.3.4 Proposed Policy on Structural Safety and Reliability

Traditionally, the load-bearing capacity of structures and structural elements is determined by the "working stress" method, which is based on the assumption that a certain safe maximum stress should not be exceeded at any point in the structure or the structural element. The safe working stress is arrived at by dividing the stress which would cause failure or inelastic deformation by a safety factor which is dependent on the material. Loads acting on the structure (design loads) are assumed to be loads or combinations of loads not likely to be exceeded during the useful life of the structure.

More recently, the concept of "ultimate strength" has been developed, which generally makes the assumption that total collapse of the structure or the structural element rather than maximum stress at one point should be the design criterion. In this case, a factor of safety is applied to loads rather than stresses, and the structure or structural element will reach the point of collapse only when subjected to a combination of loads which correspond to the design loads multiplied by a suitable factor of safety.

In general, "working stress" methods and "ultimate strength" methods of structural analysis will not yield identical results, since materials capable of inelastic deformations will yield at points of maximum stress and a significant redistribution of stresses will subsequently take place. It may be stated that in general, working stress methods of structural analysis will tend to be related to serviceability of the structure under expected loading conditions, while ultimate strength methods will tend to be related to safety under extreme loading conditions.

No structure can be absolutely safe from collapse, even though the probability of collapse may be very small, and no structure can be expected to be serviceable under all combinations of loads that may occur during its useful life, even though the probability of unserviceability may be small. The true determination of safety and serviceability must therefore be ultimately based on the probability of occurrence of certain load combinations, as well as on the probability of a certain structural behavior under the action of applied loads. In a broader sense, if we consider a human dwelling to be system, safety and serviceability must be evaluated for the entire system. No system can be optimized if these parameters are evaluated independently for each subsystem.

Hence it appears that truly performance-oriented specifications must consider the entire system as one entity. It should therefore be attempted to introduce the concept of reliability for the entire system, and in this general context the reliability of structural elements will be evaluated as part of the reliability of the system.

It appears that more than one level of performance must be considered:

Level 1. Total collapse, conflagration and other catastrophic failures.
Level 2. System performance under most extreme conditions (loads not likely to be exceeded during its useful life).
Level 3. System performance under prevailing conditions (loads not likely to be exceeded in a shorter period of time, say 5 years).

Level 1.

It may be difficult to accept a probability to failures which are likely to cause loss of life. However, this approach cannot be practically avoided.

Let us consider the case where a large investment is needed to lower the probability of total collapse of a structure during its lifetime from 1:10,000 to 1:20,000 while the probability of a catastrophic failure of another subsystem is 1:5,000. In such a case it may have been more reasonable to attempt to lower the probability of catastrophic failure of the other subsystem.

The total reliability of the system with respect to catastrophic failure should therefore be determined and the reliability of structural elements should be considered as part of the problem.

One method of determining a reasonable probability of catastrophic failure may be a "Total Loss Criterion" similar to that proposed by Tukstra (1967) [1].* Total Loss = Initial Cost + Failure Loss x Failure Probability = Minimum. "Failure Loss" in this case would include the cost of the loss of human life to society. This approach seems logical and feasible; however, different approaches, i.e., a predetermined uniform probability of catastrophic failure may be adopted.

Reliability of structural elements and of the total system could be determined by methods similar to those proposed by Cornell [2] and Benjamin [3] in 1967. Great difficulty will be encountered in the determination of "collapse loads" in the terms of probability. In the case of atmospheric loads this will require extrapolation of existing date. In the case of occupancy loads the difficulty may be even greater. Attempts to determine probability of occupancy loads have been made only in few instances: Bryson [4] (1968), Johnson [5] (1953), Harne [6] (1951); and the probability concept is introduced in the Mexican Building Code [7] (1966). Load requirements in conventional codes are generally deterministic; however,

*Numbers in brackets identify references at end of Section 1.

provisions are frequently based on probability, i.e., load reductions permitted for large floor areas and multi-story buildings, windloads, snowloads, earthquake loads, and combinations thereof.

Dynamic wind loading based on a probabilistic approach has been studied by Davenport [8, 9] (1966 and 1967), and earthquake loadings by Rosenblueth [10] (1964), and Cornell [11] (1964).

The ASCE Task Committee on Structural Safety, which will report conclusions in 1968, may introduce some recommendations which contain elements of reliability-based code requirements. However, extensive additional research is required in this area.

In the interim, it is proposed to use system reliability as a general policy in the determination of collapse loads, even though many simplifying and sometimes arbitrary but safe assumptions must be made in the absence of probability-related load and structural performance date.

Level 2:

If we define the "most extreme" conditions as conditions which are likely to occur only once during the useful life of the structure, a different policy than in Level 1 must be adopted. Evidently we do not want every structure to collapse during its useful life; however, it would also be unreasonable to expect the system to meet all normal occupancy requirements during the most extreme loading conditions. As a general policy, it is proposed for this case to relax all comfort- and maintenance-related requirements. It is also proposed not to permit damage to supporting structural elements.

However, with respect to permanent structural damage to non-supporting elements or to relatively minor elements of other subsystems, a "Total Loss Criterion" [1] may be appropriate, which in this case would result in permissible permanent damage only if major savings in initial cost can be demonstrated.

Considerable difficulty will again be encountered in the determination of most extreme loadings; however, in the absence of other data, it may be assumed that by and large, "design loads" recommended in codes will attempt to correspond to these conditions.

Level 3:

System performance under prevailing conditions should meet all user requirements and any tradeoffs on this level will result in obvious deficiencies. The statistical definition and determination of prevailing conditions will present considerable difficulties because of lack of data.

1.3.5 Structural Performance Requirements and Specifications

1.3.5.1 User Requirements:

1. Safety
2. Task Support
3. Comfort
4. Esthetics
5. Maintenance
6. Durability

1.3.5.2 Interfaces:

1. Infrastructure
2. Site
3. External Environment
4. Supporting of Abutting Soil
5. Mechanical or Service Systems
6. Openings (Windows, doors)
7. Surface Covers and Finishes

1.3.5.3 Loads to be resisted:

a. Environmental Loads:
   1. Wind loads
   2. Snow loads (Ice, Rain)
   3. Seismic loads
   4. Soil and hydrostatic loads
   5. Flood and wave loads
   6. Thermal loads

b. Man-made Loads:
   1. Occupancy loads
   2. Construction loads
   3. Fire loads
   4. Blast loads
   5. Sonic boom loads
   6. Site loads
   7. External Shock or vibration loads

c. Building System Loads:
   1. Self loads
   2. Mechanical or subsystem loads

1.3.5.4 Definition of Structural Elements

a. The supporting structural elements comprise a subsystem which supports all system loads and all external loads acting on the system.

b. Non-supporting structural elements support their own weight, the weight of their surface covers, finishes, service systems attached to them, and incidental occupancy loads that may be imposed on them.

Some structural elements are always supporting elements; i.e., foundations, columns, beams, trusses, rigid frames, roofs, shell structures and bracing systems.

Other structural elements may or may not be supporting elements; i.e., interior and exterior walls, floors and ceilings.

Performance specifications will distinguish between supporting and non-supporting structural elements because of their functional difference.

1.3.5.5 Generalized Statement of Structural Performance Specifications:

Under any combination of static and/or dynamic environmental loads, man-made loads, and building loads, likely to occur at any time:

1) The structure as a whole, any supporting structural member and the structural supports (foundations) shall have acceptable levels of reliability of performance against total structural collapse and other catastrophic failure.
2) The structure as a whole, the structural supports and any supporting and non-supporting structural member shall have acceptable levels of reliability of performance,

   A. Against distress caused by excessive stress and/or deflections.
   B. Against structural collapse and disruption of vital services by excessive deflections during a fire.
   C. Against static and dynamic deflections which

      a) will impair the usefulness, reduce the durability or unduly increase the maintenance of any structural or other subsystem element;
      b) will cause distress and separation of building fabric or finishes;
      c) will cause distress or interfere with the proper functioning of mechanical and service systems;
      d) will interfere with the proper functioning of windows, doors or other openings;
      e) will create safety hazards;
      f) will have undesirable esthetic effects;
      g) will cause excessive noise, discomforting vibrations, or cause any structural member to vibrate at resonant frequency under anticipated excitation;
      h) will cause discomfort, anxiety or nuisance to the occupants.
3) The structural supports shall have acceptable levels of reliability

   A. Against failure by yielding or excessive settlement of supporting soil or rock formations including failure caused by sensitivity to vibrations, against failure due to instability of the supporting formations and against failure caused by change in ground water levels.

B. Against excessive settlements and/or differential settlements which

a) will cause distress as defined in 2)-A;
b) will cause deflections as defined in 2)-B;
c) will interfere with the connections to utilities outside the building and disrupt access facilities;
d) will have undesirable esthetic effects;
e) will create safety hazards.

C. Against damage to adjacent properties caused by forces exerted by the structure on supporting soil or rock formations.

1.3.6 Structural Performance Criteria

1.3.6.1 Reliability

Three levels of reliability will be considered in the evaluation of structural response (See "Policy on Structural Safety and Reliability").

1) Reliability against total collapse and catastrophic failure.
2) System performance under most extreme loading conditions.
3) System performance under prevailing loading conditions.

Criteria for structural reliability are summarized in Table I.

Table I: Suggested Structural Reliability

	a Supporting Structural Members	b Non-Supporting Structural Members	c Structural Supports
1. Structural collapse & catastrophic failure	Suggested probability 1/10,000 or less	----	Suggested probability 1/10,000 or less
2. Distress caused by excessive loads and deflections	Probability to be determined	Probability <1 during useful life of structure	As in 2-a
3. Excessive static and dynamic deflections	Suggested recurrence interval 1 - 5 years	Suggested recurrence interval 1 - 5 years	As in 3-a
4. Failure of structural supports	----	----	Suggested probability 1/10,000 or less during useful life of structure
5. Settlements and/or differential settlements	As in 2-a	As in 2-b	As in 2-a
6. Fire endurance	Length of exposure time to be determined	Length of exposure time to be determined	Length of exposure time to be determined

Discussion of Table I.

1. Recommended Loads and Load Combinations:

    a) Structural collapse and failure of supports(items 1 and 4 in Table I): Loads or load combinations having a probability of 1/10,000 to occur during the lifetime of the structure.
    b) Distress and settlements (items 2 and 5): Loads or load combinations having a probability of less than 1 to occur during the lifetime of the structure.
    c) Static or dynamic deflections (item 3): Loads and load combinations not likely to be exceeded more than once in a period of 1-5 years ("prevailing"loads).
    d) Fire loads: Policy must be set for exposure time.

2. Reliability of Structural Response:

    Material properties must be taken into account when probabilities in a, b, and c (Table I) are evaluated.

3. Simplification of Reliability Criteria:

    Requirements can be simplified by:
    1) Stating actual loads in load combinations a, b, c, and d (Table I) in the performance specifications.
    2) Stating allowable stresses and yield stresses for conventional materials.
    3) Specifying standard test procedures by which allowable loads and/or stresses can be determined.

1.3.6.2 Strength

Criteria for strength will include criteria for total collapse and criteria for distress.

1) Total collapse of the structure as a whole or any supporting structural member shall occur only under a load or load combination as defined in a) above (Recommended Loads and Load Combinations).
2) Distress in any supporting or non-supporting structural member by permanent deformation or major damage to any other subsystem by excessive deflections shall not occur under any load or load combination smaller than the loads defined in b) (Recommended Loads) *.

It should be noted here that a tolerable amount of creep, which may be defined as "permanent deformation" must be permitted within the limits of "allowable deflections."

* An exception to this criterion would be made for certain non-supporting structural members, on the basis of sufficient economic justification.

The following other factors must be taken into consideration and provided for in performance criteria:

1) In structural elements subject to repeated cycles of loading, allowable loads must be modified in accordance with accepted theories and/or with test results.
2) In the case where structural performance of materials is influenced by temperatures within the range of extreme temperatures to be expected during the useful life of the building, unfavorable temperature conditions must be taken into consideration in the determination of allowable loads.

Test procedures for materials, structural elements and full-scale structures must be developed in order to evaluate compliance with criteria. Such test procedures will also include accepted methods of structural analysis.

1.3.6.3 Static Deflections:

Static deflections are a function of rigidity and not necessarily of strength. Members may assume excessive deflections without suffering distress.

The following performance criteria will be formulated:

1) Maximum allowable deflections within dimensional tolerances.
2) Maximum allowable deflections in terms of distress of surface covers and finishes.
3) Maximum allowable deflections in terms of proper functioning of and damage to service systems.
4) Maximum deflections that will not interfere with openings.
5) Maximum deflections that will not interfere with maintenance.
6) Maximum deflections that are esthetically acceptable.

The following also must be considered when deflection criteria are formulated:

a) Deflections in certain structural materials are associated with cracking. Cracking may be tolerated within esthetically and functionally acceptable limits.
b) Most materials will creep under prevailing loads.
c) When dead load deflections are offset by pre-camber they shall not be considered part of the total deflection.

1.3.6.4 Dynamic Deflections:

1) Vibrations. Criteria for human tolerance to vibrations must be formulated. Limits for tolerable vibrations may be different in different areas of the building. The following must be considered:
   a) Vibrations generated by activities within the building;
   b) Vibrations generated by mechanical and service systems;
   c) Transmission and damping of vibrations from outside the building.

2) Wind. Criteria for dynamic effects caused by wind will include: a) gust response; b) prevention of objectionable wind-induced noise caused by windows, siding, connections and geometric configurations.
3) Earthquake. Dynamic deflection due to earthquake will be mainly considered in terms of strength (prevention of structural collapse) rather than human comfort or minor damage.
4) Sonic Boom. Criteria for response to sonic boom will include vibratory response and noise reduction in terms of human perception as well as consideration of damage that repeated sonic boom may cause to siding, windows and surface finishes.

Considerable research will be necessary before such criteria can be developed.

1.3.6.5 Settlements

Criteria for settlements will be formulated on the basis of performance. The following criteria must be formulated:

1) Maximum settlements in terms of disruption of access and utilities.
2) Maximum settlements in terms of esthetical appearance.
3) Maximum settlements and/or differential settlements in terms of structural damage.
4) Maximum settlements and/or differential settlements in terms of allowable deflections.

1.3.6.6 Structural Performance During Fire:

Structural performance criteria during fire will be stated in terms of structural endurance in a fire. Requirements for fire duration must be set and test procedures to determine compliance must be specified.

1.4. Performance Requirements: Present Status

1.4.1. Loads

1.4.1.1 General

Performance specifications will strive to:

1) Define loads in terms of their probability of occurrence;
2) Relate loading requirements as closely as possible to actual loading conditions.

Probabilistic definition of loads and accurate prediction of loads will lead to optimized design. However, in the public interest, safe assumptions must be made wherever there is uncertainty.

Probabilistic definition of loads will permit introduction of the concept of reliability and the use of different levels of reliability to achieve safety, durability and serviceability. Refer to first draft of "Proposed Policy on Structural Safety and Reliability" .

The state of the art in the area of determination of design loads is evaluated in the following sections.

1.4.1.2 Wind Loads

Most major U. S. codes relate resistance of structures to wind loads to actual anticipated wind loads, based on past experience. However, existing codes do not fully reflect the present state of the art in the field. Present practice is probably best reflected in USAS A-58-1955 [12].

The present state of the art in this field is more accurately reflected by the tentative report of the subcommittee on minimum wind and snow loads of USASI Committee A-58 [13].** The document has not yet been approved by all committee members, and may be subject to minor revisions.*

The dynamic response of structures to random gusts is taken into account in the proposed document. However, recent studies conducted on full-scale structures subjected to gust loads indicate a rather wide discrepancy between model and prototype data [51]. In addition, there are indications that present techniques of model testing do not yield results which are consistent from one wind tunnel to the next [52]. Since these tests constitute the bulk of the data upon which building codes governing static wind loading are based, there is a definite need to establish criteria for wind tunnel testing.

The following additional research is desirable in order to (a) achieve an understanding of the basic phenomena which are associated with the wind loading of structures; (b) improve the information on which the report is based; (c) make the criteria applicable to probabilistic design; and (d) permit accurate determination of parameters used in the report.

1) Research project to determine the scope, nature and cost of additional research needed in the field of wind loads.
2) Correlation of atmospheric turbulence data in open country with measured response of buildings.
3) Investigation of wind effects on building elements such as cladding and window panels.
4) Improve knowledge of effects of flow alteration in urban areas by performing measurements similar to 2) in urban areas of typical configurations.
5) Extension of statistical analysis to determine winds of recurrent frequencies required for determination of structural reliability.

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* This document is based on wind data which were not available in 1955.
** Numbers in brackets identify references at end of Section 1.

6) Development of experimental methods for the determination of resonant frequencies and damping of structures (parameters in determination of gust response).
7) Research concerned with the physiological consequences of wind-induced oscillations and aeolian noise.
8) Determination of wind tunnel test methods

1.4.1.3 Snow Loads

Most major codes relate required resistance of structures to snow loads to actual anticipated snow depth in various regions. Present practice is best reflected in USASI A58-1955 [12]*

Even though the present requirements for snow loads are performance-oriented, they are based on only one variable--snow depth. The second variable is snow density, a random variable with no correlation to snow depth.

The preliminary report of the subcommittee on wind and snow loads of USASI Committee A58 [32] proposes the distribution of maximum annual water equivalent [33] as a basis for design snow loads. This is proposed in the unpublished document "Design Snow Loads for the Contiguous United States." This document best expresses the present state of the art on snow loads and could be adapted to the HUD project. Special provisions should also be made for the effect of snow drift [29].

Proposed additional research:

1) Extension of frequency ranges developed in the "Distribution of Maximum Annual Water Equivalent" to permit determination of reliability.
2) Program of snow gaging in terms of weight per unit area.

1.4.1.4 Seismic Loads

Performance specifications relating to seismic loads were developed in many U. S. and foreign codes. Present practice is best reflected in the SEAOC Code "Recommended Lateral Requirements" [22].

The January 1967 draft of the subcommittee on seismic loads of USASI Committee A 58 [21] together with the revision of Sections 6.1.2 and 6.8 which were proposed in February 1968 but rejected by a committee majority, reflect the present state of the art and do not substantially differ from the SEAOC Code.

The rejected revisions tried to define "ductility" without reference to specific materials. Such revisions would be important in a performance-oriented document. However, a measure for structural ductility must be developed before the concept can be applied effectively.

* Numbers in brackets identify references at end of Sec. 1, STRUCTURAL SYSTEMS.

Proposed additional research:

1) The relationship between overburden (surficial geology) and seismic loads.
2) Research leading to a definition of structural ductility, applicable to all materials.

1.4.1.5 Live Loads (occupancy loads)

Live loads are defined in all major U.S. Codes. USASI A58-1955 [12] probably reflects present practice, except for some minor variations.

Research [42] is currently underway at NBS to gather scientific information on the nature and characteristics of occupancy loads in buildings.

Preliminary investigations of the subcommittee on dead, live and fire loads of USASI Committee A58 indicate that there is general consensus that further research is needed.

In general, loads stipulated in codes represent loads not likely to be exceeded during the lifetime of the structure. Probabilistic data are generally not available.

Recently conducted research by the British Standard Institution [41] has led to new recommendations for dead and imposed loads in Britain.

Performance specifications would enable us to reduce some of the requirements by rational criteria developed as a result of specific usage of certain areas; however, the approach must be careful and conservative. A stipulation to that effect could be incorporated in performance specifications, requiring sufficient justification whenever a reduction of code requirements is proposed.

Existing U. S. Codes, with exception of the New York State Code, contain little information on loading requirements for vertical walls. Such requirements must be developed in anticipation of unconventional design.

Proposed Research: Survey and evaluation of live loads in multi-family housing, including statistical analysis of frequency of occurrence of loads. This would have to include a study of living habits of low-income families with respect to their effect on live loads on floors, corridors, stairways, play areas, etc.

1.4.1.6 Dead Loads

Existing code provisions may be adapted to the HUD Project without modification (See ASA A58 1955 [12].)

1.4.1.7 Combined Effect of Loads and Load Reduction

Existing codes recognize that the probability of simultaneous occurrence of maximum wind, maximum snow, earthquake and maximum live loads or even any two of these conditions is extremely low. Design loads for this combined effect are therefore reduced. Similarly, load reductions are permitted to allow for the low probability of simultaneous loading of large areas.

Ultimately, a performance code should consider such load combinations from a probabilistic point of view; however, only extensive studies could justify a change in present policies, which are generally performance-oriented. However, current policies of load reductions, which are not identical in all the major codes (see AISC Code, ACI Code, ASA A58) are also in part a result of consideration of specific construction materials (e.g., consideration of overstress of wood for short-term loading conditions).

Since the HUD project will try to avoid material specifications, a careful study of this problem will be required, in order to determine a policy which will successfully relate material properties to the expected duration of certain loading conditions.

Load reductions in occupancy loads which generally affect structural members supporting large floor areas (See ASA A58) are also a result of probabilistic considerations and could only be revised after extensive research on occupancy loads is conducted.

Proposed Research:

1) Study of probability of simultaneous loading of large areas to determine policy on load reductions for large contributing areas.
2) Study of probability of combined loading, in order to determine policy on load reductions.
3) Study of the effect of sustained loading on materials and appropriate testing methods that will determine this effect. Determination of policy on utilization of test results to determine permissible overstress under short-term loads, and generally to modify permissible loading in accordance with material properties.

1.4.1.8 Soil and Hydrostatic Pressures

Adherence to accepted engineering practice should be acceptable in this case. It is important to require sufficient subsurface exploration data to verify conditions at the building site. Performance specifications can be formulated without additional research.

1.4.1.9 Thermal Loads

Ranges of temperature change likely to occur in different regions of the U. S. should be determined for this project. Distinction should be made between supporting structural members which are exposed and members which are protected by cladding or roofing. Performance specifications may be formulated on the basis of existing data.

1.4.1.10 Sonic Boom Loads

Sonic booms originating from supersonic aircraft cause shockwaves consisting of positive and negative pressure components which are capable of causing structural distress. Reference 50 describes an extreme case of damage caused by sonic boom.

Dynamic loading by sonic boom has been investigated to some extent. The most recent investigation is summarized in reference 43. Sonic booms resulting from the introduction of supersonic transports will be within a relatively low nominal overpressure range; however, it is reasonable to assume that a small number of higher intensity booms may occur during the lifetime of a structure as a result of pilot error or other circumstances.

Immediate introduction of loading requirements on the basis of present knowledge may be difficult; however, some investigations have been conducted and data are available. Reference 43 summarizes the conclusion of a study recently conducted by the Federal Aviation Agency. Data are also presented in references 44-46, 48, 49, 51 and 52.

Proposed Research:

Proposed research is outlined in reference 47, which also includes a proposal for facilities for testing structural components and assemblies.

In addition to this research, a study should be conducted in order to determine nominal overpressures which could be used as loading requirements in performance specifications. However, much further research will be needed before structural performance under these loading requirements can be evaluated.

1.4.1.11 Fire Loads

Fire loads are here defined as load imposed during the duration of exposure to fire which the structure as a whole or individual structural elements must withstand without collapse or disruption of vital service systems. Fire loads will consist of thermal loads, hose stream impact and other loading imposed during a fire; however, the most important effect of a fire will be the change in properties of materials caused by elevated temperature. These changes will have the effect of extreme loading, even though they cannot be physically defined as loads.

Substantial information is available on the behavior of conventional structural materials and assemblies at high temperatures. Test procedures for structural members and assemblies are specified in ASTM E119; however, even in the case of conventional materials and assemblies, the interaction of structural members at high temperature which will be affected by joint action cannot be adequately determined. [54, 55, 57].

In the case of unconventional materials and structural assemblies, the determination of the effect of fire loading will be difficult and additional research will be required in this area.

Recommended Research:

Research to advance the state of the art has been recommended in NBS Report No. 9698, pp. 5-22 to 5-27 [56].

In addition, specific performance standards for fire endurance must be developed for the HUD project, as well as specific test methods to determine performance of full scale structures and structural components.

1.4.2 Structural Response

1.4.2.1 General

Structural performance will require:

1) Reliability against collapse.
2) Performance under the most extreme loading conditions expected during the lifetime of the structure without permanent damage to any structural or subsystem.
3) Satisfactory performance under prevailing loading conditions.

The state of the art in different areas of structural response is hereinafter evaluated.

1.4.2.2 Strength

1) Collapse: The structure and all supporting structural members must be capable of resisting collapse until specified collapse loads are reached. Reasonably accurate analytic procedures are available to determine collapse loads for structures. However, existing procedures tend to be deterministic and disregard probabilistic aspects of structural behavior (i.e., not all identical structures will fail at the collapse load as determined by present analytical methods. Some structures will fail at higher loads and some at lower loads). Some research is being presently conducted in an attempt to introduce probabilistic design procedures (Cornell- M.I.T.; Benjamin - Stanford University) but the present state of the art does not permit the practical use of these procedures. In most cases analytic procedures may be acceptable as equivalent to testing; however, in the case of unconventional structures and new materials, full-scale testing, or testing of parts of structures and structural components, may be necessary to determine collapse loads. The present state of the art in testing will be discussed in a later section.

2) Performance under maximum probable loads (design loads:
Under such loads no supporting structural member should be stressed in a manner that would cause permanent deformations, except for a tolerable amount of creep which is unavoidable when loads are applied over a long period of time. Distress to non-supporting structural members, surface covers, cladding, service systems and other subsystems should also not exceed tolerable limits. Reasonable accurate analytic procedures are available to determine structural behavior under loads that will not cause permanent deformation (elastic behavior). Such methods may be acceptable as substitutes for testing for conventional assemblies and materials, provided that effects of stresses and deflections on other subsystems can be adequately determined.
3) Performance under prevailing load conditions:
Under these conditions strength will not be the critical factor. Structural behavior will be discussed under static and dynamic deflections.

1.4.2.3 Static Deflections

Static deflections generally will be a function of rigidity and not necessarily strength. Members may assume intolerable deflections under loads that will not cause permanent deformations. Structural adequacy in terms of strength does not, therefore, imply adequacy in terms of deflections.

Major U.S. codes define permissible deflections numerically, as a ratio of deflection to total length of member. However, these stipulations primarily relate to known structural assemblies, and even in these cases they are not always satisfactory. The New York State Code stipulates deflections "under imposed loads" and distinguishes between plastered surfaces, unplastered surfaces, and roofs.

Existing code provisions for deflections are basically intended for conventional materials and assemblies. There is also substantial evidence that even for conventional assemblies these provisions are inadequate. (Deflection Characteristics of Residential Wood Joist Systems, FHA Housing Research Paper No. 30 [43]). Provisions are particularly unsatisfactory for exposed "architectural" concrete and long unsupported spans. In recognition of this fact, the ACI Task Committee on deflection of concrete building structures was formed in 1957. The new ACI building code, which will be published in 1970, will set a new policy on deflections, distinguishing between dead load and live load deflections. This is particularly significant since dead load deflections can be canceled by camber.

Performance specifications must define deflections in terms of performance, and also must anticipate the introduction of unconventional assemblies and materials. The following performance criteria will have to be defined:

1) Maximum deflection to satisfy dimensional tolerances.
2) Maximum deflection in terms of distress of surface covers.
3) Maximum deflections in terms of proper functioning of, and prevention of damage to, service systems.
4) Maximum deflections that will not interfere with or damage windows and doors.
5) Maximum deflections which will not cause deterioration of structural elements.
6) Maximum deflections which are esthetically acceptable. (This will include consideration of cracking caused by deflections, which is inevitable in certain materials).
7) Maximum deflections which will not interfere with maintenance.

Drift: It is felt that the state of the art in determination of wind loads permits the determination of satisfactory criteria for drift (see Section 1.4.1.2).

Analysis: The state of the art in structural analysis permits us to determine elastic and creep deflections with reasonable accuracy. The analytic determination of deflections may therefore be acceptable as a substitute to testing provided that the magnitude of the permissible deflections can be determined without such testing.

Required Research:

1) The problem of effects of deflections as defined by items 1 to 7 above will have to be thoroughly investigated in order to determine reasonable criteria for low-income housing.
2) A test procedure must be devised, whereby entire structural assemblies, together with surface covers and possibly utilities, will be subjected to static, dynamic and cycles of repeated loading in order to define performance in terms of criteria 1 to 7.

1.4.2.4 Dynamic Deflections:

Vibrations: Present major U. S. codes do not contain performance criteria for vibrations. With the development of thin, light weight floor systems, vibrations of floors create an increasing problem. However, in residential construction, where unsupported spans are not so great, the problem is less acute than in other types of construction.

Several attempts have been made to determine human sensitivity to vibrations which persist for an appreciable length of time. Examples are the Reiher-Meister Scale [45], an adjustment to that scale by the Commonwealth Experiment Station of Australia [47], the Goldman Scale [46] and many others.

Research by Kenneth Lenzen [44] conducted at the University of Kansas indicates that in buildings which are not subjected to a steady-state excitation, sensitivity to vibration will be controlled by damping. Damping provided by the structural system may be enhanced by proper design or by mechanical dampers.

Research presently conducted by the University of Kansas, and by the firm of Skidmore, Owens and Merrill in Chicago, will probably advance the state of the art to a point where natural frequencies and damping of floor systems can be analytically determined. The determination of the parameters affecting human response and the definition of tolerable levels of vibration can not be made without additional research.

Vibrations caused by mechanical equipment should also be considered in evaluating performance of a structure, as well as damping of vibrations caused by traffic, etc., outside the building.

Wind loads have been discussed in Section 1.4.1.2. It is felt that application of design criteria outlined in that section together with "drift" not to exceed 1/500 of Height would be tentatively used to control dynamic response. However, in the case of unconventional structural assemblies, test procedures should be developed to evaluate response to wind. Two such test procedures have been outlined in Section 1.4.1.2. Structural performance under wind load should also consider noise effects caused by dynamic response of the structure. Dynamic response to earthquakes has been discussed in Section 1.4.1.4.

Proposed Research:

1) Determination of human response to structural vibrations and determination of test methods and criteria to evaluate levels of vibrations.
2) Development of test methods that will subject structures and structural elements to excitations causing measurable vibratory response.
3) Standardization of test methods developed in 1) and 2).

1.4.2.5 Testing of Structural Response

Present testing procedures for Building Assemblies are listed under "Methods of Testing Building Construction" ASTM Standards, Part 14, 1967 [48]. Test procedures for different materials are specified in various parts of the ASTM Specifications. U. S. and foreign building code provisions for testing are summarized in "A Philosophy on Loading Tests" [49]. (See Table II).

Development of test procedures for full-scale structures is currently considered by the ASCE Research Council on the Performance of Full-Scale Structures, which issued a report on the feasibility of conducting full scale performance tests on existing structures [50].

The state of the art in testing of full-scale structures will be further advanced by the "Phoenix project", a study of industrialized construction of multi-family reinforced concrete prefabricated structural systems, currently being carried out by the NBS Building Research Division.

However, the philosophy of performance specifications requires testing procedures which will evaluate parameters which have not been considered before, and will be divorced from consideration of specific structural assemblies and conventional materials.

Required Research:

An extensive research program will be required in order to develop and standardize testing procedures and design suitable testing equipment. Feedback from actual projects will later be used to refine and improve these procedures. The following steps are proposed:

Stage I: Evaluation of all existing testing procedures and determination of scope of research work necessary to develop testing procedures responsive to performance specifications.

Stage II: Development of testing procedures for structural performance related to:

1) Structural collapse;
2) Performance under extreme loads;
3) Deflections (including repeated loading cycles);
4) Vibrations;
5) Determination of natural frequencies and damping;
6) Integration with other subsystems.
7) Use of models to predict full-scale structural behavior.

All of the above procedures will be standardized in order to insure uniform evaluation of results.

1.4.3 Structural Support

Structural support must be provided by the soil or rock formation on which the structure rests.

Structural support must be provided in a manner that will not cause structural collapse, distress, excessive deflections, or intolerable settlements.

Existing codes will generally specify "allowable bearing values," sometimes based on "presumptive bearing values" which were derived from local experience over long periods of time. Some codes require specific amounts of subsurface exploration, including load-bearing tests (N. Y. State Building Codes). Specifications for pile foundations are also incorporated in many codes. The New York City Code reflects the present state of the art in the design of pile foundations in an excellent manner.

In some respects all existing codes for foundations are performance codes; however, structural performance as a result of foundation support is not specifically stated, even though it is implied that structures will perform satisfactorily if the codes are complied with.

The present state of the art in foundation design and subsurface exploration permits safe and economic design of foundations provided sufficient subsurface exploration is conducted and experienced foundation engineers are employed to evaluate the data.

Performance specifications for structural support would be sufficiently stated by the second paragraph of this section, provided that tolerances for settlements are numerically defined.

However, it would also be disirable to state required frost cover in different regions of the United States, to require a minimum of subsurface investigation and soil testing, and to create a professional organization under HUD control to review all structural foundations plans.

It also may be desirable to make specific statements about regions of unstable soil conditions which are numerous in California and other parts of the United States.

Only limited research will be required to formulate performance specifications for structural foundations.

1.5 Summary of Recommended Research

(Note: Research necessary immediately in order to formulate performance criteria is indicated by *)

1.5.1 Wind Loads

1) Research project to determine scope, nature and cost of additional research needed in the field of wind loads.
2) Correlation of atmospheric turbulence data in open country with measured response of buildings.
3) Investigation of wind effects on building elements such as cladding and window panels.
4) Improve knowledge of effects of flow alteration in urban areas by performing measurements similar to 2) in urban areas of typical configurations.
* 5) Extension of statistical analysis to determine winds of recurrent frequencies required for determination of structural reliability.
* 6) Development of experimental methods for the determination of resonant frequencies and damping in structures (parameters in the determination of gust response).
* 7) Research concerned with the physiological consequences of wind-induced oscillations and aeolian noise.
* 8) Determination of wind tunnel test methods.

1.5.2 Snow Loads

* 1 Extension of frequency ranges developed in the "Distribution of Maximum Annual Water Equivalent" to permit determination of reliability.

1.5.3 Seismic Loads

1) Relationship between overburden (surficial geology) and seismic loads.

* 2) Research leading to a definition of structural "ductility," applicable to all materials.

1.5.4 Live Loads

* 1) Survey and evaluation of live load in multi-family housing, including statistical analysis of frequency of occurrence of loads. This would include a study of living habits of low-income families with respect to their effect on live loads of floors, corridors, stairways, play areas, etc.

1.5.5 Combined Loads

* 1) Study of probability of combined loading in order to determine a policy of load reduction.

1.5.6 General Loads

* 1) Study of the effect of sustained loading on materials and appropriate testing methods to determine this effect. Determination of policy on utilization of test results to determine permissible overstress under short term loads and to modify permissible loading in accordance with material properties.

1.5.7 Sonic Boom Loads

* 1) Research as outlined in reference 47.

* 2) Study to determine nominal overpressures to be used in loading requirements.

1.5.8 Fire Loads

1) Research recommended in reference 56.

* 2) Developments of performance standards in fire endurance.

* 3) Development of performance tests for full-scale structures.

1.5.9 Static Deflections

* 1) Development of criteria for static deflections.

* 2) Development of test procedure for structures and structural assemblies to determine compliance with deflection criteria.

1.5.10 Dynamic Deflections

1) Determination of human response to structural vibrations and determination of test methods and criteria to evaluate levels of vibration.

* 2) Development and standardization of vibration testing procedures and equipment.

1.5.11 Testing

* 1) Comprehensive research program as outlined in Section 1.4.2.5.

1.5.12 Structural Support

* 1) Development of criteria for structural supports.
* 2) Development of criteria for subsurface exploration.

Table II. Existing Test Procedures

Authority	Material	Type of Test	Time of Test	Superimposed Test Load	Duration of loading, hr	Requirements After Loading	Requirement on Removal of Loading
National Building Code-National Research Council of Canada	Concrete	Strength	Not Specified	1½ live load	24	No signs of weakness or of faulty construction	75% recovery of max. deflection on first test or 75% recovery of max deflection shown during second test
British Standard Code of Practice CP 113 (1948)	Steel	Stiffness	Structure should be loaded with actual dead load for as long as possible before testing	Stiffness: 1½ live load	24	Maximum deflection —not excessive	80% recovery of deflection on first test or 90% recovery of deflection on second test
		Strength		Strength: 2 live load + dead load For 2-story dwellings and schools, 2 live load Wind load: 2 wind load with or without vert. load	24	. . . . .	20% recovery of deflection
British Standard Code of Practice CP 114.100-114.105 (1950)	Concrete	Strength	56 days to be allowed for hardening of concrete	1¼ design live load	24	No evidence of failure	75% of recovery of deflection on first test or 75% recovery of deflection on second test
American Concrete Inst. Building Code (ACI 318-51)	Concrete	Strength	Not specified	2 live load + ½ dead load	24	No signs of failure. Limiting deflection $D = L^2/12\,000t$*	If D is exceeded, residual deflection 24 hr after removal of load must not exceed 40% of max deflection observed under load or 60% of D. Deflection must not exceed $3D$ under load
Uniform Building Code-Pacific Coast Building Officials Conference	Steel	Strength	Not specified	2 design load	No time specified	Sustained load without failure	Determination of elastic properties should be based on deformations at (1) 75% of max load which can be sustained or (2) a total load equal to 1 design dead load + 1½ design live load, whichever is the larger
		Performance		1½ design live load + ½ design dead load	No time specified	Local distortions should not develop	
Basic Building Code-Building Officials Conference of America, Inc.	All construction materials	Strength	Not specified	2½ live load	No time specified	Sustain load without failure	. . . . .
		Performance		Approved working load	No time specified	Limiting deflections under working load not to exceed: (1) 1/360 of span for plaster (2) 1/240 of span, unplastered floor construction (3) 1/180 of span for unplastered roof Construction	. . . . .
		Workmanship	Not specified	2 live load	24	No signs of failure. Total deflection not to exceed theoretical deflection calculated from accepted engineering formulas	If computed deflection is exceeded, structure must recover 75% of max deflection within 24 hr of removal of test load

* Where D = the maximum deflection of the portion of the structure under test, L = the span of the member under test between faces of supports, and t = the depth of the member under test.

Table II.(contd.)

Authority	Material	Type of Test	Time of Test	Superimposed Test Load	Duration of loading, hr	Requirements after loading	Requirement on Removal of Loading
Southern Standard Building Code-Southern Building Code Congress	Concrete	Strength	Not specified	1½ live load + ½ dead load	24	No signs of failure. Limiting deflection, $D = 0.001L^2/12t$*	If D is exceeded, structure must recover 75% of observed deflection within 24 hr of removal of test load
	Prefabricated construction (panels)	Strength	Not specified	2½ live load	24	Sustain load without failure	75% recovery of observed deflection within 24 hr after removal of full test load
		Performance		1 live load	...	Measured deflection shall not be more than 1/360 of clear span	.....
National Building Code-National Board of Fire Underwriters	All materials	Strength	Not specified	Not less than 2 design live load	No time specified	.....	75% recovery of max deflection within 24 hr of removal of test load
Chicago Building Code and Index-City of Chicago	All materials	Workmanship	Not specified	2 design live load	24	No signs of failure. Total deflection not to exceed that calculated by theoretical engineering formulas	If calculated deflection is exceeded, structure must recover 75% of observed deflection within 24 hr of removal of test load
State Building Construction Code-State of New York	All materials	Strength	Not specified	2 uniformly distributed imposed load	24	Sustain load without failure	.....
		Performance	Not specified	1 uniformly distributed imposed load	No time specified	Limiting deflections: (1) 1/360 of span for plaster (2) 1/240 of span, unplastered (3) 1/180 of span for unplastered roof construction	.....
		Performance	Not specified	1½ uniformly distributed imposed load	No time specified	Sustain load without structural damage	For floor assemblies, residual deflection after first test shall not exceed 25% max deflection under load. Residual deflection on second test not to exceed 1.1 residual deflection from first test
New Zealand Standard Code of Building By-Laws-New Zealand Standards Inst.	Concrete and Steel	Strength	Ample time to be allowed for hardening of concrete before test	150% of load for which structure has been designed	No time specified	No signs of failure	.....
Uniform Building Regulations-Melbourne, Australia	All materials	Strength	Not specified	1½ live load + ½ dead load	24	Limiting deflection at the end of 24-hour period, $D = 0.001L^2/12t$*	If D is exceeded, structure must recover at least 75% of observed deflection within 24 hr after removal of test load
Model Building Regulations of South Africa	Concrete	Strength	28 days after concrete is placed or on date agreed upon	Slab or beam: 1½ design live load + ½ dead load	24	No evidence of failure. Limiting deflection at the end of 24-hr period, $D = L^2/12\,000t$* D.B.R. Dwg.* BR 602	Residual deflection not to exceed ¼ max deflection at the end of 24-hr period. If there are no signs of failure and allowable deflection was exceeded on first test, second test may be carried out after 72 hr have elapsed

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2. SAFETY

2.0 Executive Summary

The following are the important standards and test methods for fire safety in housing based on performance requirements:

2.0.1 Fire Resistance

ASTM E119 Fire Tests of Building Construction and Materials
ASTM E152 Fire Tests of Door Assemblies
ASTM E163 Fire Tests of Window Assemblies
ASTM E108 Fire Tests of Roof Coverings

2.0.2 Combustible Content

ASTM E136 Determining Noncombustibility of Elementary Materials
NBS method for Potential Heat of Materials (published description not yet adopted as a standard).

2.0.3 Flame Spread

ASTM E162 Surface Flammability of Materials using a Radiant Heat Energy Source.
ASTM E84 Surface Burning Characteristics of Building Materials (Tunnel Test).
ASTM E286 Surface Flammability of Building Materials using an 8 foot Tunnel Furnace.
NFPA 701 Fire Tests for Flame Resistant Textiles and Films.

2.0.4 Smoke and Hazardous Combustion Products

NBS Smoke Chamber and Detector Tubes (in report; not adopted as a standard).

2.0.5. Fire Detection, Alarm and Extinguishing Systems

NFPA 74 Household Fire Warning System

The following standards, while pertinent to the provision of fire safety in housing, are drawn mainly in terms of material specifications rather than performance requirements.

NFPA 13 Sprinkler Systems
NFPA 14 Standpipe and Hose Systems
NFPA 72A Local Protective Signaling Systems
NFPA 101 Code for Safety to Life from Fire in Buildings and Structures.

The 12 standards listed under the performance category cover requirements established for fire safety performance, or the method by which that performance may be tested and evaluated, or both. The standards do not establish quantitative criteria of performance, a function left to such documents as minimum property standards, fire regulations, or building codes, which may be at variance in their requirements and their interpretation of performance and the results of tests for its determination.

It does not seem that there can be any disagreement on the necessity for the performance requirements for fire safety developed under this project. However, the adequacy of the test methods by which the performance of a structure in meeting these requirements may be evaluated is seriously questionable. In the field of smoke and combustion products hazard, test methods are almost nonexistent, the single entry listed above giving an indication of the visual obscuration that may be expected without regard to the toxicity of the combustion products or the relation of the two hazardous effects.

In addition to the considerable research that could be expended in studies of fire and smoke in buildings, especially aspects of their growth and spread as well as effect on the building structure, an investigation could be made of the deficiencies in present test methods with a view to their correction, or the development of new and more suitable methods. It would be useful to examine current performance criteria in an effort to arrive at a consensus of the best available requirements, or where criteria are lacking, an estimate of the necessary criteria (or even an educated guess). For the future, an investigation of the validity of the criteria used should be made on the basis of their correspondence to conditions in an actual fire, and their relation to improved test methods which simulate real fire conditions.

2.1 Fire Protection

Fire protection requirements in housing are necessary to the safety of life and property. Fire, although a relatively infrequent occurrence, has the peculiar characteristic that, once initiated, it is a hazard not only in its place of origin, but also in adjoining and succeeding areas.

The provision of fire safety is not usually the primary function of a building element or component, which in itself may be a solution to the general requirement that fires be confined. Most fire performance requirements for buildings were established to provide property safety by limiting the spread of fire. The increasing emphasis now being placed on the provision of safety to life from fire hazards makes it necessary to draw new requirements for the fire performance of buildings in fields formerly accorded little or no attention.

Although provisions for fire safety have usually been restricted to multifamily residential occupancies, the rather meager statistics on fire occurrences and casualties seem to indicate that in new apartment buildings, fatalities do not result from fires initiating in any adjacent or remote part of the building, but only in the apartment where the fatality occurs. Great loss of life, however, is suffered in single family dwellings, and considering that these may continue to predominate in towns and rural areas, most of the performance requirements for fire safety developed herein should be made applicable to them.

The performance requirements for safety from fire are, briefly, as follows: (1) building elements shall resist the passage or effects of heat, flame and combustion products without structural failure; (2) building elements shall contribute a minimum of fuel to a fire; (3) interior finishes of buildings shall resist the spread of flame along their surfaces; (4) building elements shall produce a minimum of hazardous combustion products; (5) mechanical systems shall not initiate, contribute to, or spread fire; (6) fire detection systems shall quickly signal the presence of fire; (7) exitways shall be adequate for the building occupancy, and shall not increase the fire or accident hazard.

In the several areas of requirements for fire safety in housing listed above, specific performance requirements in terms of stated numerical values for fire resistance and for flame spread have been established in a number of regulatory codes and statutes. Some of the other requirements are covered by prescription type specifications. Both types of requirements, performance and solution, are not necessarily indicative of actual conditions in a fire, nor are the tests by which performance may be evaluated a true reflection of fire severity and behavior. The requirement covering the production of hazardous combustion products is entirely omitted from codes for the reasons that this principal danger to life, and the possible means to mitigate it were only recently recognized, and also because standards for and methods of evaluating smoke production are as yet largely undeveloped.

A large number of standards and test methods have been devised covering the listed fire safety requirements. Of these, approximately twenty may be considered as pertinent to the study, the rest being eliminated because of their narrow scope, which restricts their application and may lead to unrealistic conclusions. The pertinent standards and test methods are by no means perfect, but are replete with deficiencies and anomalies that impair their usefulness. However, through long experience and the general acceptability of the results derived from them, they are suitable for use now, and their improvement is not of immediate urgency. A serious deficiency is that the standards do not completely cover the field of fire safety, especially in the area of life safety, so that development is necessary both in establishing performance requirements and the test methods by which the performance of a structure in meeting the requirements may be evaluated.

A project for future research, perhpas basic to all others, is the assembly of primary cause statistics relating fire casualties and building losses to properties of building structures or elements. Another would be the study of what fire resistance and other fire properties are really necessary in a building, based on tests relevant to actual fire conditions. This would include a study of combustible loadings. Together with this, an investigation could be made of the deficiencies in the present fire test methods for building construction.

To fill out relatively undeveloped, but highly important (to life safety) areas in fire safety requirements, studies should be undertaken of the penetration and distribution of smoke and other combustion products in a building, and also of the growth and spread of fire in buildings and building contents. As a corollary, a sensitive, low-cost fire- and smoke-detection alarm system for all types of residences should be developed. Several other projects could be suggested, such as the development of criteria and methods of measurement for radiant heat transmission through doors and windows, and also for the flame-resistant properties of textiles relevant to their behavior in actual fires. An examination of emergency exiting requirements may also be in order. An important project, in an almost totally unknown area, would be the study of and development of tests for the interaction of building elements and the action of whole buildings or units under fire conditions.

It should be remembered that lowering structural fire safety requirements may not be feasible because protection must be provided to both life and property--dual considerations not always compatible. While research may show that certain requirements are too restrictive in relation to actual fire severities that will be encountered, it may also reveal that the requirements should be raised. Rather than reducing construction costs, a better possibility is that, by judicious and knowledgeable choice of constructions and materials, increased fire safety may be had at no additional cost.

2.1.1 Standards and Test Methods Pertinent to the Provision of Fire Safety in Housing (Abridged from "State of the Art" Fire Protection Sources of Information List)

An examination of the all-inclusive list of standards and other sources of test methods indicates that many of these may be omitted from the designation of pertinent test methods for fire protection. The basis for the omission is one or more of the following:

1) The test method is of such limited scope as to be applicable to only a small number of materials, usually of a single type.
2) The test method, perhaps because of its design for a specific material, may give results that are neither realistic nor valid.
3) The test methods listed as pertinent are at least as suitable as those omitted for evaluating the elements of buildings and building systems, and have the utility of wide application.

To illustrate the above, many of the test methods are for the purpose of determining the flammability of such materials as treated paper, or rigid plastics, or vinyl chloride tubing, etc. Others treat the fire retardant properties of paints. One flame spread test, such as the radiant panel method, ASTM E162 will provide such data for these materials, as well as all others. As to the lack of validity of certain test methods, one that is used to classify plastics as "burning" or "self-extinguishing" has been shown to rate various species of wood, sometimes including balsa, as "self-extinguishing."

The following is a listing of the test methods considered pertinent to the determination of the fire safety of housing. Standards for mechanical equipment and energy sources are omitted, as these presumably will be described by the assignees to the particular fields. The several standards and test methods are grouped according to the performance requirement which they are intended to evaluate. A brief description of each standard or test method is included. As some of the deficiencies in the test methods are applicable to all within a group, these defects and shortcomings will be treated in a separate section.

2.1.1.1 <u>Fire Resistance</u>

1) ASTM E 119 Fire Tests of Building Construction and Materials.

A test to determine the fire endurance of a floor and ceiling assembly, a wall or partition panel, or a column by exposure of the structure to a fire regulated to follow a standard, constantly increasing time-temperature curve. The criteria for evaluating the performance of floors and walls are (1) ability to sustain required applied loading (2) passage of flame or gases hot enough to ignite cotton waste, and (3) transmission of heat through the structure sufficient to raise the temperature on the unexposed surface an average of 250 degrees F or 325 degrees F at one point. Column performance is based on ability to sustain the applied load, or alternately (for steel columns) transmission of heat through the insulation to raise the average temperature of the steel above 1000 F.

2) ASTM E 152 Fire Tests of Door Assemblies

A test to determine the capability of door assemblies to resist the passage of fire. The structures are exposed to fire according to the standard time-temperature requirements of the fire resistance tests. Acceptable performance of a door assembly is evaluated from the amount of movement of the door in its frame (movement up to $1\frac{1}{2}$ times the thickness of the door allowed in some cases) and the maintenance of structural integrity. There are no requirements for measuring the passage of smoke around the door, or the temperature on the unexposed surface, although a method for the latter is described.

3) ASTM E 163 Fire Tests of Window Assemblies

Applicable to all window assemblies including glass block and other means of transmitting light. Exposure of the window assembly is to a fire controlled to the standard time-temperature curve for fire resistance for a period of 45 min. Acceptance criteria are in terms of the window assembly's remaining in its fastenings and movement of the openable components.

4) ASTM E 108 Fire Tests of Roof Coverings

Tests to determine the retardant characteristics of roof coverings against fire originating outside the building. Three different tests are made on the covering materials: (1) intermittent flame exposure, (2) spread of flame, and (3) burning brand exposure. The evaluation of the roof covering performance is made in terms of time to appearance of sustained flame on underside of roof deck, the production of brands, the spread of flame on the outer surface, and exposure or destruction of a portion of the roof deck.

2.1.1.2 Combustible Content

5) ASTM E 136 Determining Noncombustibility of Elementary Materials

Test for materials of which building elements are composed. Small specimens are exposed at 750C in a small furnace, and classified as noncombustible and not adding appreciable heat to an ambient fire if the interior temperature of the specimen does not rise more than 30 degrees C above the furnace air temperature, and if there is no flaming from the specimen after 30 sec.

6) NBS Method for Potential Heat of Materials

Measures the total heat release of materials under conditions simulating building fires. The method employs standard oxygen-bomb calorimetric techniques in which the burning of small quantities of combustible in an otherwise inert material is assured by use of a combustion promoter which is added prior to test. Calorimetric measurements are made both before and after exposure to a "standardized fire" (2 hr in air at 750 C) and the difference considered as the potential heat. The test method is suitable for measuring the potential heat of all types of building materials including metals and materials of low combustibility.

7) Factory Mutual Construction Materials Calorimeter

A 4-ft. square section of a test construction forms the horizontal cover of a heptane fuel-fired furnace. The flue temperature history resulting from the combined burning of the heptane fuel and the test panel under standardized exposure conditions is recorded. The same procedure is then followed using a noncombustible cover while supplying a metered quantity of propane fuel through auxiliary burners to reproduce the temperature-time curve of the test construction. The rate of heat supplied in burning the propane represents the rate of heat produced by the sample.

2.1.1.3 Flame Spread

8) ASTM E 162 Surface Flammability of Materials Using a Radiant Heat Energy Source.

A small scale test using a 6 by 18-in specimen exposed to a 12 by 18-in radiant heat source; ignition is forced near upper edge of specimen and flame front progresses downward. A flame spread index is computed from a factor derived from the rate of progress of the flame front and another relating to the rate of heat liberation by the materials. Smoke evolved during the test is also measured.

9) ASTM E 84 Surface Burning Characteristics of Building Materials

A test to determine the comparative burning characteristics of building materials by evaluating the flame spread over its surface, fuel contributed by its combustion and the density of the smoke developed when exposed to a test fire in a tunnel approximately 18 in. wide and 25 ft. long, of which the specimen forms the ceiling. Red oak flooring is used as the standard for comparison.

10) ASTM E 286 Surface Flammability of Building Materials Using an 8 ft. Tunnel Furnace.

Test determines flame spread of materials using specimens mounted within a 14 in. by 8 ft. test frame. The specimen, tilted 30 degrees from the horizontal transversely, forms the top of the test chamber and is covered. Techniques for measuring heat production and smoke density are included.

11) NFPA 703 Fire Retardant Treatments of Building Materials

Applicable to building materials treated by pressure impregnation or surface coating. Materials are evaluated only in terms of flame spread characteristics as determined by ASTM E 84 surface burning characteristics of building materials (Class A has flame spread rating of 25 or less, Class B rating between 26 and 75).

12) NFPA 701 Fire Tests for Flame-Resistant Textiles and Films.

Includes small scale (10 in. long) and large scale (7 ft. long tests). Evaluation criteria are in terms of time flaming continues after discontinuing exposure, and the spread of flame and afterglow (smoldering combustion) on the material (measured by length of char or material destruction).

2.1.1.4 Smoke and Hazardous Combustion Products.

13) ASTM E 84 Surface Burning Characteristics of Building Materials (see under Flame Spread).

UL Tunnel Test used for smoke determinations by measuring light absorption in a section of the furnace vent pipe. Time-absorption curve of red oak is standard for comparison (by ratio of areas under curves).

14) Rohm and Haas XP-2 Smoke Chamber

Utilizes a 12 in. by 12 in. by 30 in. chamber with 1 in. high ventilating openings around the bottom. The 1 in. square by 1/4 in. thick specimen is supported on a wire screen and exposed to the flames from a controlled-pressure propane burner. The photometer, horizontally mounted, consists of a light source, a visually-corrected barrier layer photoelectric cell and a meter to indicate increase in light absorption with time. Test duration is 5 min. Results are given in terms of maximum percent light absorption, and maximum rate of smoke production (percent/min.).

15) NBS Smoke Chamber and Detector Tubes.

Smoke production is measured photometrically in a 18 cu. ft. closed chamber containing an electrically heated furnace which provides a fixed irradiance on the surface of a nominal 3 in. sq. specimen. Tests are performed under separate flaming and smoldering conditions, and results are reported in terms of (a) total maximum smoke accumulation, (b) maximum rate of smoke accumulation, and (c) the time period to reach a "critical" smoke level. To relate smoke quantity to potential visual obscuration, measurements are in terms of specific optical density, a dimensionless quantity which takes into account optical path length, the chamber volume and the surface area of the material producing smoke. The presence of specific chemical compounds that may present a toxic hazard is determined by colorimetric gas detector tubes.

2.1.1.5 Fire Detection, Alarm and Extinguishing Systems.

16) NFPA 72 A Local Protective Signaling Systems.

A specification standard for supervised systems for fire alarm within the protected premises, primarily to provide safety to life. The systems may provide for manual or automatic fire alarm service, and includes smoke detection. The provisions of the National Electrical Code are basic to the requirements for the installation of these systems.

17) NFPA 74 Household Fire Warning System.

Primarily to provide fire safety in one- and two-family dwellings. Installation provides for detection of heat and smoke. Many requirements in terms of performance, but National Electric Code is basic to the specifications wherever applicable.

18) NFPA 13 Sprinkler Systems.

Detailed specifications for the components and their installation for all types of sprinkler systems. Specific requirements are included for water supplies and connections, and rules for hydraulic calculations are given. Methods of testing systems for acceptance are also provided.

19) Standpipe and Hose Systems.

Standpipe systems classified as to intended use by firemen or building occupants. Detailed specifications are given for piping, number and location, and hose connections. Acceptable water supplies are described. Methods of test for new systems, and rules for maintenance of old systems are included. In addition to the requirement of wrought steel or wrought iron pipe, other types may be used if tested and listed for the service by a nationally recognized testing agency.

2.1.1.6 Exitways

20) NFPA 101 Code for Safety to Life from Fire in Buildings and Structures.

Covers construction, protection and occupancy features to minimize danger from fire, smoke or panic. Specific requirements are made for the number, size and arrangement of exit facilities to permit escape of occupants (without a time stated in which the escape may be effected). All types of occupancies are considered, and some (but not major) treatment is accorded multifamily residences.

Provisions for single family units are included to the extent that bedrooms must have at least one door and one other exit (such as window), stairways must meet minimum requirements, and interior finishes of occupied spaces shall have limited flame spread.

21) NFPA 501B Mobile Homes and Travel Trailers

Includes requirements for mechanical systems. Provides that mobile homes shall have two exterior doors located remote from each other, openable from the inside by a single knob or lever.

2.1.2 Deficiencies and Lack of Knowledge in Standards and Test Methods for Fire Safety

2.1.2.1 Fire Resistance

ASTM E-119 Fire Tests of Building Construction and Materials.

1) Effect of openings for services and joints on fire performance of a structure.

2) Effect of furnace design and function (such as pressure) on specimen performance.

3) Effect of mechanical restraint of specimen; also type of loading applied.

4) Effect of moisture content of specimen, or method for compensating results for moisture content.

5) Effect of variables in measuring unexposed surface temperature.

6) Needed to complete coverage of test method:

   a) suitable criteria for structural failure.
   b) method to simulate the rapid growth and decay observed in many actual fires.
   c) fire exposure in terms of heat input rather than furnace temperature.

ASTM E-152 Fire Tests of Door Assemblies

1) No measurement of radiant heat passing through door,

2) Smoke transmission around door not measured,

3) Effect of pressure in furnace on smoke transmission; relation to conditions in an actual fire.

ASTM E-163 Fire Tests of Window Assemblies

1) Radiant heat through window assembly not measured.

2.1.2.2 Combustible Content

NBS Method for Potential Heat of Materials

1) Lacks method for determining rate of heat release,
2) Reliability of results and suitability for use in any or all laboratories not determined.

Factory Mutual Construction Materials Calorimeter

1) Sensitivity of method questionable,
2) No experience in suitability for use in different laboratories, or the reproducibility of results from one lab to another.

2.1.2.3 Flame Spread

ASTM E-162 Surface Flammability of Materials Using a Radiant Heat Energy Source.

ASTM E-84 Surface Burning Characteristics of Building Materials (UL Tunnel)

ASTM E-286 Surface Flammability of Building Materials Using an 8-ft. Tunnel Furnace.

(Applicable to all)

1) Relation of flame spread index to the spread of flame in rooms and corridors in actual fires.

2) Effect of orientation of involved surface on flame spread rate.

3) Relation of flame spread to the development of flashover conditions.

NFPA 701 Fire Tests for Flame-Resistant Textiles and Films

1) Gives a comparison of materials under the conditions of the test, but relation between test results and behavior of materials in actual fire conditions not established.

NFPA 703 Fire Retardant Treatments of Building Materials

1) Effectiveness of fire retardancy only in terms of surface flame spread characteristics, and not related to fire resistance or combustible content.

2.1.2.4 Smoke and Hazardous Combustion Products

ASTM E-84 Surface Burning Characteristics of Building Materials (UL Tunnel)

Rohm and Haas XP-2 Smoke Chamber

NBS Smoke Chamber and Detector Tubes

(Applicable to all)

1) No established method for measuring potentially toxic gaseous combustion products.

2) Validity of extrapolation of test results to larger volume configurations is questionable.

3) Sufficiency of exposure (to test fire) of some materials to simulate their behavior in actual fire conditions.

4) Effect of smoke stratification.

5) Effect of smoke particle deposition on surfaces; effect of test chamber surface/volume ratio on results.

(Applicable to ASTM E-84 UL Tunnel Test and R&H Chamber)

1) Standard for comparison (red oak = 100) depends on flaming conditions although more smoke may be produced without flaming.

2) Linear absorption scale not a true measure of smoke concentration.

2.1.2.5 Fire Detection, Alarm and Extinguishing Systems

NFPA 72A Local Protective Signaling Systems

1) The standard is comprised mainly of elaborate material specifications and specific requirements rather than general performance requirements that could permit the development of cost saving innovations.

NFPA 13 Sprinkler Systems
NFPA 14 Standpipe and Hose Systems

(Applicable to both)

1) The standards are descriptive of current practice in the field, and are composed of material specifications and requirements to and extent allowing little or no innovation.

2.1.2.6 Exitways

NFPA 101 Code for Safety to Life from Fire in Buildings and Structures.

1) The requirements are almost entirely stated in terms of specifications for known and currently used solutions to the problem of providing for the movement of people, by their own locomotion, from a hazard area to a place of refuge.

2) Validity of exitway values may be questioned.

3) Assumption made that evacuation of a hazard area may be effected in a given time does not seem to be based on any knowledge of the time that may be available in a specific emergency, or the effect of human variation on the assumed time.

2.1.3 Conclusions

An examination of existing test methods for fire safety reveals a number of gaps in our knowledge of their meaning and application. In general terms, the problems relate to the following fields.

1) Relevance of the test method to actual conditions in a fire and the criteria of performance that should be specified.

2) Reliability and uniformity of the test method and its application.

3) Completeness of test method in terms of all the criteria that should be examined and evaluated.

The deficiencies and lack of knowledge outlined for the several test methods serves as a basis for the delineation of required research projects. Some of these may be categorized as short or medium term efforts, and so may be suitable for immediate initiation to provide relatively quick solutions. Unfortunately, however, many of these must be classed as low-priority, while really high priority problems, those of the utmost urgency, are of such complex implications that only long sustained effort will provide the required answers.

In assigning priorities, it would appear that projects pertaining to life safety are urgent, while those relating to the safety of property from fire may be placed lower on the scale. As safety to life from fire has hitherto been little considered, the required areas of development are indeed broad. Standards and test methods for evaluation under their requirements are available for property safety to a large extent. Although, as stated above, there are deficiencies in the standards, and gaps in our knowledge, these standards and test methods, through long experience and the general acceptability of the results derived from them, are suitable for use now, so that their improvement, while desirable, is not of immediate urgency.

We have serious gaps in our fire statistics, to the extent that the precise nature of the fire hazard problem cannot be ascertained. As an example, it is generally conceded that single family homes are firetraps, while new apartment buildings are relatively safe. In fact, evidence suggests that in new apartments, fire fatalities do not result from fires initiating in either adjacent or remote parts of the building, but only in the apartment where the fatality occurs, and often from the actions of the victim. But we have no figures on fire fatalities in apartments.

It would appear, then, that if all new residential construction is to be in the form of multifamily buildings, adequate fire safety can be provided by a continuance of present code requirements coupled with intelligently applied good building practice. Many substandard housing units, however, are found in small towns and rural areas, where the predominant pattern is the single family house. If people continue to live in such areas, or in garden type "new towns," with single family units prevailing, provision for added safety to life from fire is urgent.

From the standpoint of lowering the cost of housing, an examination of the possibilities in modifying fire safety requirements is not encouraging. An often mentioned trade-off is the provision of a good fire detection and alarm system to give additional life safety to the extent that fire resistance requirements on the structure may be relaxed. But the fire resistance requirements also provide property safety, which a detection system may not necessarily enhance. There is some possibility that research will reveal that the requirements are too restrictive in relation to the actual fire severities that will be encountered. The research may also reveal that the requirements should be raised. Further, it does not necessarily follow that lowering fire safety requirements will reduce construction costs. A better possibility is that, by judicious and knowledgeable choice of constructions and materials, we may get increased fire safety at no additional cost.

2.1.4 Projects for Future Fire Safety Research

I. High Priority - Short Term

1) Assembly of detailed primary cause statistics relating fire fatalities and building losses to properties of building structures or elements, to determine extent of problems.

II. High Priority - Medium Term

2) Development of a sensitive, low-cost fire and smoke detection/alarm system for all types of residences.

III. High Priority - Long Term

3) Study of smoke penetration and distribution in a building and means to minimize.

a) improve or develop methods of measuring the properties of smoke and combustion products as they affect life safety (medium term).

4) Study of the growth and spread of fire in buildings and building contents, including effects of combustible content and flame spread of interior finish materials on life safety.

IV. Medium Priority - Very Long Term

5) Study of and development of tests for interaction of building elements and the action of whole buildings or units under fire conditions.

V. Medium Priority - Long Term

6) Study of required fire resistance and other fire properties, based on tests relevant to actual fire conditions; includes study of combustible loadings.

VI. Low Priority - Short to Medium Term

7) Investigation of deficiencies in the fire test method for building construction (present ASTM E-119), with revisions to secure uniformity in the function of the furnace and other test equipment, and in the condition and restraint of the specimen. Also, to develop criteria for structural failure, and improved standards of heat input.

8) Develop criteria and methods of measurement for radiant heat transmission through doors and windows.

9) Development of criteria and test method for the flame-resistant properties of textiles and films relevant to the behavior of these materials in actual fires.

10) Examination of exit requirements in terms of time available for exit as determined by results of studies on growth and spread of fires and smoke production and distribution (low priority because not feasible until projects 3 and 4 have been completed).

2.2 Falls

Collectively, falls constitute the single greatest life hazard in the home, with approximately 12,000 fatalities occurring each year, or 40 percent of all home accidental deaths. Recent statistics (U. S. Public Health Service 1959-61) also indicate an incapacitating injury rate of about 7 million annually. This represents a third of all the accidental injuries incurred in the home. Of the 7 million, approximately 3 million are the result of falls from one level to another (on stairs, or from a height), while the remainder occurred from various causes (slippery surface, tripping, etc.) on a single level.

Falls are a particular problem among the elderly, and are the principal cause of accident fatalities in those 65 years of age or over. While many falls among the elderly are attributable to the infirmities and physical and mental instability attendant upon the aging process, and are in little or no way the result of the structural features of a residence, the incidence of falls, and especially fatalities arising from them, can probably be considerably reduced by eliminating stairs as a means of transit in housing which will be occupied by any number of senior citizens.

Few standards have been established for safety in residential occupancies, perhaps because accidents are often the result of the victim's action, and so, uncontrollable. Falls in the home often may be characterized as accidents of this type, and except for certain provisions (specification, not performance) for stairs and railings in building exit codes, are usually not covered by any standards. It must be noted, too, that these provisions in the codes are applicable only to multifamily buildings, and not to single or even two-family dwellings.

In the absence of standards, an approach to the problem of providing a measure of safety from falls may be made by examining the various causes of this type of accident and the possibility of eliminating, or at least minimizing the effect of some of these causes.

A principal cause of falls on a level surface is an abrupt change in the coefficient of friction in the walking area, although an extreme degree of slipperiness may in itself cause falls because of impatience on the part of the user, or his unwillingness to expend the required attention to the hazard. In addition to the changes in the coefficient of friction of flooring that may be built into a structure, a major cause of such change is the intermittent or occasional wetting of a small area of otherwise homogeneous floor surface, as occurs in kitchens, exterior entranceways, bathrooms, and laundry areas. The effect of such wetting can be mitigated by provision of water absorbing floor surfaces in the hazard areas. The danger from wet surfaces may be increased if the surface is sloping, a condition typical of bathtubs and shower stalls, and also of ramps. Tripping is another cause of falls on level surfaces, and may result from rough areas on floors, protrusions, certain carpet weaves, and also from raised door sills. Tripping over objects left on the floor, low furniture items or open drawers are the fault of the occupant (or his family) and cannot be provided for in the building.

Small changes in floor level, because they tend to be unnoticed, cause many falls. Thus step-down living rooms, sunken baths, etc. offer a considerable hazard as well as added building expense. Increased safety, then, can be had at a saving, simply by avoiding these particular designs. Considering, too, that the project encompasses a study of the needs of special groups of occupants, such as the elderly, these and other design features that entail additional hazard should be evaluated in terms of the special requirements of that segment of housing occupants.

Among the causes of falls from one level to another are unguarded balconies, and stairs and landings. For these, codes and standards have requirements for guard rails with specifications for height, space at bottom, and clear space between balusters. These are definite material requirements having the intent to secure suitable performance for safety. They are solutions to the unstated performance requirement, and while other solutions may be available or devised, these requirements are based on the physical measurements of human beings, and represent a consensus in the present state of the art for preventing falls from heights. Windows are a slightly different problem, for these are usually at a distance above the floor level, and may be screened or unopenable. If openable, however, a safeguard against falling out should be provided unless the height of the sill is about equal to that required of handrails on balconies. Some provision should be made for the safe washing of windows by the occupants, as professional window cleaners, who are covered by standards and codes, will probably not be employed in low-cost housing projects.

Falls resulting from standing on furniture, ladders or other objects to extend one's vertical reach add considerably to the accident statistics. This type of hazard, however, is subject to little control in the construction of housing, except that the necessity for such overextension of bodily height may be reduced by limiting the height of built-in shelving and avoidance of overhead light fixtures wherever possible.

Stairs are a major cause of falls, and as the victim usually ends on a different step than at the start of the fall, these may be classified as falls from one level to another. Such falls are the result of tripping or slipping, and as such are distinguished from falls from an unguarded edge, as previously mentioned. Code requirements in specification form have been established to enhance the safety of stairs in performing their function as means of vertical travel. These requirements cover stair width in relation to occupancy population, the dimensions of treads and risers, prohibition of the use of winders, and provision of handrails. An important requirement, usually omitted from codes, is that the step treads should have a uniform coefficient of friction in all the stairways that might ordinarily be used by the occupants.

Falls that occur on the grounds of the residential building or development may result from many of the same causes as falls in the interior areas. Broken or rough pavement may cause tripping. When wet, walking surfaces may be slippery, and the danger may be aggravated by the presence of grades and slopes. A further problem is that in many parts of the country, snow and ice are seasonal hazards, and their removal, or means to allay the hazard of slipping they present, requires a special effort. While sophisticated means of removing or preventing the accumulation of snow and ice, such as heating elements beneath pavements are available, their use is not likely in areas of low-cost housing in the foreseeable future. Because of the already considerable use of salts on ice, materials resistant to the action of these melting agents should be used in paving to avoid surface deterioration that is usually not quickly repaired. Cost permitting, children's play areas should be paved with a material softer than concrete, and because some falls are inevitable, the use of rough materials, such as cinders, should be avoided to minimize the injurious effects of the fall.

As falls are often the result of the actions of the victim, 100 percent safety from this type of hazard cannot be achieved. Children will run, jump, and climb, and their elders will go about unheeding of the dangers underfoot, and will dare to engage in activities wherein there is a high risk of falling. What can be done for falls, however, is to implement the intent of the general requirement for safety (see Section 2.3) to the end that the residential building will be constructed to eliminate so far as possible accident sources or remove their availability to the residents.

2.2.1 Requirements for Safety from Falls in Residential Occupancies

1) Walking or standing surfaces shall be provided with a coefficient of friction high enough to prevent slipping in ordinary traverse of the surface, and with increased friction on sloping surfaces.

2) Abrupt changes in the coefficient of friction shall not be permitted, nor shall materials of which the coefficient of friction is appreciably reduced by wetting be used in areas where such wetting may occur.

3) Rough floor surfaces, protrusions, projections, raised sills and carpet weaves that may cause tripping, shall not be permitted.

4) Floors shall present a uniform level surface, with no small changes in level.

5) All balconies, stairs or landings from which falls are possible by reason of being open on one or more sides shall be provided with guard rails or walls sufficient to reasonably protect the occupants from falling over, through or under.

6) Windows, if operable shall have sills of sufficient height above the floor, or be provided with guards or rails to protect the occupants from falling out. Windows shall be so designed that

the exterior surface may be safely cleaned by the resident without special equipment.

7) Stairs shall be of sufficient unobstructed width to provide safe emergency passage for all of the building occupants, with step treads and risers of suitable uniform dimensions, and with treads of uniform coefficient of friction and constant depth throughout the width of the stairs. Hand rails or other means shall be provided for increased stability of each user of the stairs.

2.3 General Safety

The annual toll of casualties resulting from home accidents, 28 to 30 thousand fatalities and 4 or 21 million incapacitating injuries (according to definition), makes it imperative that consideration be given to the establishment of safety requirements in residential occupancies.

The toll would be even higher if not held in check by the currently applied codes and standards for buildings, which in the field of safety, provide for fire protection, structural stability and in multifamily dwellings, emergency exit means.

Falls cause by far the greatest number of fatalities in home accidents, about twice that resulting from fires. Together they account for more than 60 percent of the deaths and many serious injuries, although the bulk of minor injuries may arise from other causes, such as cuts, burns (not connected with accidental fires) and bumps.

As the hazard of fire must be considered with reference to safety to property as well as life, and its characteristics of growth and spread, it is treated separately in this report. Falls, because of their major contribution to casualties and the possibility that some of the causes may be mitigated in their effect through building design, are also accorded a separate section. The safety requirements for structural elements and mechanical equipment are pertinent to the general studies in these areas.

Accidents are often the result of the actions of the victim, and the causes of some, such as cuts, drowning, suffocation, ingesting poisonous substances, use of firearms and others are usually not attributable to any feature that may be required for a dwelling or its environs. For the others, the following is a general statement of requirements:

The residential building and all its parts shall be so constructed as to minimize the possibility of accidents occurring by eliminating so far as possible all accident sources or removing their availability to the residents.

Residential occupancies shall meet the following requirements for safety to the inhabitants by features of structure or equipment having a usable life span equal to that of the building, or, if normally of more limited duration of use, readily replaceable by features of equal or greater safety:

1) The sources of and causes leading to falls, either on the same level or from one level to another shall be minimized. (To be presented in separate part).

2) The causes of casualties from accidental fires shall be reduced to the extent practical, or alternatively, suitable warning systems and means of safe exit allowing evacuation of the endangered area before it becomes untenable shall be provided. (Fire safety separately treated).

3) To avoid the possibility of suffocation in closed spaces, all such spaces provided as part of the structure or in installed equipment, if of such size as to contain a small child, shall be readily and easily openable from the inside.

4) Heating and cooking equipment shall not present the hazard of burns from excessively hot surfaces, or carbon monoxide poisoning due to incomplete combustion or other malfunction, and shall be provided with sufficient capacity, based on the occupancy, to obviate the necessity for improvised or temporary facilities which can present fire, explosion or burn hazards.

5) Installed energy facilities and installed equipment based on this energy shall not be a source of fire, shock, burns, or other injurious effect to the occupants.

   (Note: Energy sources and mechanical equipment are covered in existing codes and standards, and specific requirements presumably will be drawn by the assignees in the respective fields).

6) Structural elements or installed equipment or furnishings shall, to the extent practical, be free of sharp or pointed projections, and invisible transparent surfaces (if in a line of travel).

7) Safe storage facilities shall be provided for hazardous materials and objects such as poisons, medicines, firearms, etc. Closets and cabinets shall be so illuminated either directly or indirectly as to obviate the need for using improvised light sources in examining their contents. Suitable facilities for the safe storage of perishable foods shall also be provided (food storage otherwise assigned).

8) Built in structures, equipment or furnishings, or those supplied with the residential unit or building shall be so constructed and secured as to preclude the possibility of their falling or toppling.

9) The building housing the residential occupancy shall be so constructed as to not present to the occupants hazards associated with structural failure of the building or any of its parts.

10) The building shall be so constructed as and provided with the means to prevent the ingress of insects, vermin and rodents; nor shall breeding places be provided in the form of concealed spaces beneath or behind built-in or installed equipment.

11) Provision shall be made for the safe distribution of potable water to the building occupants, and the removal of wastes resulting from the human occupancy of the building.

12) Refrigeration and air conditioning equipment shall be installed in accordance with existing safety codes, and shall be maintained adequately to prevent hazards from leaks, explosions, moving parts, or contamination of water supply.

Further generalized requirements for safety from environmental factors: 1 - the building shall not be endangered by climatological factors, 2 - building approaches and play areas shall be constructed to minimize the possibility of falls, 3 - safety from vehicular traffic around building shall be provided; also good access to emergency vehicles, 4 - buildings and environs shall be so situated and arranged as not to provide places for criminal activity, 5 - sufficient lighting shall be installed to provide night-time safety to the degree contemplated for daylight hours.

Outside the areas separately covered, performance specifications (or any other kind) for safety are largely nonexistant. While standards and test methods can possibly be developed for some of the other requirements indicated, many of them can be met by recognized good and desirable practice in design and construction, often with little or no added cost. Considering also that falls and fires cause the majority of accidental fatalities in the home, and many of the others cannot be assigned to controllable elements in the victims' environment, it does not appear that research in the minor sources contributing to the accident toll is justified under a project to develop performance requirements for housing.

3. DURABILITY

3.1 DURABILITY AS THE TIME DIMENSION OF PERFORMANCE

3.1.0 Executive Summary

Durability is described as denoting the ability of a material, component or system of a structure to resist destruction for a normal period of time, with normal usage. Durability is the time dimension of performance. In the housing area, durability is applied to most components of the structure from the vapor-barrier waterstop beneath the basement floor to the protective covering on the roof of the structure. Generally, a durability requirement is stated for the structure as a whole; i.e., the structure must meet the user's need for a period of say 50 years. More specifically, the durability of some component or sub-system of the structure is frequently stated in respect to adequate performance for a specified period of time under normal usage. This is sometimes known to the user as a "guarantee". More often, the guarantee period is the period for which the seller is willing to be partially or wholly financially responsible for premature failure, rather than normal deterioration. The guarantee period is usually only a fraction of the expected useful life of a material or component. It is made apparent that there can be no single measure of durability due to the many diversified materials and components comprising the structure and the various and sundry destructive forces which result from natural, man-generated and normal or abnormal wear sources.

In reviewing the durability aspect, a convenient approach is to identify the user's needs in terms of the performance of specific building systems comprising the fabric portion of the structure; i.e., openings, exterior-interior walls, ceilings-floors, roofings, and sealant systems.

Performance requirements for the building systems are currently available for fabric portions of the structure. In some cases, the requirements apply to the particular parameter, e.g., weather resistance of the structure. In other cases the performance requirement often refers to a very specific material in the system; e.g., load tests for windows, extruded aluminum, vertical and horizontal sliding, medium duty.

There is a host of national standards, federal specifications and standards, and industry test methods and standards designed to evaluate various aspects of deterioration and durability of materials and systems in the laboratory. Among these are USA Standards, ASTM Standards, Federal Specifications, Federal Standards, and Commercial Standards that apply to walls, windows, ceilings, floors, roofs, and sealant materials. In addition, the American Iron and Steel Institute, the Portland Cement Association, the Porcelain

Enamel Institute, the Architectural Aluminum Manufacturers' Association, and others, have test methods and application standards for selected classes of materials. The Canadian Government Specifications Board has extensive specifications on windows, doors, and sealants.

A review of the above standards and test procedures indicate that, for the most part, they are of the prescription type. They appear to rely heavily on stating the nature and composition of a certain product although frequently they do incorporate some performance requirements for the prescribed materials. For example, a good exterior house paint may be described as one having a minimum of (X)% of non-volatile vehicle (composition) and, further, a cured specimen must resist (X) number of cycles in a weatherometer (performance). It is important to note that although there is a performance requirement, it refers only to one specific type of exterior house paint whose record of durability in service has been satisfactory. In contrast, to have a true performance standard, one must be able to describe the requirements, select a test procedure to measure performance, and establish limiting values for the acceptance or rejection of a material, composite or system regardless of its composition.

It is obvious that the durability plays a major role in performance requirements, since it implies change or lack of it in a material with time. The amount and type of change which occurs determines whether or not the user's needs are met for a normal period of time.

A large effort has been expended by manufacturers of materials, users, and research organizations in the development of measurement techniques for evaluating climate-related deterioration of materials and components of buildings. These efforts have followed at least five avenues:

1. The observation of buildings in use in a real-time scale and in the existing environment of human activities and climate.
2. The exposure and periodic examination of samples of materials or systems on racks in selected climatic zones representative of rather extreme values of certain weather parameters.
3. The development of accelerated laboratory test procedures in which materials are exposed to cyclic patterns of conditions that simulate to a greater or lesser degree the natural weather cycles of the country.
4. Research to more faithfully reproduce natural weather phenomena and existing air contaminants in the laboratory weathering apparatuses used for accelerated weathering tests.
5. Efforts to correlate the observed results from the four techniques described above.

In general, the efforts up to the present time to correlate the observed results from accelerated laboratory tests with natural exposure have not permitted reliable estimates of useful life of building materials and components to be made. This lack of correlation has been due to several factors; namely:

1. Inadequate understanding of the physical and chemical processes of deterioration.
2. Incomplete simulation of natural weather.
3. Incomplete identification of the components of natural weather that are related to deterioration.
4. An inadequate program of simultaneous field and laboratory work on identical specimens.

Simulated service testing has been the forte of the Building Research Division of the National Bureau of Standards for many years as a means to measure performance characteristics for materials of construction. Although the information developed from the many, many research programs has proven to be extremely helpful in the advancement of the state-of-the-art and, in many cases, useful in predicting a material's performance, little of this information has found its way into performance type specifications. However, this multifarious data will prove extremely useful in conducting any short-term (6 mo. to 1 year) program whose objective is the prediction of long-term performance on the basis of short duration tests. This vast data source together with the expertise of the technical staff of the Building Research Division provides a capability for producing performance requirements for specific building systems with a minimum effort devoted to new research requiring longer time periods.

3.1.1 Rationale

The concept of performance of a building material, component or system is the ability of the building element to fulfill the important requirements of the user without regard to the materials employed in its construction. It is apparent that the satisfaction of the user's needs depends not only on the original performance characteristics of a building element or system but also on its ability to retain the desirable performance characteristics over a period of time under service conditions. Durability, therefore, denotes the ability of a material, component, or system to resist destruction for a normal period of time with normal usage and taking into account normal destructive factors and normal maintenance. Since the destructive forces may be divided into a number of classes, e.g., natural, man-generated, normal wear, etc., there is no single measure for durability. Durability may involve resistance to weathering, resistance to wear, resistance to decay, resistance to freezing and thawing, and resistance to impact. The durability of a structure will be modified by its end use and its location, which involves ranges of temperature, moisture, and other atmospheric factors.

In enumerating the functional requirements for residential structures, Blachere [1] has identified four series of requirements, one of which refers directly to durability. The requirements are:

1. A house must provide its occupier with a healthy environment, favorable to rest, in spite of troublesome external factors, whether natural or otherwise, and also provide him with certain amenities.
2. The dwelling must offer adequate facilities for family life; e.g., minimum area, provision of special room for each activity, etc.
3. Requirements in this category are aimed at ensuring that those of the other series remain satisfied for a reasonable period of time (this requirement implies good durability).
4. Maintenance should be not only reasonable in cost and time but it should be easily accomplished.

3.1.2 Generalized Performance Statement with Respect to Durability

Frequently performance statements have been used to describe, in general terms, durability in building codes and standards. These can be stated in various and sundry ways. By way of paraphrasing, the section on durability of the Building Standard Regulations of Scotland [2] is quoted in the following example:

"All materials used in the construction of a building shall be:

a) of suitable quality and of suitable properties for the purposes for which they are intended.

b) sufficiently resistant to deterioration and wear taking into account the conditions to which they will be subjected.

c) properly prepared.

d) so applied, fixed, or otherwise used that those parts of the building in which they are used attain the standards prescribed in these regulations:

Provided that nothing in this regulation shall prevent the use of a material which does not comply with requirements of this regulation:

a) where the material can achieve a sufficient standard of durability by added protection, if the material is given such protection as its nature and the conditions to which it will be subjected, will require and, where the periodic maintenance and

[1] Innovation in Buildings, The Second CIB Congress, Cambridge 1962; Elsevier Publishing Co., New York, 1962. p 186.

[2] The Building Standard (Scotland) Regulations, Part II, Sect. 12, Materials and Durability, Her Majesty's Stationary Office, 1963.

renewal of the protective work is necessary and used only in a position where the protective work will be readily accessible for inspection, maintenance and renewal or;

b) where the material itself is readily accessible for inspection, maintenance and renewal, and in either case such maintenance and renewal is reasonably practicable."

3.1.3 System Performance Requirements with Respect to Durability

Generally there seems to be no need to formulate a durability requirement for the total residential structure other than say fifty years. However, the service life of a given building should be related to some degree to the way in which it is financed. A residential structure financed on the basis of amortization over thirty years could not have a life covering a shorter period.

Obviously it is not sufficient to state durability in such general terms as indicated above. In order to define performance requirements of the total structure in terms of durability, the permanence of the initial properties of the materials, composites and subsystems must be measured in respect to service conditions and elapsed exposure time. The fabric of the structure appears to be more susceptible to wear and tear than most other parts of the structure. Therefore, a convenient approach to measure durability is to define the functions of the building subsystems which make up the fabric. Figure 1 is a function matrix which identifies the functions of the various elements of the fabric. Durability implies that the functions should be maintained at a level commensurate with the user's needs for the useful life of the building. Service conditions may include:

a) Exposure to exterior environment; radiation (heat, light, ultraviolet, etc.), temperature change, moisture (rain, snow, vapor, dew, etc.), air pollutants, wind.
b) Operation in a conventional manner for which it was designed. (Opening and closing of windows and doors, etc.).
c) Subjection to anticipated abuses.
d) Susceptibility to premature failure when one of the protective subsystems fails to perform its intended function.

3.1.4 Initial Costs versus Maintenance-Replacement Costs

Durability implies that the required performance characteristics be retained by a material, composite and system for a specified time. There are three approaches to evaluating whether or not the material or system will retain this desired performance for the required time span. The three approaches involve:

FABRIC SUB-SYSTEM ↓ / FUNCTION →	STRUCTURAL SUPPORT STRUCTURE-OCCUPANTS, OBJECTS	SPACE SEPARATION	PROTECTION FROM OUTDOOR ELEMENTS	DECORATION	PRIVACY	SECURITY	LIGHT	VENTILATION	VISIBILITY	ACCESS BETWEEN SPACES	FIRE BARRIER	THERMAL BARRIER	VAPOR BARRIER	SOUND BARRIER	RODENT BARRIER	INSECT BARRIER
STRUCTURAL ELEMENTS	X															
EXTERIOR WALLS	X	-	X	-	X	X					-	X	-	-	-	-
INTERIOR WALLS	-	X			X	-					X	-		X		
ROOFS		-	X	-	-						X	X	-	-	-	-
WINDOWS			-	-		X	X	X	X			-		-		-
DOORS			X	-	-	X	-	-	-	X	X	-		-	-	-
CEILINGS		X		-							-	-	-	X		
FLOORS	X	-		-							-	-	-	X	-	
SEALANT SYSTEMS			X	-									-	-	-	-

X = more important
- = less important
Blank = no function

FIGURE I. FUNCTIONS OF BUILDING SUB-SYSTEMS

a) Determining that the material will retain the desired performance for the life of the structure.
b) Determining that the material will retain desired performance for the required time span, provided that a program of periodic maintenance and repair can be assured.
c) Determining that the desired performance can be retained for the required span by periodic replacement of a material, component or system.

The annual expenditures for the maintenance of residential structures amounted to over $5 billion during 1965. The cost of replacement of failed materials and systems during the same period was approximately $1.7 billion. These substantial sums reflect the dilemma of an administrator in making a judgment regarding initial cost versus maintenance costs versus periodic replacement costs. Unfortunately, initial cost is frequently the major consideration because there is little or no feedback between the ultimate consumer and the contractor and manufacturer. In some cases it may well be the more economical alternative to purchase a "maintenance free" item at a high initial cost rather than to select a less expensive one which will require frequent and costly attention. In other cases a periodic maintenance program developed to extend the useful service life of an initially inexpensive item until replacement in kind is required may produce the better payoff to the consumer. It should be stressed, however, that there is no reason, other than safety, to use materials or systems which will last substantially longer than the structure for which they were intended.

In any attempt to determine the cost-utility of the selected alternative, the additional costs for the use of initial cost monies over the life span of the mortgage must be taken into account. This factor will reduce the apparent gap which exists between first costs and maintenance-replacement costs.

3.1.5 Durability of Fabric Systems

3.1.5.1 Exterior-Interior Walls

3.1.5.1.1 Rationale for Performance Requirements of Wall Systems

Wall systems, along with floors and roofs, are the three most important system elements in a building. The external walls provide for many of the fundamental requirements of the user of a residential dwelling. The internal walls, while serving a somewhat lesser function than the external walls, still provide for several important user requirements.

The principal functions of the external walls are:

a) to provide a barrier between the dwelling occupants and the elements of weather,

b) to serve as a thermal insulator,

c) to provide visual and acoustical privacy, and

d) to exclude entry into the structure of unwanted animals, objects, sounds, light, etc.

In some cases a primary function of an external wall is to provide structural support to the roof.

The principal functions of the internal walls are:

a) to divide the living space into convenient compartments,

b) to provide visual and acoustical privacy, and

c) to serve as barriers to fires, noises, odors, pests, etc.

There are many materials available today that, when properly assembled, can provide one or more of these functional requirements. Ideally, one material should fulfill all requirements of a system, but the state of the art has not as yet reached this stage, so we have to start with what is available. Thus, we start by naming a particular material to be a component of a system, and when we do this the system often loses most of its freedom; e.g., other materials and perhaps techniques become "locked" into the system simply because they are compatible with the original material.

The alternative to designing a building on the basis of known materials is to develop a set of comprehensive performance requirements. When we have developed such requirements and the means to measure them, we will have gone a long way toward opening up the opportunity for innovations and competitive materials.

3.1.5.1.2 Generalized Performance Requirement Statements for Wall Systems

A. External Walls

An external wall system should effectively exclude the undesirable elements of outside weather from reaching the inside of the structure. Specifically, the system should prevent the penetration of rain, hail, snow, sleet, wind, and lightning. In addition, it should serve as a thermal barrier--confining the fuel-generated heat within the building during cold weather and excluding solar-generated heat during warm weather.

The wall should provide visual and acoustical privacy to the occupants; e.g., a person on the outside of the building should not be able to discern distinct images through the wall without the consent of the occupant, nor should the outsider be able to audit normal human vocal communications within the structure. This is not to say that the occupant should not have the capability to relinquish at his discretion some of his privacy, for example, through openings, such as picture windows. In addition to furnishing acoustical privacy, the sound transmission character of the wall should be such as to exclude normal street noises and to diminish to an acceptable level high-intensity sounds, such as emanate from jet aircraft.

An external wall system should serve as an impenetrable barrier to insects, rodents and other forms of animal life; also, it should provide security against the unauthorized entry of human beings. It should effectively exclude dust, soot, air-pollution particulates, and wind-blown objects. Furthermore, it should be opaque to visible light, or should be capable of being made so at the wish of the occupant.

The external wall system should be reasonably resistant to impact damage, should be fire-resistant, and should have an acceptable level of aesthetic appeal.

B. Internal Walls

Internal wall systems should effectively separate the spaces in a dwelling into compartments compatible with the wishes of the potential occupants. The walls should provide both visual and acoustical privacy and should be capable of accepting decorative finishes, accessories, and ornaments. The walls should serve as barriers to fires, odors, insects, rodents, and intruders.

3.1.5.1.3 Additional Specific Requirements of Wall Systems

In addition to the generalized performance requirements of wall systems, there are specific requirements related to the current state of the art. Some of these are:

a) Walls should resist impact damage when struck by objects,

b) Walls should not deteriorate to the detriment of their functions when subjected to the elements of weather, to solar radiation, to air pollutants, etc.,

c) Walls should resist damage during normal maintenance procedures, and when subjected to accidental or deliberate abusive treatment, and

d) Walls should be structurally adequate to support closure devices associated with openings in the walls.

3.1.5.1.4 Abstracts of Durability Performance Test Procedures for Interior and Exterior Walls

a) Corrosion Resistance.* (Source: NBS-FHA)

A visual comparison is made of specimens exposed for 1100 hours in a carbon arc Weatherometer with a cycle of 3-minute tap water spray and 17 minutes dry.

b) Washability.** (Source: NBS-FHA)

Specimens are soiled with a standard soiling medium, washed mechanically, then evaluated instrumentally for changes in gloss and reflectance.

c) Impact Resistance.** (Source NBS-FHA)

A steel ball is dropped, under controlled conditions, onto the surface of a specimen of the test material. Damage to the specimen is noted as a dent, deformation, cracks, puncture, or splinters. The impact resistance of the material is classified into one of three categories.

d) Resistance to Solar Radiation.* (Source NBS-FHA)

Specimens are exposed dry in a Xenon arc Weatherometer for a specified length of time, then evaluated for changes in gloss, color, and washability.

* Applied to Exterior walls

** Applied to Both Exterior and Interior Walls

e) Abrasion Resistance.**

1. (Source: ASTM D-968). A stream of sand of specified particle size falls from a fixed height onto a test surface. The measure of abrasion resistance is the time required to abrade through the coating.

2. (Source: ASTM D-658 and Federal Test Method Standard No. 141a). Both of these are air blast abrasion tests in which the abrasive under pressure impinges on the test surface. The end point is the time required to abrade through the coating.

3. (Source: ASTM C-448). Specimens are abraded with a mixture of abrasive particles and small steel balls, then measured for loss of gloss to determine surface abrasion resistance or loss of weight to determine sub surface abrasion resistance.

f) Flexibility.** (Sources: NBS-FHA and Federal Test Method Standard No. 141a, Method 6222).

Specimens of coating films are bent over 1/4- and 1/8-inch cylindrical mandrels to determine the smaller of the two diameters that the coating can be bent without cracking.

g) Resistance to Freezing or Low Temperature Damage.*

1. Concrete (Sources: ASTM C-290, C-291) Concrete specimens are subjected to controlled conditions of freezing and thawing, then evaluated with respect to their resistances to cracking and spalling.

2. Plastics (Source: ASTM D-746) The resistance of plastics to impact damage at low temperatures is tested.

3. Organic Coatings (Source: ASTM D-1211) This is a test of the resistance to cracking of nitrocellulose lacquer films on wood when exposed to temperature changes.

h) Humidity Resistance.** (Sources: Standards for Painted Aluminum Sheet, No. 10, The Aluminum Assoc., and ASTM D-714)

Specimens are exposed for 1000 hours at 100% relative humidity. The material is rated according to the number and size of blisters that form.

3.1.5.2 Windows - Doors

3.1.5.2.1 Rationale for Performance Requirements

A) Openings: Windows

Windows, as structural elements of a building, serve certain functions which are unique and at the same time share other functions with the exterior walls of the structure. In the first category we find provision for the admission of light and arrangements for ventilation, whereas the shared functions include protection of the interior from the weather while serving specifically as a barrier to heat, cold, moisture, sound, rodents and insects. Additionally, both windows and exterior walls may contribute to the esthetic appeal of the building; certainly they should not detract from it.

Traditionally, the transparent portion of a window has been glass and the supporting or framing members made of wood or steel. Recent developments in the plastics field suggest the possiblity of utilizng such products as the acrylics and polycarbonates as well as glass. Similarly, aluminum is already a strong entrant in the area once dominated by wood and steel. Other possibilities readily come to mind: light, strong, corrosion-resistant titanium, for instance, or certain alloys which have been used successfully in other areas of construction.

From the foregoing it is apparent that various options are available to designers and builders and that these options can be exercised either in terms of currently known materials or by setting forth performance requirements appropriate to the function served. The first approach is subject to criticism on the grounds that poor judgment, bias, and lack of knowledge can all contribute to the use of ill-suited materials. The performance requirement approach on the other hand is subject to none of these limitations while at the same time it envisions the introduction of materials and solutions not yet developed.

In brief summary, the performance requirement technique is one that admits all currently available satisfactory solutions to window problems; it does not exclude innovations that may be even better; and it seems especially well adapted for consideration in a large scale construction program.

B) Openings: Doors

The logic that governs the performance requirement approach to the window openings problem is equally valid with respect to door openings.

Door materials include softwoods, hardwood veneers, and various metals such as lead and steel. The steel may be coated typically with paint or with other metals including terne plate, tin, and zinc. Various types of construction are also available including the panel door and the flush door; furthermore the installation may contemplate a swinging door or one that slides horizontally.

The important consideration, however, is that a door must serve its function properly regardless of the materials used in its construction. These functions can be identified to include protection from the weather, providing access between spaces, insuring privacy and security, and serving as a barrier to fire and rodents, for example. All of these functions and others can be described in terms of performance requirements. Once these are established, specifications for door openings can be drafted that are free from the limitations of materials requirements and enjoy the same positive advantages previously cited for window openings.

3.1.5.2.2 Generalized Performance Requirement Statements on Windows and Doors

The complex functional characteristics of windows, of necessity, lead to a complex performance requirement statement. For example, the functions of the window include air and light transmission, contrasting with the functions of the window as weather barrier, thermal barrier, sound barrier, and insect barrier.

1) The light transmission characteristics of windows should not change under the influence of solar radiation or other elements of the weather, or under the abrasive treatment used in routine maintenance operations.

2) Windows should maintain their dimensional stability under the influence of both outdoor weather conditions and indoor temperature and humidity changes. Dimensional stability enables the window to act as a barrier for the elements of weather, sound, heat, and insects, and also to be opened and closed for the control of air transmission.

3) The window should be impact resistant to perform its functions. Impact-resistant windows imply an added safety feature.

4) The window should have fire- and explosion-resistant performance characteristics to serve its function as a barrier to a potentially dangerous fire.

5) The window system has also performance requirements of a decorative nature; the maintenance of controllable privacy, the esthetic value to the total building system, and the psychological communication between indoors and outdoors.

Doors, as windows, also require a complex performance statement because their functional characteristics are contradictory. Consider that the door serves as weather barrier, thermal barrier, sound barrier, fire barrier, insect and rodent barrier, and aid to security; it also functions as the access between units of the building system and between the indoors and outdoors.

1) Doors should maintain their dimensional stability when exposed to the weather elements, indoor temperature and humidity changes, and physical abuse from the occupants of the building.

2) As the door serves as an access where many physical forces are used, mechanical stability and impact resistance are essential.

3) The door should have fire- and explosion-resistant performance characteristics to function as a fire barrier.

4) The door should have also as performance requirements the maintenance of controlled privacy, and access, security, and esthetic values in relation to the complete building system.

3.1.5.2.3 Additional Specific Requirements

A) Openings: Windows

A survey of specifications and standards for windows and doors shows a strongly intrenched practice of specifying the material, design, dimensions, method of nailing (for wood units), and other characteristics in considerable detail. Performance requirements are the exception rather than the rule; those in current use are listed below by source.

American Society for Testing and Materials

ASTM E 283-65T - Rate of Air Leakage Through Windows, Test for

ASTM E 330-67T - Structural Strength of Closed Windows Under the Influence of Wind Loads, Test for

ASTM E 331-67T - Water Resistance of Windows by Uniform Static Air Pressure Differential, Test for

ASTM E 163-65 - Fire Tests of Window Assemblies

B) Openings: Doors

American Society for Testing and Materials

ASTM E 152-66 - Fire Tests of Door Assemblies

Federal Specifications

Fed. Spec. LLL-D-581b,
Doors, Wood, (Exterior and Interior), 4.4.1 - Racking Resistance

Fed. Spec. LLL-D-581b,
Doors, Wood, (Exterior and Interior), 4.4.3 - Sound Resistance

U.S. Department of Commerce
Commercial Standards

Comm. Std. CS 171-58, Hardwood Veneered Doors, 5.1	- Cold Soak Test for Type II Doors
Comm. Std. CS 171-58, Hardwood Veneered Doors, 5.2	- Waterproof Bond Test for Type I Doors
Comm. Std. CS 262-63, Water-Repellent Preservative Non-Pressure Treatment for Millwork, 5.2.1	- Toxicity Test
Comm. Std. CS 262-63, Water-Repellent Preservative Non-Pressure Treatment for Millwork, 5.2.2	- Water Repellency Test

American Standards Association
(now USASI)

ASA Z 2.4.19 - 1957 - Laboratory Measurement of Air-Borne Sound Transmission Loss of Building Floors and Walls

National Fire Protection Association

NFPA No. 252 - Standard Methods of Fire Tests of Door Assemblies.

Underwriter's Laboratories, Inc.

UL Std. 10(b) - Fire Tests of Door Assemblies

3.1.5.2.4 Abstract of Pertinent Performance Requirements from Published Material

A) Openings: Windows

Review of published standards for windows and doors including specifically Federal Specifications, Commercial Standards, and those of the Canadian Government Specifications Board reveals that only the latter have made any significant effort to include performance requirements. Even so the performance requirements outlined are specifically applicable to the particular material specified. Separate specifications have been issued for each of the four types of materials contemplated, viz., extruded vinyl, wood, aluminum, and steel.

The following abstracts are from the Canadian Government (CGSB) Standards:

41-GP-19 - Rigid Vinyl Extrusions for Windows and Doors

Shrinkage - When tested at 180°F for 30 minutes the linear shrinkage shall not exceed 3.0 percent.

Extrusion Quality - When tested by acetone immersion for 20 minutes the loss in weight shall not exceed 1.0 percent.

63-GP-1 - Windows; Aluminum, Vertical and Horizontal Sliding, Heavy Duty

Horizontal Load Test - When a concentrated load of 40 pounds is applied at the center of the span there shall not be a horizontal deflection of more than 0.145 inch for vertical sliding windows or more than 0.100 inch for horizontal sliding windows.

Vertical Load Test - A 40 pound load acting vertically shall not cause a vertical deflection of more than 0.065 inch.

Air Infiltration - Requirements are established under which air leakage must not exceed 1/2 cu ft/min/ft of crack length with sash in closed position and locked. Applies to vertical sliding, horizontal sliding and double windows with outer sash open.

63-GP-2a - Windows: Extruded Aluminum, Vertical and Horizontal Sliding, Medium Duty

Load Tests

Perpendicular Load Test - For vertical sliding windows a concentrated load of 30 pounds acting perpendicular to plane of sash shall not cause deflection exceeding 0.220 inch. Same for horizontal sliding windows except maximum deflection is 0.145 inch.

Parallel Load Test - For vertical sliding windows a concentrated load of 30 pounds acting parallel to the plane of the sash shall not cause a deflection of more than 0.100 inch. Same for horizontal sliding windows except deflection limit is 0.145 inch.

Air Infiltration - Test same as ASTM E 283 with pressure difference across window of 1.567 pounds per square foot. For vertical sliding windows maximum leakage is 1/2 cu. ft/min/ft. Same maximum for horizontal sliding windows.

Water Resistance Test - A water spray system is described which is maintained for 15 min. No water is permitted on interior face of window, none shall pass into space between sill and frame, and any that appears elsewhere shall drain to the exterior.

Thermal Break Test - A temperature difference no greater than 14°F is permitted when test is conducted as described. Test involves sealing window unit with one face exposed to low temperature and other at normal room temperature. Air movement is provided. Cold and warm side temperatures are measured with thermostats.

Resistance to Blow-out - A sealed window unit is subjected to a chamber pressure of 30.4 lb/ft^2, equivalent to 110 mph for one minute. Glazing is required to remain firmly in place.

Enameled Finish - Tests for effect of high humidity, effect of accelerated weathering, effect of salt fog, and adhesion are established in terms of methods described in CGSB 1-GP-71.

63-GP-3a - Windows: Extruded Aluminum, Vertical and Horizontal Sliding, Standard Duty

See requirements for 63-GP-2a.

63-GP-4 - Windows: Sashless, Horizontal Sliding

Air Infiltration - A maximum air leakage of 3/4 cu ft/min/ft of crack length is permitted with inner panels closed and locked. A static air pressure equivalent to wind velocity of 25 mph is applied in accordance with Technical Note No. 375 published by the Division of Building Research, National Research Council, Ottawa, Canada.

63-GP-5 - Windows; Steel, Vertical and Horizontal Sliding, Standard Duty

Air Infiltration

Load Tests

Tests of Enamel Coatings

See abstracts of 63-GP-2a which are similar.

63-GP-8 - Windows: Extruded Aluminum, Projected, Medium Duty

Enameled Finish

Load Tests

Air Infiltration Test

Water Resistance Test

Thermal Break Test

Resistance to Blow-Out

These are generally similar to those in 63-GP-2a, which see.

B) Openings: Doors

82-GP-1 - Doors; Glass, Aluminum Frame, Sliding, Standard Duty (1)
and

82-GP-2 - Doors; Glass, Aluminum Frame, Sliding, Medium Duty (2)

Load Tests - A load of 20 pounds acting horizontally and parallel to the plane of the door shall not cause a horizontal deflection of more than 0.200 inch for (1) above or more than 0.100 inch for (2) above.

The same load applied horizontally and perpendicular to the plane of the door shall not cause a horizontal deflection of more than 0.200 inch for (1) above or more than 0.150 inch for (2) above.

The same load acting perpendicular to the plane of the door and applied to the muntin bar shall not cause a horizontal deflection of more than 0.200 inch in either (1) or (2) above.

Air Infiltration - The door is subjected to a static air pressure equivalent to the pressure exerted by a 25 mph wind. Maximum permitted air filtration for (1) is 0.75 cu. ft/min for (1) and 0.50 cu. ft/min for (2).

Tests of Enamel Coatings - Tests are described in terms of CGSB Standard 1-GP-71. Accelerated aging is covered by Method 122.2, followed by a tape test to determine adhesion. A salt fog test is conducted to determine corrosion resistance. Requirements are identical for (1) and (2).

82-GP-3 - Doors: Aluminum, Combination Storm and Screen

Load Tests - Perpendicular and parallel load tests (see 82-GP-1) are described. Maximum deflections permitted are respectively, 0.150 inch and 0.050 inch.

Cycling Test - The door is mounted in a rigid wood frame and is then opened and closed continuously by means of a pneumatic ram for 225,000 cycles. A closing time of not more than 25 percent from the initial closing time is permitted. No evidence of failure or malfunction of hardware is tolerated.

Closing Force Test - A force meter is used on the door mounted as above. Minimum required closing force is 3-3/4 pounds.

Tests of Enamel Coatings - Tests for effect of high humidity, accelerated weathering, salt fog and adhesion are conducted in accordance with methods described in CGSB 1-GP-71.

3.1.5.3 Ceilings - Floors

3.1.5.3.1 Rationale for Performance Requirements

The primary functions of the floor/ceiling system, (one of the horizontal elements of a dwelling) are those of space definition or isolation of the whole enclosure into small units, and provision of a level support surface.

The floor/ceiling system also may encompass the following broad range of functions:

1. Structural function

   a) Environmental loads; such as thermal - The heat flow resistance of the floor/ceiling construction with flooring is mainly of economic interest because it determines the heat requirement of the rooms insofar as the floor/ceiling partition divide rooms which may be at different temperatures. The foot warmth, which has a unique health significance, is also of concern.

   b) Building systems loads; strength, stiffness, flatness and distress as the determinant of the overall structural system.

   c) Mechanical and service loads; - as a carrier of electrical, heat and communication distribution systems and other fixed service equipment.

   d) Esthetic loads; - as a carrier of acoustical control, decorative and decorative-functional surfaces.

   e) Man-made loads; - occupancy (i.e. furnishing, appliance and people).

2. Space conditioning function

   a) Temperature, humidity, ventilation

   b) Acoustics, as floor/ceiling construction features useful controlling of impact noise, also limits the transmission of airborne noise.

   c) Lighting, color

3. Traffic bearing function

   a) Protection of floor/ceiling (i.e. itself) from such destructive agencies as traffic or effluents.

   b) Better appearance

   c) Increased comfort and safety - These three functions are not given equal weight in deciding the floor/ceiling for any particular use; in some circumstances the first may be the most important, whereas in others the second or third may be required in greatest measure.

The floor/ceiling system has been used by man since his dwellings have developed more than one story. In recent years attempts to determine the level of performance of the many component parts that make up the floor/ceiling system with respect to user needs, durability and maintainability have been considered and in some cases established. All-encompassing ceiling assemblies, i.e. the fully integrated systems that combine the functions of acoustical control, fire protection, air distribution, and lighting in a simplified assemble must be rated against the performance of the whole floor/ceiling with respect to the performance and cost.

3.1.5.3.2 Generalized Performance Requirement Statements of Floor/Ceiling Systems

1. Floor coverings

a) Wear - Floors receive an estimated 90% more wear than any other part of the dwelling. They are subjected to severe abrasion from foot traffic. Concentrated loads or stationary and moving casters or furniture feet may cause pits or depressions. It is sometime necessary to remove stains or surface blemishes by abusively abrading the floor.

b) Heat and sunlight - Floors are exposed to relatively high heat either from introducing heat into space, i.e. ducts, hot water pipes etc., or from damaging effects of sunlight through windows.

c) Moisture - Excessive moisture is found in some floors which are mopped frequently, particularly around plumbing fixtures. Moisture causes the fading, rotting, staining or dissolving or materials. The proper bonding of certain types of floors to the substructure is difficult under moist conditions. Necessary sanitation may be impaired by the presence of excessive moisture.

d) Chemical (household) - Accidents frequently happen in which there is a spillage on floors. The use of disinfectants and cleaning solutions often proves damaging.

2. Structural floor

a) Provide strength

b) provide rigidity

c) provide support for carrying systems and other fixed service equipment

d) provide surface for attachment of coverings (i.e. floor coverings on top and acoustic, decorative, and environmental subsystems on bottom.

e) Flatness: the structural floor should provide a level surface suitable for pedestrian traffic and rolling and sliding of objects of furniture on the top and for attaching ceiling elements on the underside. The top surface of the structural floor must provide a finish suitable for placing floor covering.

3. Ceiling

No live load need be assumed for ceiling elements. The ceiling surface is the underside of a floor element, or roof element; therefore, it is subject to the requirements (performance) of the system of which it is a component, such as:

1) acoustic properties,
2) fire retardance and flame spread
3) thermal properties.

The ceiling itself should not deflect (stability); should have good gloss retention and resistance to color change, and be resistant to fungi growth.

3.1.5.3.3 Additional Performance Requirements for Currently Used or Known Solutions

As a result of an extended technical study developed under the FHA Technical Studies Program a guide to "Impact Noise Control in Multifamily Dwellings" was prepared. This guide presents three practical ways to control impact noise in floor/ceiling systems by:

1. Providing a curve of recommended maximum impact sound pressure level for floor/ceiling constructions.

2. Showing a collection of impact performance curves characteristic of typical U.S. floor/ceiling construction.

3. Suggesting through architectural sketches means of proving good construction from impact noise standpoint and precautions to be taken.

3.1.5.3.4 Trade-offs - Operation costs, etc.

According to "Factory", roughly 1 out of 10 industrial employees is engaged in a maintenance function. Of these about 7 to 32% - depending on the industry - are involved in cleaning and sanitation activities. Industry's annual maintenance bill is over $20-billion, 40% of which goes for floor care. While this appears to be a high price to pay for clean-up work, and is based on industrial buildings, not dwellings, statistics show that the depreciation of property and increased hazards resulting from poor housekeeping practices cause losses many times greater.

Floor maintenance requires more consideration and effort than other types of maintenance. The constant attrition due to traffic (frequently more noticeable when some portions of the floor are used more than other portions) and the transfer of dirt from shoes and gravitational deposits of soil are factors which increased the maintenance problem. Floors account for about 40% of the overall building operations cost. For this reason, proper selection and maintenance of floor coverings is one of the most important aspects of good building operation.

An unappropriate choice inevitably mars total appearance and substantially increases maintenance costs. Maintenance must be protective or preventive, rather than curative.

At entranceways, common access halls and areas of high water and reagent spillage (bathrooms, laundries and kitchens), a floor surface of high wear and impact resistance, high resistance to water and reagent spillage, without the need of sealers, frequent dressing of top coatings, stripping and buffing (i.e., low maintenance) would be desirable, but at the tradeoff of the following:

1) High initial cost;
2) High impact noise;
3) Loss of comfort value (both thermal and resiliency).

It is also pointed out that a single level of performance might well be satisfactory throughout a dwelling, but that different uses of the living areas demand different durability levels. Entranceways, corridors, kitchens and bathrooms, characterized by the amount and type of usage, require highly durable floors, whereas living rooms and bedrooms need only moderate levels of durability with respect to performance.

3.1.5.3.5 Test Procedures

The tests for performance properties of floor-ceiling systems are listed in the attached Table I. The abstracting of the methods are listed below and referenced by Table I.

3.1.5.3.5.1 Abrasion Resistance

A laboratory test of abrasion resistance may be of value for measuring relative differences of abrasion resistance between systems. The degree of correlation of the laboratory test with actual service exposures is questionable. All of the indicated methods listed below (only a few of the many) have doubtful reproducibility with some types of floor systems, and have seldom been used on ceiling materials.

a) Method of Test for Abrasion Resistance (Taber Abrader), 6192 Federal Test Method Standard 141a.

b) Method of Test for Abrasion Resistance of Paint Products ..... by the falling sand method (ASTM D 968-51).

c) Method of Test for Abrasion Resistance (Jet Abrader), 6193 Federal Test Method Standard 141a.

d) Method of Test for Abrasion Resistance of Coatings ... with the Air Blast Abrasion Tester (ASTM D 658-44).

3.1.5.3.5.2 Acoustics

The control of noise, impact and air transmitted in dwelling units is in the interest of the occupants and owners. Privacy and peace of mind are much enhanced for the occupants. A higher percentage of steady occupancy and better return on investments are promoted for the owners. Methods of evaluation are well spelled out:

a) Impact Noise Control in Multifamily Dwellings, FHA No. 750 (updated with report HUD Technical Study 24).

3.1.5.3.5.3 Adhesion

No method available covering both chemical and mechanical bonding over or under different substrates for both floors and ceiling. There are a few methods of tests covering a few systems:

a) Adhesion to fabric, 7211 Fed. Test Method Standard 501a.

b) Keying test, 7221 Fed. Test Method Standard 501a.

c) Acoustical tile adhesive, Fed. Specification

3.1.5.3.5.4 Coefficient of Friction

A method for measuring the relative degree of slip of smooth surface flooring systems versus textile flooring should be established. Here again the degree of correlation of the laboratory tests listed below with actual service experience is questionable.

a) Method of Test for Static Coefficient of Friction of Waxed Floor Surfaces (ASTM D 2047-64).

b) Method of Test for Measuring Surface Friction Properties Using the British Portable Tester (ASTM E 303-66T).

3.1.5.3.5.5 Color Change - Gloss Retention

Specific colors may be controlled by visual comparison of panels of test systems. Other methods are well defined and need only be worked out to specific systems.

a) Method for Visual Evaluation of Color Differences of Opaque Materials, (ASTM D 1729-60T).

b) Resistance to Light, 5411 Fed. Test Method Standard 501a.

c) Colorfastness to Light, 5421, Fed. Test Method Standard 501a.

d) Specular Gloss, 7411 Fed. Test Method Standard 501a.

3.1.5.3.5.6 Compression, Indentation, Resiliency

Method of tests and performance requirements for most systems are well established. A relation between resiliency and human comfort in numbers is needed.

a) Indentation, spherical foot, 3211 Fed. Test Method Std. 501a.

b) Indentation, flat foot, 3221 Fed. Test Method Std. 501a.

c) Indentation, residual, 3231 Fed. Test Method Std. 501a.

d) Recovery from indentation, 3241 Fed. Test Method Std. 501a.

3.1.5.3.5.7 Fire Retardancy

The fire retardancy properties of the complete system or component parts can be determined according to the following methods:

a) Method of Test for Fire Retardancy of Paints (ASTM D 1360-58).

b) Fire resistance, 6411 Fed. Test Method Std. 501a.

3.1.5.3.5.8 Flame Spread

The flame spread properties of the complete system, tested on both combustible and noncombustible substrate can be determined by:

a) Method of Test for Surface Burning Characteristics for Building Materials ASTM E 84-61.

b) Flame Spread Index, 6421 Fed. Test Method Std. 501a.

3.1.5.3.5.9 Fungi Resistance

The effect of fungi on plastics can be determined by test method listed below, modification of procedure can be established to evaluate other materials.

a) Method of Test for Determing Resistance of Plastics to Fungi (ASTM D 1924-63).

3.1.5.3.5.10 Immersion, Stain, and Chemical Resistance

Performance test procedures for resistance under immersion conditions, to the action of various liquids and effects of chemicals and staining agents are well defined.

a) Method of Test for the Effect of Household Chemicals on Clear and Pigmented Organic Finishes (ASTM D 1308-57).

b) Test Method for Immersion Resistance, 6011 Fed. Test Method Std. 141a.

c) Resistance to Acids, Alkalies, and Organic Materials, 9311 Fed. Test Method Std. 501a.

d) Resistance to Detergents, 9341 Fed. Test Method Std. 501a.

e) Method of Test for Water Absorption of Plastics (ASTM D 570).

3.1.5.3.5.11 Impact

As applied to substrate the resistance to cracking, chipping, etc. when subjected to impact is well defined.

a) Test Method for Impact Flexibility, 6226, Fed. Test Method Std. 141a.

b) Impact, 3311, Fed. Test Method Std. 501a.

3.1.5.3.5.12 Scratch Resistance

Improvement of test methods need to ensure better consistency of result, otherwise procedures are well defined.

a) Scratch resistance, 7711, Fed. Test Method Std. 501a.

3.1.5.3.5.13 Shrinkage, Stability

With little effort, time and patience the change in consistency and related properties may be determined and the measure of the degree of such behavior would be significant.

a) Method of Test for Package Stability of Latex Paint (ASTM D 1849-63).

b) Dimensional Stability, 6311 Fed. Test Method Std. 501a.

c) Accelerated Aging Tests, 5001 Fed. Test Method Std. 501a.

d) Air-Heat Test, 5111 Fed. Test Method Std. 501a.

e) Oxygen Pressure Test, 5211 Fed. Test Method Std. 501a.

f) Artificial Weathering for Paint, Varnish, etc. (ASTM D 822).

3.1.5.3.5.14 Thermal Conductivity

The ability of floor/ceiling system to transfer heat or insulate can be measured.

a) Thermal Tests, General, 6001 Fed. Test Method Std. 501a.

Table 1. FLOOR-CEILING SYSTEMS
SUGGESTED GUIDE TO PERFORMANCE CHARACTERISTICS

Essential Performance	Category of Importance			Evaluated By	Is Available Test Adequate	Abstract Section No.	Modification Needed?	Need For Test Development
	Floors	Core	Ceiling					
Abrasion Resistance	X			test	no	3.1.5.3.5.1	yes	yes
Acoustics	X	X	X	test	yes	.2		yes
Adhesion	X		X	test		.3		
Coefficient of Friction	X			test	no	.4	yes	yes
Color Change Gloss Retention	X		X	test-visual	yes	.5		
Compression-Indentation Resiliency	X			test	no	.6	yes	yes
Fire Retardance	X	X	X	test	yes	.7		yes
Flame Spread	X	X	X	test	yes	.8		yes
Fungi Resistance	X	X	X	test	yes	.9	yes	
Immersion, Stain and Chemical Resistance	X			test	yes	.10		
Impact	X		X	test	yes	.11		
Scratch Resistance	X			test	no	.12	yes	yes
Shrinkage, Stability	X	X	X	test	no	.13	yes	yes
Thermal	X	X	X	test	yes	.14		
Flatness	X		X	test	yes			

3.1.5.4 Roofing

3.1.5.4.1 Rationale

The function of a roofing system is to protect a structure, its occupants and contents from the weather both initially and after long periods of exposure. Therefore, in addition to possessing essential performing characteristics, the materials comprising the system must be durable. All roofing systems, per se, deteriorate on exposure to the elements, the rate of deterioration being determined largely by the properties of the materials in the system and the conditions of exposure. Further, in considering durability of the roofing system, both natural (hail, falling tree limbs, etc.) and man-made (foot traffic, missiles, etc.), abuses and test methods simulating these abuses should be investigated.

The durability of a roofing system, unlike some other major systems, e.g. electrical, plumbing, etc., is not always commensurate with that of the structure which it protects. This situation is permitted largely by two factors; one of which is the economics of roofing; i.e., roofing materials are inexpensive; and the other is the fact that repair, maintenance and replacements of a roofing system are relatively easy due to its accessibility.

3.1.5.4.2 Performance Characteristics

a) Weather Resistance -- to withstand, without adverse effects on roof system performance, exposure to the weather within the climatic range anticipated.

b) Water Resistance -- to prevent the penetration of water from outside, either by transfer through the material or by leakage and wind-driven rain.

c) Wind Resistance -- to withstand anticipated wind loads without removal or other adverse effects.

d) Fire Resistance -- to provide resistance against flame spread and combustibility for the life of the roofing.

e) Impact-Puncture Resistance -- to withstand abuse from anticipated foot traffic and falling objects, such as hailstones, tree limbs, etc.

f) Slippage Resistance (roofing) -- to prevent interply slippage of multiple-ply sheet materials, and slippage between substrate and covering for the specific slope.

g) Rupture Resistance -- to withstand without rupture, at the lowest temperature of the climatic range anticipated, repeated bending caused by stresses imposed during service, e.g., vibration, structural or thermal movement.

h) Abrasion Resistance -- to withstand anticipated wearing away from wind-blown elements.

i) Thermal-Movement Resistance (roofing; insulation; deck) -- to minimize components which could adversely affect the desired performance of any portion of the system.

j) Thermal-Shock Resistance -- to withstand rapid and repeated temperature fluctuations, such as may be encountered during 24-hour cycles, so that the integrity of the system is not adversely affected.

k) Resistance to Water-Vapor Transfer -- to prevent such penetration of water vapor, from either outside or inside, as would result in condensation, decrease in insulation efficiency, and adverse effects (differential movement, deflection, rot) on other system components.

l) Fungus-Attack Resistance -- to prevent, during service life of the system, any appreciable reduction in performance or appearance resulting from decay.

3.1.5.4.3 Test Procedures

a) Weather Resistance -- No single test method is available to measure weather resistance of roofing systems. At best, the results of a selected combination of tests may be used to indicate durability in weather. Obviously an accelerated testing procedure is required which will predict long-term performance on the basis of a short-term test. The critical question asked by a prospective user of accelerated weathering test is: For a roofing material where I have only accelerated test data,what level of confidence can I have that these data will reflect long-term outdoor test results? To be relevant to the users needs, the data must provide a clear answer to the question even if some assumptions must be made in projecting the data.

b) Water Resistance -- Absorption by hygroscopic roof covering materials may be tested in accordance with ASTM D-471.

Water penetration of the non-continuous types of roofing materials (shingles, etc.) should be tested in accordance with a procedure developed by Asphalt Roofing Industry Bureau to measure leak resistance.

c) Wind Resistance -- Roof systems should be required to withstand, as a minimum, the design wind loads specified in USASI, A 58.1 Building Code Requirements for Minimum Design Loads in Buildings and Other Structures: U.S.A. Standards Institute.

Resistance to wind up-lift should be determined:

For asphalt shingles, in accordance with test procedure promulgated by Underwriter's Laboratories, Inc.

For flat roofs, in accordance with the procedure described in Underwriters' Laboratories Bulletin of Research No. 52. April, 1962.

d) Fire Resistance -- Resistance to flame exposure, burning brand, and flame spread should be determined in accordance with Underwriters' or Factory Mutual's official requirements for applicable ASTM tests, such as E-84, E-108, E-119, and E-163.

e) Impact-Puncture Resistance -- Impact resistance for film- or sheet-type materials should be determined in accordance with ASTM Method D-1709, modified to accomodate the specific material under test; for semi-rigid or rigid materials, it should be determined in accordance with ASTM Method D-758, also modified according to the type of material under test.

For puncture resistance, two types of test should be employed, one involving sudden application, and the other, gradual application of load. For the former condition the test should be made in accordance with ASTM Methods D-781 and E-154. For the latter condition, ASTM Methods C-165 and D-1621 should be investigated for feasibility of modification to evaluate a wide range of roofing materials or combinations thereof.

f) Slippage Resistance -- Tests for resistance to slippage should be conducted in accordance with ASTM Method D-1167, modified to accomodate the material under test. The test temperature of 100 $\pm$ 5°C should be reduced to 60 $\pm$ 5°C.

g) Rupture Resistance -- The feasibility of modifying ASTM D-790 for testing rigid or semi-rigid sheets, and ASTM D-1167 and D-228 for testing coating or other roof-covering materials, should be investigated.

h) Abrasion Resistance -- The feasibility of modifying the following procedures should be investigated:

1) ASTM D-658 for determining the amount of abrasive required to wear through a unit film thickness of a coating of sheet-applied material at a uniform rate, under the action of a controlled air blast.

2) ASTM D-968 for determining the amount of abrasive required to wear through a unit film thickness of a coating or sheet-applied material at a uniform rate by the falling sand method.

3) Underwriters' Laboratories 55B for determining the limits for granule loss from granule-surface roll roofing and shingles.

i) Thermal-Movement Resistance -- The extent and rate of the thermal movement of each component and of the integrated roof system should be measured on each of two major axes in the roof plane -- both with and without anticipated moisture content -- for the temperature changes to which the system and its components may be subjected.

The National Bureau of Standards procedures should be used for measuring thermal expansion coefficients of composite built-up members.

There are a number of test methods which are worthy of investigation for modification as a means of determining the coefficient of linear thermal expansion--particularly, ASTM C-263-52, Linear Change of Magnesium Oxychloride Cements, and D-696-44, Coefficient of Linear Thermal Expansion of Plastics--and it so recommends.

j) Thermal-Shock Resistance -- A thermal-shock test developed by the Pittsburgh Testing Laboratory, Pittsburgh, Pennsylvania, entitled Thermal-Shock Test for Assembled Roofing Systems (File No. 9811) should be investigated. This test was conducted under conditions more severe than any normally encountered in service, to compensate for the fact that materials were assembled under ideal conditions of workmanship. This test should be investigated for adequacy, as should ASTM tests C-484 and C-149 for feasibility of modification as a means of determining thermal-shock resistance.

k) Resistance to Water-Vapor Transfer -- Resistance to water-vapor transfer for materials with a thickness of 1/8 inch or less should be determined in accordance with ASTM E-96; materials with a thickness of over 1/8 inch should be determined in accordance with ASTM C-355.

l) Fungus-Attack Resistance -- Test procedures for fungus-attack resistance for roof-covering materials are currently not available; however, the feasibility of modifying ASTM D-862 (for paperboard) and ASTM D-2020 (for textiles) should be investigated.

3.1.5.4.4 State-of-the-Art Roofing

Performance Characteristics	Evaluated by	Is Available Test Adequate	Investigate for Feasibility of Modification	Need for Test Development
Weather Resistance	test	no	--	yes
Water Resistance	test	no	--	yes
Wind Resistance	test	yes	--	--
Fire Resistance	test	yes	--	--
Impact-Puncture Resistance	test	no	--	yes
Slippage Resistance	test	no	--	yes
Rupture Resistance	test	no	yes	--
Abrasion Resistance	test	no	yes	--
Thermal-Movement Resistance	test	no	yes	--
Thermal-Shock Resistance	test	?	yes	--
Resistance to Water-Vapor Transfer	test	yes	--	--
Fungus-Attack Resistance	test	no	yes	--

3.1.5.4.5 References (ASTM Methods of Test)

C-149	-	Method of Thermal Shock Test on Glass Containers
C-165	-	Method of Test for Compressive Strength of Preformed Block-Type Thermal Insulation
C-263	-	Spec. for Mineral Fiber Blanket Insulation (Metal-Mesh Covered) (Industrial Type)
C-355	-	Methods of Test for Water Vapor Transmission of Materials Used in Building Construction (Tentative)
C-484	-	Tentative Method of Testing for Thermal Shock Resistance of Glazed Ceramic Tile
D-228	-	Testing Asphalt Roll Roofings, Cap Sheets and Shingles
D-471	-	Method of Test for Change in Properties of Elastomeric Vulcanizates Resulting from Immersion in Liquids (Tentative)
D-658	-	Method of Test for Abrasion Resistance of Coatings of Paint Varnish, Lacquer, and Related Products with the Air Blast Abrasion Tester
D-696	-	Method of Test for Coefficient of Linear Thermal Expansion of Plastics
D-758	-	Impact Resistance of Plastics at Subnormal and Supernormal Temperatures
D-781	-	Method of Test for Puncture and Stiffness of Paperboard, Corrugated and Solid Fiberboard
D-790	-	Method of Test for Flexural Properties of Plastics (Tentative)
D-862	-	Methods of Test for Evaluating Treated Textiles for Permanence of Resistance to Microorganisms
D-968	-	Method of Test for Abrasion Resistance of Coatings of Paint, Varnish, Lacquer, and Related Products by the Falling Sand Method
D-1167	-	Methods of Testing Asphalt-Base Emulsions for Use as Protective Coatings for Built-up Roofs (Tentative)
D-1621	-	Method of Test for Compressive Strength of Rigid Cellular Plastics (Tentative)
D-1709	-	Test for Impact Resistance of Polyethylene Film by the Free Falling Dart Method
D-2020	-	Tentative Methods of Test for Mildew (Fungus) Resistance of Paper and Paperboard
E-84	-	Method of Test for Surface Burning Characteristics of Building Materials (Tentative)
E-96	-	Methods of Test for Measuring Water Vapor Transmission of Materials in Sheet Form (Tentative)
D-108	-	Methods of Fire Tests of Roof Coverings
E-119	-	Methods of Fire Tests of Building Construction and Materials
E-154	-	Method of Testing Materials for Use as Vapor Barriers under Concrete Slabs and as Ground Cover in Crawl Spaces
E-163	-	Method of Fire Tests of Window Assemblies

3.1.5.5 Sealants

3.1.5.5.1 Rationale

What is a joint? What is a sealant? What is a sealant system? For the purpose of this report the following definitions are given:

3.1.5.5.1.1 Joint

Any discontinuity between two surfaces in a building that is designed for economy, convenience, necessity or other reasons. Most frequently an attempt is made to fill or "bridge" this opening with an appropriate material.

3.1.5.5.1.2 Sealant

A non-rigid material used for filling a joint which will restrict, or prohibit the movement of gases, liquids and solids through the joint. (Note, example: a cement grout placed around bathtubs, sinks, shower stalls, etc. is not regarded as a sealant in the light of this definition.)

3.1.5.5.1.3 Joint Sealant System

A situation where detailed joint design, predetermined joint movements and other pertinent factors for effective joint performance have been planned cooperatively by the architect, engineer, sealant consultant, sealant producer and builder in advance of the design of the building. The details might include one, two or three types of sealants for any specific joint.

3.1.5.5.2 Today's Building Sealant Problem

Never in history has the joint sealant figured so prominently in buildings as it does today. This situation has resulted from changes brought about by contemporary building design. These changes include thin pre-cast masonry panels, exceptionally large areas of glass units, and application of metals and plastics of high thermal expansivities as exterior wall units. Furthermore, the problem is complicated by the fact that the curtain wall unit itself is generally impervious to water, which leaves the caulked joint as the sole defense against water penetration. The slightest failure in such a joint is likely to result in leakage into the building from a wind-driven rain.

3.1.5.5.2.1 General Effects of Sealant Failures

It is almost common knowledge how joint failures affect a building. First, as much as 30% of the efficiency of the building curtain (or envelope) can be lost. This means leaky and drafty rooms with accompanying rise in heating and air-conditioning. Driving rains through faulty joints cause damage to interior walls, floors, carpeting and furniture. It is not unusual for entire buildings to be re-caulked a few years after construction at cost ten times the original cost of the installation.

3.1.5.5.2.2 Joints in Window Areas

This is an area where the properly designed sealant system is of prime importance in the prevention of leakage. High wind loads cause stresses and strains in the sealant. Where wide differences occur in expansion coefficients between glass and sash members, stresses in shear, tension and compression are placed on the sealant. Other factors affecting the performance of the sealants are sunlight, moisture accumulation, sealant mass, channel or rabbet dimensions, fixed or operating sash, type, design and rigidity of sash, type and size of glass. Sealants used for glazing include the bulk compounds, the pre-formed tapes and the pre-formed gaskets.

3.1.5.5.2.3 Joints in Pre-Cast and Other Masonry-Type Panels

In more than half of the installation in this category sealant failures are due to reasons other than the selection of an inferior grade sealant. The surfaces of the panels which contact the sealant are often left with contaminants such as dust, loose particles, release agents, and retardants, all of which contribute to bond failure. Improper joint design as well as inexperienced application of the sealant are important factors. Failure to adhere to producer's specific application instructions relating to primers, application temperature limits, etc. contribute to failure. Furthermore it should be noted that the "perfect" sealant in an ideal joint design will not resist, without failure, joint movements exceeding plus or minus 25% of the nominal joint width over an extended 20 year period — the expected life of the sealant.

3.1.5.5.2.4 Joints in Metal Panels

Unlike masonry panels which are subject to moisture movements the joint movements in metal curtain walls are due only to thermal changes and wind loads. The magnitude of the movement to be accomodated in each joint in a metal wall system is much larger than that in a masonry system, because of the higher thermal expansion coefficients and also because of the larger units used. However the effects of expansion in metal walls are never residual since the metal always contracts on cooling. Most important of all in the sealing of metal panels is the selection of the proper sealant system which will perform in the specific joint design be it lap, mating, batten spline, or frame and stop type.

3.1.5.5.2.5 Joints in Plazas, Decks and Walkways

High-rise apartment buildings are often surrounded by plazas, decks, patios and walkways. These areas often need expansion joints which are filled by the same type of resilient sealants generally used for joints in pre-cast panels. The sealants in horizontal joints are subject to all the pitfalls leading to failure as described in Section 3.1.5.5.2.3. The type of sealant used in these areas should have additional performance properties of high resistance to abrasion and penetration. This performance requirement necessitates the use of a tougher sealant which in turn places an added stress on the adhesive and cohesive properties of the joint filler when the latter is extended. The sealant is also subjected to more UV radiation and heat effects than a typical wall joint. It is subjected to long periods of water immersion from hard rains and melting snow-producing an effect that is more detrimental to certain sealants than others.

3.1.5.5.2.6 Joints in One- and Two-Story Family Dwellings

Fortunately the problem of sealing a small dwelling is relatively simple when compared to a high-rise apartment. A relatively low-cost sealant will perform well when applied by an experienced applicator who follows directions and precautions spelled out by the manufacturer. The sealant should meet the requirements of a Federal Specification. When the dwellings are located in areas subject to frequent hurricanes or heavy rains it is always good practice to use a top grade sealant of the type used for pre-cast panels, for example——When considering the fact that the cost of sealing a small dwelling is about 0.25% of the total cost of the construction the slight additional cost of using a higher priced sealant certainly appears to be justified.

3.1.5.5.2.7 A Summary of Causes for Sealant Failures in Residential Buildings

1) Improper selection of sealant type; 2) Poor grade of selected sealant; 3) Improper joint design; 4) Improper sealant depth; 5) Improper use of back-up material; 6) Substrate contamination; 7) Inadequate joint preparation (primers); 8) Excessive joint movement; 9) Insufficient experience with sealant properties regarding specific substrates; 10) Installation of sealants on wet, damp, cold, or hot substrates; 11) Improper mixing procedures (2-part compounds); 12) Application of sealant which has passed its pot-life; 13) Inexperienced sub-contractors; 14) Inexperienced applicators; and 15) Failure to follow the producer's recommendations and precautions regarding application.

3.1.5.5.3 Classification of sealants

There are several ways of classifying the available sealants. The following is one simplified method using the terminology of the trade:

3.1.5.5.3.1 Bulk Type Compounds

1. Putties

2. Caulking Compounds (gun and knife grade)

3. Glazing Compounds (Bulk)[1/]

4. Tapes

5. Butyl Rubber (solvent release)

6. Acrylic (solvent base)

7. Acrylic (water base)

8. Acrylic (liquid polymer)

9. Neoprene - polychlorpropene

10. "Hypalon" - chlorosulfonated polyethylene

11. Polysulfide - 1 and 2 part

12. Urethane - 1 and 2 part

13. Silicone

14. Polymercaptan - 1 and 2 part

3.1.5.5.3.2 Pre-formed Gasket Sealants

1. Elastomeric structural

2. Elastomeric, Cellular

[1/] Includes several general types.

3.1.5.5.4 Specifications with Performance Requirements

3.1.5.5.4.1 Federal Specifications

1. TT-C-598b, Calking Compound, Oil and Resin Base Type (For masonry and other structures) 1965.

   (Seven Requirements) - (a) Shrinkage; (b) Tenacity; (c) Bond; (d) Slump; (e) Stain; (f) Tack-free-time; (g) Extrudability.

2. TT-G-00410-C, Glazing Compound, Sash, (Metal for Back Bedding and Face Glazing, Not for Channel or Stop Glazing) 1961.

   (Seven Requirements) - (a) Workability; (b) Degree of Set; (c) Cracking and Peeling; (d) Deep bead cracking; (e) Loss of adhesion; (f) Wrinkling; (g) Oil exudation.

3. TT-P-781a, Putty and Elastic-Compound; (For) Metal Sash Glazing (1941).

   (Nine Requirements) - (a) Workability; (b) Tensile adhesiveness; (c) Shearing adhesiveness; (d) Worked consistency; (e) Penetration; (f) Bending; (g) Appearance after heating; (h) Keeping qualities; (i) Slump.

4. TT-S-230a, Sealing Compound, Synthetic Rubber Base, Single Component, Chemically Curing, (For Calking and Glazing in Building Construction) - Non-sag and flow types (1967).

   (Seven Requirements) - (a) Rheological; (b) Tackness; (c) Extrusion rate; (d) Hardness; (e) Weight loss, cracking and chalking after heat; (f) Stain and color change; (g) Adhesion-in-peel; (h) Adhesion-in-peel after UV radiation.

5. TT-S-00227c, Sealing Compound, Rubber Base, Two Component (For Calking, Sealing, and Glazing in Building Construction) - (Non-sag and flow types (1967).

   (Ten Requirements) - (a) Rheological properties; (b) Application life; (c) Hardness; (d) Hardness after heat; (e) Weight loss after heat; (f) Tack-free-time; (g) Stain and color change; (h) Durability (bond-cohesion); (i) Adhesion-in-peel; (j) Adhesion-in-peel after UV radiation.

3.1.5.5.4.2 USASI Specifications

A116.1, Two-component Elastomeric Sealing Compound For the Building Trade (1967).

(Thirteen Requirements) - (a) Application life; (b) Rheological properties; (c) Adhesive strength; (d) Adhesive strength after heat and water immersion; (e) Adhesive strength after cycling; (f) Adhesive strength after UV radiation; (g) Adhesion-in-peel; (h) Resistance to crazing; (i) Stain; (j) Hardness; (k) Hardness after heat; (l) Weight loss after heat; (m) Recovery.

3.1.5.5.4.3 Canadian Specifications - Canadian Government Specifications Board

1. 19-GP-2, Glazing Compound, Elastic, for Metal Sash Face and Channel Glazing (1962).

   (Seven Requirements) - (a) Degree of set; (b) Cracking; (c) Adhesion; (d) Wrinkling; (e) Accelerated Weathering; (f) Bleeding; (g) Slump.

2. 19-GP-3, Compound, Caulking and Glazing, Elastomeric, Chemical Curing Type, Gun Grade (1959).

   (Six Requirements) - (a) Hardness; (b) Tack-free-time; (c) Flexing properties; (d) Slump; (e) Bleeding; (f) Working life.

3. 19-GP-5, Compound; Caulking and Glazing, Elastomeric, Solvent Release Type, Gun Grade, One Component (1963).

   (Eleven Requirements) - (a) Hardness; (b) Tack-free-time; (c) Slump (sag); (d) Bleeding; (e) Extrusion rate; (f) Adhesion and cohesion; (g) Adhesion after UV exposure; (h) Low-temperature flexibility; (i) Flexing properties; (j) Self sealing test; (k) Shrinkage.

4. 19-GP-6, Compound; Caulking Oil Base, Gun Grade (1961).

   (Six Requirements) - (a) Low-temperature resistance; (b) High-temperature resistance; (c) Slump (sag); (d) Flexibility; (e) Oil bleeding; (f) Shrinkage.

5. 19-GP-9, Compound; Caulking and Glazing, Chemical-Curing Type, Gun Grade, One Component (1962).

   (Nine Requirements) - (a) Hardness; (b) Tack-free-time; (c) Resistance to sag; (d) Bleeding; (e) Extrusion rate; (f) Adhesion and cohesion; (g) Adhesion after UV exposure; (h) Low-temperature flexibility; (i) Flexing properties.

3.1.5.5.4.4 ASTM Specifications

1. C509-66T, Cellular Elastomeric Preformed Gasket and Sealing Material.

   (Ten Requirements) - (a) Compression deflection; (b) Compression set; (c) Stress relaxation; (d) Heat aging; (e) Dimensional stability; (f) Ozone resistance; (g) Low-temperature brittleness; (h) Water absorption; (i) Flammability resistance; (j) Staining.

2. C542-65T, Elastomeric Structural Glazing and Panel Gaskets.

(Ten Requirements) - (a) Tensile strength; (b) Elongation; (c) Tear resistance; (d) Hardness; (e) Compression set; (f) Brittleness; (g) Ozone resistance; (h) Heat aging effects; (i) Flame resistance; (j) Lip seal pressure.

3.1.5.5.4.5 Producers' Association Specifications - National Association of Architectural Metal Manufacturers

1. #5C-1.1, Non-skinning Bulk Compounds (1960).

(Seven Requirements) - (a) Applicability; (b) Viscosity; (c) Rheological properties; (d) Shrinkage; (e) low temperature flexibility; (f) Adhesion.

2. #5C-2.1, Non-Skinning, Non-resilient Preformed Compounds (1960).

(Three Requirements) - (a) Hardness; (b) Low temperature flexibility; (c) Adhesion.

3. #5C-3.1, Non-skinning Resilient Preformed Compounds (1960).

(Eight Requirements) - (a) Hardness; (b) Adhesion; (c) Adhesion after treatment; (d) Compression set; (e) Accelerated aging; (f) Accelerated weathering; (g) Low temperature flexibility; (h) Resistance to corrosion.

4. #5C-4.1, Two-part Rubber-Base Compounds (1960).

(Seven Requirements) - (a) Application life; (b) Rheological properties; (c) Adhesive strength; (d) Adhesive strength after treatments; (e) Recovery; (f) Effect UV radiation; (g) Stain.

5. #5C-5.1, Narrow Joint Sealants (1960).

(Five Requirements) - (a) Adhesion in peel; (b) Adhesion in water; (c) Resistance to weathering; (d) Low temperature flexibility; (e) Surface characteristics.

6. #5C-10.1, Rubber-like Gasket Materials (such as neoprene) (1960).

(Eight Requirements) - (a) Hardness; (b) Tensile strength; (c) Elongation; (d) Compression set; (e) Effect of heat aging on Hardness, tensile strength, elongation; (f) low temperature effects; (g) Ozone resistance; (h) Dimension stability.

7. #5C-11.1, Specifications for Plastic Gasket Materials (such as vinyl) (1960).

(Ten Requirements) - (a) Hardness; (b) Tensile strength; (c) Elongation; (d) Modulus; (e) Specific gravity; (f) Heat loss; (g) Brittleness at low temperature; (h) Dimensional stability; (i) Flame resistance; (j) Effect of Weatherometer.

3.1.6 FUTURE RESEARCH

3.1.6.1 Weather Resistance

Weather appears to be the most important single parameter as far as the durability of a structure's exterior or related component-systems are concerned. In fact, a prime function of this portion of the structure is to withstand, without adverse effects on the systems performance, exposure to weather within the climatic ranges anticipated. When the variations of climate in any one locality are considered, it appears unlikely that any single test procedure can be devised which will simulate the climatic conditions to which a material, composite or system may be exposed in service. However, when the variations in climate throughout the United States are considered, it can be stated, without reservations, the task is impossible. Nevertheless, in the future, the careful selection of a series of simulated service testing procedures may yield results which will be helpful in predicting durability of building materials and systems. Research and research alone is the key to the development of test procedures which will provide the needed information. A correlation study among data developed by laboratory simulated-service tests, that obtained by controlled outdoor tests, and that experienced during exposure in-service will advance the state-of-the-art significantly.

Obviously such a research program is not one of short-duration. The broad objective would be to determine, by experimental methods, long-term performance on the basis of short-duration tests. A number of rather complicated steps are involved, such as:

a) Identification of those factors of the weather or combination of factors which cause deterioration;

b) Development of techniques to measure these factors as they represent actual service conditions;

c) Development of short-duration laboratory tests to simulate various weather parameters and measure in-service behavior;

d) Correlation of laboratory, controlled outdoor exposure and in-service behavior.

e) Generation and promulgation of performance criteria for use in requirements, standards and codes.

Conceivably a research program of this type could be undertaken in three stages which, fortunately, can be carried out concurrently.

a) Field Survey - There is a wealth of untapped information available for countless building materials, composites and systems after exposure for periods from a few days to a century or more, to practically all the climatic conditions of the United States. By means of a comprehensive field survey of preselected systems in selected areas, qualitative data could be developed on in-service behavior of materials and systems. Ideally samples could be obtained and measured in the laboratory in order to quantify as much information as possible, so that computer techniques could be utilized to store and process data.

b) Controlled Outdoor Testing - Outdoor exposure sites, where future weather can be predicted based on climatology and real-time weather measurements can be made, could be developed. It is interesting to note here that the Building Research Division of NBS has established six such exposure sites representing the climates of various areas of the United States. Included are the extreme environment of Alaska; the tropical climate of Puerto Rico; the industrial atmosphere of Baltimore, Md.; the desert exposure of Nevada; the moderate climate of the Pacific-Northwest; and the rural setting of NBS Gaithersburg.

The purpose of controlled exposure testing is to use to advantage the natural environments and still be able to retain control of specimens and samples throughout the duration of the tests. In this manner a quantitative measure of both weather data and physical and chemical changes which occur in materials on exposure to weather can be realized.

c) Simulated Service Tests - There are a number of laboratory techniques by which a simulation of in-service behavior can be accomplished. A number of radiation devices are available which simulate solar radiation. Some of these devices also simulate various moisture conditions such as rain, dew, and frost. Further developments are being constantly made in laboratory techniques to measure and produce the contaminated atmospheres which result from air pollution. Techniques are also available to accurately measure the changes which are likely to occur in the properties of materials of construction as they are exposed to various environments. It is obvious that under laboratory conditions both the conditions of tests and the results can be readily quantified.

In summary, the needs for building research of this type are legion. Although the argument is often made that much of this type of research should be conducted by the private sector, the costs and time required probably will be prohibitive for a single manufacturer or association to measure long-term performance of several sub-systems in a full scale building. In this connection the Building Research Division has, for several years, been planning to conduct engineering experiments on a full-scale building exposed to natural weather conditions. The broad objectives of this program are to provide a means for determining, under controlled conditions, the long-term performance of full-scale elements, and environmental aspects of a building under conditions duplicating those for a building exposed to natural weathering conditions.

3.1.6.2 Other Weather-Related Parameters of Durability

In addition to weather resistance, there are other weather-related factors of durability which have a significant effect on the long-term performance of building materials and systems. For example, moisture (effect of liquid or vapor water penetration into or through a building system); impact (effect of hail or other wind-blown objects); abrasion (wind-blown sand); and other similar factors have an influence on the durability of a material or system. The need to predict and measure the behavior of materials in these environments has resulted in the development of performance-type test methods which are currently being promulgated by recognized standard making organizations. Unfortunately, it is often the case that the tests relate to specific materials under a specific set of circumstances. The strength of a building plastic or the abrasive effects of falling sand on an organic coating are typical examples. It is recognized in the building research community that a more sophisticated approach to research will be required to develop meaningful testing procedures to measure performance.

In this exercise to suggest areas of future research, it is felt that the better approach is to identify areas of research in terms of the user's needs in the performance of building systems comprising the fabric of the structure. Once the user's needs are identified test methods, currently in use, should be reviewed for adequacy in measuring the desired performance characteristics. If they are inadequate, modifications of existing methods should be investigated or new test methods developed.

3.1.6.3 Exterior-Interior Walls

There are numerous test procedures for determining specific properties of wall component materials. Most of these appear to do a good job of ranking materials in their proper order of durability in the limited environmental test conditions to which they are subjected. The materials are usually exposed to one or more of what are believed to be the potentially destructive environmental parameters that might be encountered in service. For example, the Weatherometers at NBS subject specimens simultaneously or alternately to simulated solar irradiance, water spray, high humidity and heat.

Although many of the tests available today are useful for rating materials according to their resistances to particular test environments, they leave much to be desired in regard to actually simulating service conditions. In fact, in the absence of intelligent application and interpretation, some materials evaluation tests can lead to erroneous conclusions.

The total service environment will probably never be exactly simulated in the laboratory, and if simulated, certainly not accelerated also. But there is a need to approach the ideal goal of both simulation and acceleration much closer than has been done in the past. Such is the object of this proposal.

It is proposed that a massive effort be exerted toward developing an apparatus and a comprehensive test procedure that will, to the extent that the current state-of-the-art and science permit, incorporate all of the environmental parameters affecting the durability of external wall systems. What is proposed is a chamber in which specimens are exposed to computerized cycles and sequences of: 1) the elements of weather, 2) normal human use and abuse, 3) routine maintenance procedures, 4) pests, 5) accidents, and 6) vandalism.

The elements of weather would include all or most of the following: rain, wind, snow, sleet, hail, fog, dew, humidity, heat, cold, freezing and thawing, radiation, and lightning. Other environmental factors would include atmospheric pollution, dust and sand impingement, abrasion, scratching, cleaning procedures, impact, puncture, chemical and biological exposure, stresses, and insect and rodent exposure.

The environmental factors would be imposed in varying combinations, for varying durations, and for varying frequencies as determined by a computer simulation program of actual service conditions. No factor would be exagerated or made more severe than would normally be encountered in service unless it could be shown that such intensification had no unnatural effect. Acceleration of time would be accomplished primarily by increasing the frequency of occurrence of the deterioration events, or conversely eliminating those periods of time when little or no deterioration is occurring in normal service.

It is envisaged that a large two-compartment environmental test chamber would be constructed, the two parts separated by a specimen which would be an actual size section of an external wall system. The environment in one compartment of the chamber would be typical of that found in a residential structure, while the other compartment would contain the simulated natural outdoor environment and facilities for imposing the man-made and animal hazards.

3.1.6.4 Openings: Windows and Doors

In reviewing the literature pertaining to window and door openings, including specifications and standards, one is impressed by the fact that a variety of construction materials have been used. These include a number of wood species, painted steel, aluminum, and plastic. All of the structural materials, however, are used in conjunction with just one product, glass, when transparency to light is desired in housing construction.

With the availability of clear plastics which have been used imaginatively in other forms of construction, it is suggested they deserve consideration in the field of housing. Specific plastic materials deserving of attention include at least the acrylic types and the polycarbonates. The former are known for their exceptional clarity and excellent ultraviolet resistance. Polycarbonates have good toughness which would make them attractive for uses where breakage of glass has been a factor.

To determine whether plastics merit serious consideration as glazing materials in housing, it is suggested that preliminary research be conducted along the following lines:

a) Retention of Light-Transmitting Properties
b) Resistance to Normal Maintenance
c) Impact Resistance.

In order to study a) above it is anticipated that selected candidate clear plastics would be exposed to accelerated and exterior weathering with a view to determining significant evidence of degradation, including loss of transmittancy of light.

Resistance to normal maintenance (b) would be determined by subjecting panels to cleaning operations of the type employed with glass. Materials represented in the cleaners would include commercial types, especially those containing ammonia and mild abrasives. A logical extension of this test is to combine it with a) in order to study the effect of aging on maintenance properties.

Tests for impact resistance would be made in parallel with similar tests on regular glass panels in order to place the results in proper perspective. Again, it is logical to conduct a portion of the study on panels that have been exposed to the degrading influences described in a).

Since the foregoing program is of a preliminary nature only, there will be a need to assess the results obtained before planning further work. Implicit in the initiation of such research is the assumption that successful materials would be given an opportunity to demonstrate their all-round ability to serve as glazing materials. To fill such a role adequately their performance should be compared with that of glass when subjected to tests such as those for resistance to water, wind, air leakage, fire, racking, shrinkage, and blow-out.

3.1.6.5 Ceilings-Floors

A flooring is required to retain its chosen properties for as long as possible--it must be durable. Because of its importance, durability has sometimes been regarded as a basic property of a flooring, depending, however, as much on the conditions of use as on its properties for service life expectancy. Other influences that operate to reduce the life of a floor are: wear, water and other liquids, indenting loads, impact blows, sunlight, fungi, and high temperatures.

Of these, wear is of great general importance because it is unavoidable and because it occurs alongside all the others. A classification of flooring in terms of resistance to wear is therefore of some importance. In fact, notwithstanding the many years of experience, there is as yet no means of translating test results on resilient floorings into performance predictions. The tests specified in the federal and other existing specifications for flooring are used mainly to assure uniformity of material from order to order. In this respect, it might help to quote from a recently published article in the Textile Journal of Australia, July 1967 "Today's Carpet Testing Methods Evaluated" by Dr. J. I. Dunlop. The following statement of reference to carpets applies equally well to all flooring.

> "The difficulties in predicting carpet performance lie in the fact that little is known about the relationships between the specific properties of a carpet such as pile height, tuft density, or even tenacity of pile fiber, and how the carpet performs in service. This is due to several factors, not the least being the diversity of degrading actions to which carpets are subjected in use. Assessment of how the carpet is performing is to a large extent subjective, and this presents complications. There is also a lack of knowledge on the mechanisms of carpet fiber wear which by their nature are both complex and diverse.

"At the present, therefore, one of the most accurate methods of assessing a carpet's performance is to install it and to observe it during its subsequent life."

Establishment of a fundamental method of appraisal for flooring to relate to its performance under in-use conditions is needed. The following research tasks are suggested to establish performance standards for flooring.

3.1.6.5.1 Wear

Evaluate flooring materials by service trials and by means of simulated laboratory methods, with consideration of the long-term behaviour, physical properties and characteristics (resilient, hard, textile, non-textile, smooth surface, non-smooth surface).

Prepare performance criteria of the wear index needed to meet particular use under the different circumstances encountered in low cost housing.

3.1.6.5.2 Resistance to Water and Other Liquids

By laboratory method measure dimensional change, bond, and surface change of complete floor systems. Establish the relationship to service durability (wear) as affected by exposure of floor surfaces to liquid treatments. These treatments should include spillage or those used in routine maintenances. Amount of waterproofing needed to protect living areas below rooms known to receive considerable water spillage.

3.1.6.5.3 Acoustics

Establish the method of test for evaluating the acoustical contribution to the whole dwelling of the floor/ceiling systems.

3.1.6.6 Roofings

For the past 10 years a number of innovations in roofing systems have appeared on the residential roofing market. The systems utilize materials and composites which cover a wide range, including reinforced plastics, elastomeric films on organic and inorganic bases, coated metals, fluid-applied elastomeric films and improved bituminous products. Currently, these systems are specified by material descriptions alone which are not adequate to describe durability. A number of areas can be identified where research is needed to develop performance requirements and arrive at reasonable and easily measured solutions. The following areas suggest more research:

3.1.6.6.1 Weather Resistance

This subject has been discussed in detail in Sec. 3.1.6.1. However, it cannot be overstressed as far as roofing is concerned, since this component of the structure is continuously and directly exposed to the elements. As previously pointed out any research program should be directed toward the correlation of laboratory, outdoor and in-service behavior.

3.1.6.6.2 Liquid-Water Resistance

Strange as it may seem, there are no test methods or performance requirements in existance to measure or indicate the watertightness of continuous roofing membranes. Test methods should be developed to measure this property of roofings both initially and after periods of exposure.

3.1.6.6.3 Impact Resistance

Every year hail storms do more damage to buildings than do tornadoes in that part of the United States, between the Appalachian and the Rocky Mountains. Roofings, per se, sustain a large percentage of these losses and they are getting progressively larger as more people move into the affected areas. Test methods should be developed and performance criteria established in this area which is vital to the behavior of roof coverings.

3.1.6.6.4 Slippage Resistance

In order to fulfill its prime function, i.e. to protect a structure, its contents and occupants from the weather, the roof system must remain in place. Slippage of built-up roofing membranes frequently have resulted in serious and costly failures of residential structures. Here then is a need to develop performance criteria to eliminate this failure.

3.1.6.6.5 Wind Resistance

Test Procedures and performance criteria should be developed for wind resistance of roofing with membrane type covering on both flat and sloping roofs.

3.1.6.6.6 Movement Resistance

Roofings are subjected to large and rapid temperature changes. Therefore, thermal movements in and among components frequently lead to less-than-satisfactory performance. Ways and means should be investigated to ameliorate effects due to temperature changes. Research is needed to identify and measure performance requirements.

3.1.6.7 Further Research on Building Joint Sealants

For background information on the need for research on the building sealant problem see Section 3.1.55.1 "Rationale." Specifically, a research program should be directed along the following lines:

1. Continue development of performance criteria based on standard test methods which can be incorporated into purchase specifications.

2. Re-examine existing specifications to determine if performance standards correlate with field usage. Revise the specifications when necessary.

3. Make laboratory and field studies of the new sealants that are being formulated at a rapid pace in the present market.

4. Make inspections of sealants in buildings from the time of original application to a final stage of failure of the sealant in order to collect needed data on the causes of failure.

5. Study the feasibility of the use of primers that are required to promote adhesion to sealants as it is related to long-term durability of the bond.

6. Explore the possibility of developing an accelerated weathering test which would predict breakdown of the sealant's elastomeric properties over a 20-year period.

7. Investigate the credibility gap that exists among the architects, builders, formulators, contractors, specifiers and owners regarding the ultimate responsibility of each in relation to sealant failure.

8. Study the joint sealant systems based on open-drained joints, and other new design detail where the joint sealant is protected from the elements and serves as a secondary barrier against leakage.

9. Study the relationship between joint design and the various generic sealant types in regard to long-term performance in the field.

3.2 AIR, MOISTURE AND WATER TRANSMISSION

3.2.0 Executive Summary

Very recently a study was concluded at the National Bureau of Standards and a report "Performance Criteria for Exterior Wall Systems," NBS Report No. 9817, was submitted to the Federal Housing Administration. This document discussed performance requirements, test procedures, and performance limits with respect to air, moisture, and heat transfer for exterior wall systems. The sampling of wall systems evaluated was rather small, but it does establish an approach that is needed for determining the performance criteria of such systems. The large overall building system needs investigation to determine the interaction of subsystem and components and their effect on the performance of the whole system.

One of the best approaches to the development of performance-based requirements is the Agrément System of Europe. A good example is the "Joint Directives for the Acceptance of Windows," issued by the Agrément Board of Great Britain for purposes of assessing the suitability of windows for use in that country. A document of this type should be developed for performance requirements for exterior wall systems, whereby all components would be evaluated on a performance basis. The performance limits of the Agrément Board document should be evaluated to determine if, in fact, the limits are realistic with respect to U. S. requirements. The methods of test are rather loose, and efforts should be made to establish recognized test methods for required procedures in making the performance evaluation. Some of the existing test methods, such as those of ASTM, referenced in Section B4.3, could be incorporated into the performance evaluation process.

Some of the other performance-based documents, such as SCSD and URBS, give performance criteria and test methods in some areas of the building system, but are rather lacking in other areas, particularly in the area of exterior wall performance with respect to air, moisture, and water leakage.

Near-term Research in Air, Moisture, and Heat Transfer

Probably one of the most rewarding areas of research with respect to short-term gain is that of moisture retention in full-scale tests of wall systems. The facility has been developed and a test method is available for making such evaluations. Some basic information is needed on the moisture retention process and the parameters which affect the process.

Additional work is needed to adequately evaluate the performance of wall systems, including the components such as doors, windows and electrical wiring.

As the performance concept develops, a program of classification of system, subsystem and components should be set up in terms of performance so that not only a minimum performance is required but a class rating would be awarded to the products which perform above the required minimum.

3.2.1 Rationale of Performance Requirements

The control of air, moisture and water leakage or transfer through the exterior fabric of the building is necessary to provide a comfortable and healthy environment and to prevent destruction of the building fabric. Under uncontrolled conditions, dirt and possibly disease can be spread throughout a building from within or from the outdoor environment to the living space; unconditioned air can cause discomfort within the living space; and moisture build-up or water leakage can produce a condition within the building walls which could cause damage to the structural members and to interior surface finishes.

Performance requirements with regard to air, moisture and water movement in low cost structures can be categorized into two areas: (a) the requirements necessary to maintain the desired level of the conditioned environment, and (b) the required performances of the components of the structure which make the control of the conditioned environment possible.

3.2.2 General Requirement Statements

3.2.2.1 Air

A. Conditioned Environment

In structuring requirements for the conditioned environment with respect to air movement within the building, some of the items to be considered are:

1. Odor
2. Drafts
3. Contamination
4. Stack effect.

1. Odor. One of the objectionable "by products" of low - cost housing in the past has been generation of odor or lack of odor control. Whether in multi-family dwellings or single-family dwellings for low-cost housing, the odor control has been a problem. Control of odor sources so that the transmission of the objectionable smell does not alienate other people in a confined neighborhood should be recommended as a building system performance requirement, particularly for the ventilation system.

2. Drafts. Within the conditioned space, drafts of air moving at higher-than-normal velocities can be quite objectionable. The drafts can originate from sources as: high-velocity discharges of supply air into a living space; air returns, where large central stations force return air to

the furnace; and movement of air at a temperature different from that of the enclosure due to infiltration through the exterior wall or due to cold convection currents caused by heat losses at exterior walls.

3. Contamination of air supply. In the case of central ventilating systems, consideration should be given for setting requirements for controlling the degree of contamination between separate parts of the building. Particularly in the case of low-cost housing, medical care may not be readily available to all tenants and infectious diseases could spread throughout the building complex via central ventilation (also objectionable odor). Other sources of contamination are dirt, smoke and fumes caused by fire. Requirements could be set to prevent the level of contamination from reaching a dangerous point. Detectors could be placed in the ventilating system to sense an excessive concentration of contaminants and upon reaching an undesirable level could activate a control for diluting or cleaning the air of the enclosure.

4. Stack Effect. In large buildings stack effect could be a cause for having an undesirable flow of air between portions of the building, or to or from the building through the exterior walls. Difficulty of temperature control in parts of the building could be caused by the stack effect of warmer air rising to the upper part of the building. The movement of air within the building by stack effect could also cause contamination of the space as in the case of fire. The smoke would tend to move to the upper part of the building because of the stack effect. Depending on the moisture content of the air, the outdoor temperature, and the building construction, moisture in the leakage air may be deposited within the building construction with serious deleterious effects. Requirements could be set to prevent stack effect beyond a specified limit.

B. Performance of Structure

Penetration of air through the exterior wall and wall components such as windows, doors and cracks where materials are joined, is of considerable importance, in that the lack of proper shielding of the interior of the building from the natural elements makes control of interior environment impossible. Windows and doors are of special importance as sources of leakage through the exterior fabric of a building. Reference should be made to Section 3.1, Durability as the Time Dimension of Performance, which treats in detail the performance of windows and doors as separate elements. Levels of performance must be maintained to limit the amount of infiltration or exfiltration since they affect the performance of the structure as well as the conditioning system.

With infiltration of air, unusually high demands might be made of the conditioning equipment working to maintain the desired conditions of temperature and humidity. Infiltration is also a source of dirty air, as airborne particles penetrate the walls and are deposited within. Airborne water droplets can be blown into small cracks and penetrate the exterior wall to cause damage to items in the living space or within the walls. In some types of construction, cracks in the exterior wall are permitted which are large enough to cause uncomfortable drafts. Performance requirements should be set to prohibit the rate of infiltration beyond some maximum value.

3.2.2.2 Moisture

A. Conditioned Environment

In many cases of low-income type dwellings, the living habits of the occupants are such as to produce a condition of undesirable temperature and humidity. Under these extreme conditions, damage to interior surfaces and wall components can be considerable. Either the condition of the air should be set to prevent condensate from forming on the wall surfaces, or the performance of the wall should be such as to prevent condensing of moisture on its surface.

B. Performance of Structure

Two methods of transfer of moisture through the structure are by air infiltration or exfiltration and hygroscopic action. Moist air can at times penetrate the exterior wall, causing a rise in the level of humidity in the living space, or penetrate the wall from a relatively warm-moist living space to a rather cold outdoor environment. Under certain conditions, moisture from the air can be deposited on the inner members of the wall structure, causing damage or change in performance of the wall. Hygroscopic movement can occur when the moisture level of adjoining spaces or materials are different and, due to the difference in vapor pressure, moisture is transferred. This could be a serious problem in:

(1) Built-up roofs
(2) Below-grade construction
(3) Slab-on-grade construction
(4) Cold rooms, etc.

Under these conditions spalling or blistering of surfaces can occur. Requirements should be set to limit the permeability of materials for proper performance of the roof, wall or floor structure.

3.2.2.3 Water

The penetration of unwanted water into the living space even to a limited extent in most cases cannot be tolerated. Even small consistent water leakage can damage interior furnishings and decorations and cause general dissatisfaction on the part of the occupant.

Leakage of water through exterior walls and wall components can occur with wind-driven rain. Large pressure differences due to wind can be imposed on the wall at a time when the surface is thoroughly wetted and the water will be forced through small openings. Often run-off water cannot be accommodated and spillover occurs, or as in the case of wind-driven rain, the droplets are blown upward in an irregular manner which overrides normal design of the construction.

For underground construction, parging and application of vapor barrier material is required to prevent leakage of ground water into the living space.

The roof system must be designed in a manner to provide the necessary runoff of rain water and prevent leakage to the living space underneath.

Considerable damage and inconvenience can be caused by surface condensation both in the attic and basement areas in particular. Prolonged presence of the moisture can cause growth of fungus and generation of unpleasant odor. Deterioration of the interior surface finishes and weakening of the total wall system can result. Condensation can be prevented by taking the proper precaution of maintaining the moisture content in the living area below a specified level and maintaining the interior surface to air temperature difference at a reasonably small value. As the temperature difference between the air and the interior surface becomes increasingly larger, the probability of the formation of condensate on the walls or attic surfaces increases.

3.2.3 Existing Test Methods and Standards

Generally existing test methods for air and moisture leakage are directed toward static or non-cyclic climatic conditions. Obviously, variable ambient conditions of temperature, humidity, and pressure could be made to more nearly simulate conditions which would be experienced in practice. However, the complexity of the equipment and test procedures required to determine adequately the response to changing condition is considerably greater. The test methods abstracted here are the best available, but are steady state and generally treat components or subsystems rather than the whole system.

Adequate limits are not available on air and moisture penetration rates, although some work has been done on air penetration rates of selected types of construction. However, the scope of this work thus far is too limited to be of general value as performance requirements. The work at the National Bureau of Standards on performance of exterior wall systems comes closer to providing performance limits but here again the wall systems were rather simple in that they contained none of the subsystems such as doors, windows, and electrical wiring or fixtures. With respect to water leakage, the limiting value should be set (1) to allow no penetration through to the interior surface, and (2) to minimize the penetration of water through the exterior surfacing material.

One area of vital importance for which there is relatively little control is that of workmanship. The penetration of air, moisture, and water through the building fabric is strongly related to the workmanship during construction. With newer prefabricated construction, presumably more uniformity in workmanship can be attained, since assembly will be done in the factory with specialized technicians. Of course, the joints between prefabricated elements become of great importance during field assembly with respect to leakage of water, water vapor, and air.

Abstracts of Test Methods (being revised to include exterior walls and doors as well as windows).

ASTM E 283-65T. Method of Test for Rate of Air Leakage through Windows.

This method covers the determination of the rate of air flow through closed windows resulting from air pressure differences. The air pressure differences are those which may be due to wind action on a building, stack effect in a building, the operation of mechanical ventilation and exhaust systems, or a combination of these effects. The method describes general principles of pressure and flow measurement to be followed. The apparatus as described is intended for testing with constant temperature and relative humidity across the window unit.

ASTM E 331. Method of Test for Water Resistance of Windows by Uniform Static Air Pressure Differential.

The method of test is intended for the determination of water resistance of closed windows when water is applied to the outside face with the static air pressure at the outside face higher than inside.

ASTM E 330-66T. Standard Method of Test for Structural Strength of Closed Windows Under the Influence of Wind Loads.

This method is intended for the determination of structural soundness of closed windows under air pressure differences. As outlined the method may be used to test the structural soundness of the entire window assembly, either including or excluding its anchorage to the structure. The method describes the apparatus and the procedure to be used for applying specific or unknown maximum valves of air pressure to a specimen.

ASTM E-96-66. Standard Methods of Test for Water Vapor Transmission of Materials in Sheet Form.

These methods cover determination of rate of water vapor transmission of materials in sheet form. The methods are applicable to materials such as paper, plastic films, and sheet materials in general. Six procedures are provided for the measurement of transmission under different test conditions.

Procedures:

A. Low range of humidities.
B. High range of humidities, but not wetted.
BW. Wetted on one surface.
C. Elevated temperature - low range of humidities.
D. Elevated temperature - high range of humidities, but not wetted.
E. Elevated temperature - low humidity on one side - high humidity on the other side.

ASTM 355-64. Standard Methods of Test for Water Vapor Transmission of Thick Materials.

These methods cover determination of water vapor transmission of materials through which passage of water vapor may be of importance, such as fiberboards, gypsum and plaster products, wood products and plastics. Two methods, the Desiccant Method and the Water Method, are provided for the measurement of the permeance under two different test conditions.

ASTM E-154-64T. Methods for Testing Materials for Use As Vapor Barriers Under Concrete Slabs and As Ground Cover in Crawl Spaces.

These methods cover procedures for determining the properties of flexible membranes that are related to the serviceability of vapor barriers, when such membranes are used under concrete slabs and as ground cover in crawl spaces. Test procedures are provided to simulate the conditions to which a vapor barrier may be subjected.

The procedures covered are:

1. Water Vapor Transmission of Material As Received.
2. Resistance to Transmission of Water Vapor After Alternate Wetting and Drying and Deterioration from Long-Time Soaking.
3. Wet Tensile Strength.
4. Resistance to Decay.
5. Resistance to Puncture.
6. Resistance to Plastic Floors and Elevated Temperature.
7. Resistance to Deterioration from Petroleum Vehicle for Soil Poisons.
8. Effects of Low Temperatures on Bending.

4. CHARACTERISTICS OF INTERIOR ENVIRONMENT

4.1 ACOUSTICS

4.1.0 Executive Summary

The acoustical privacy required between dwelling units and the acoustical environment in residential housing can be expressed most properly in terms and concepts of performance. The performance requirement for visual privacy between dwelling units, obviously, is the provision of a barrier through which one cannot observe activities in an adjacent unit. Similarly, the performance requirement for acoustical privacy is the provision of a barrier through which one cannot hear and identify activities in an adjacent space. The latter requirement, unfortunately, is not satisfied as easily as that of visual privacy.

The acoustical performance of a barrier is expressed, technically, in terms of its sound transmission loss properties, or in general, its ability to prevent sound from traveling between the spaces it separates. The degree of performance can be measured non-destructively and characterized numerically.

In the United States, the American Society for Testing and Materials (ASTM) has published tentative recommended practices for the laboratory measurement of airborne sound transmission loss of building partitions and the field measurement of airborne sound insulation in buildings. These tentative recommended practices, in general, can provide some uniform bases for performance measurements. Some housing authorities, building code agencies, financial organizations, and others, have incorporated acoustical performance criteria, of varied degrees, in their requirements. The FHA Minimum Property Standards (MPS 2600), for example, contains some acoustical performance requirements. In these, there are some inconsistencies and other faults that should be removed through revision and updating. Article 12 of the New York City Local Law Int. No. 436 contains some acoustical performance requirements applicable primarily in large cities. The State Building Construction Code, applicable to Multiple Dwellings, of the state of New York, contains a "performance-like" statement that is somewhat ambiguous and should be considered as obsolete. Insurance companies and other organizations that invest in building construction generally do not have published acoustical performance requirements, but engage acoustical consultants to advise, recommend and specify performance levels and measures to achieve them in order to help assure their investments.

Relatively recent projects such as the SCSD (School Construction Systems Development) and URBS (University Residential Building System, have produced documents that contain some acoustical performance requirements. The former publication, unfortunately, contains some inconsistent statements and obsolete material, e.g., "Tests shall be performed in accordance with the Provisional Code for Measurements of Sound Insulation 1948 summer symposium of the Acoustics Group of the Physical Society in London." The ASTM recommended practices for laboratory and field measurements are dated

1966 and 1967, respectively, and are more representative of the present state of the art. The URBS document of June, 1967, contains performance criteria that are generally good but also appear to have internal inconsistencies.

A recent useful publication is "A Guide to Airborne, Impact and Structure-borne Noise Control in Multi-family Dwellings," prepared for the FHA and designated HUD TS-24.

Present areas of great concern that need immediate attention and improvement include the continuing problem of impact-generated sound transmission through floor-ceiling assemblies, means to attain actual field performance in buildings commensurate with potential performance indicated by laboratory measurements, and the acoustical performance of total systems--completed buildings--in reducing intrusions of aircraft-generated and other exterior noises.

While some might question the relevance of concern for acoustical privacy and noise control in low-cost housing, or may consider achievement measures too expensive and luxurious, the sociological, psychological, and perhaps physiological requirements of the occupants must be considered. In addition, the sites for low-cost housing construction are often chosen near noisy airports, industrial centers, and other relatively noisy locations that place increased performance burdens on the exterior wall assemblies and roof systems.

4.1.1 Introduction

Although the acoustical environment usually is thought to be a luxury and therefore too costly for inclusion in low-cost housing plans, it is probable that a suitably comfortable acoustical environment can be attained at little or no additional construction cost if acoustical performance is incorporated initially as part of the total housing performance concept.

4.1.2 User Requirements

The needs, or requirements, of the consumer (owner/occupant) basically consist of psychological, sociological and physiological factors.

4.1.2.1 Psychological health and well-being

Most people seem to require a conscious, or subconscious, assurance that sounds of their activities, perhaps of a personal or intimate nature, are not audible to their neighbors and vice versa.

Interruption of sleep, concentration or communication due to noise or intrusive sounds, e.g., a crying child, may cause adverse psychological effects.

4.1.2.2 Sociological implications.

The lack of acoustical privacy, especially in high-density multifamily housing, could be a factor in difficult social interactions among occupants of such housing. An example might be the audition of a family domestic quarrel prompting some neighbors toward interference that possibly could lead to a large-scale disturbance.

4.1.2.3 Physiological health and well being.

Prolonged exposure to high noise levels, produced by aircraft, rapid transit systems, industrial plants, etc., could impair the normal hearing capacity of individuals.

Persistent loss of sleep, caused by intrusive sounds or noises, indirectly could produce deleterious physiological results.

4.1.3 Housing Performance Requirements

A suitable acoustical environment in residential housing results from adequate provisions for acoustical privacy and noise control, which are the fundamental performance requirements.

4.1.3.1 Site Selection and Planning

An anomalous situation arises, from the acoustical viewpoint, in that low-cost housing sites often are selected near rapid-transit systems, i.e. elevated and/or subway trains and other railways, near airfields or near industrial plants or other relatively noisy areas. In order to establish a comfortable interior acoustical environment, the exterior wall system and roof assembly should provide greater sound attenuation than would be required on a less noisy site. The end result could be increased construction costs.

1. Low-cost housing sites should be selected consistent with intelligent (noise-control-conscious) land-use planning and zoning.

2.. Building orientation, on the site, should be planned to minimize potentially intrusive exterior noises. Natural barriers should be exploited for acoustical shielding wherever possible.

4.1.3.2 Requirements of Structures

1. Exterior walls nearest outdoor noise sources should contain a minimum member of window and door openings, i.e., the airborne sound transmission loss of exterior walls shall be sufficient to provide a comfortable interior acoustical environment.

2. Spatial designs and floor plans should optimize opportunities for noise control and acoustical privacy provisions. Noisy service areas, for example, should be as far from acoustically critical spaces (bedrooms) as possible.

3. Airborne sound transmission loss of party walls and floor-ceiling assemblies separating dwelling units shall be sufficient to provide acoustical privacy.

4. Floor-ceiling assemblies shall reduce impact-generated noise sufficiently to provide acoustical privacy.

5. Wall and door assemblies separating dwelling units from corridors, stairs, and entranceways shall provide acoustical privacy.

6. Corridors, stair-and-entranceways, utility areas that usually are quite reverberant shall have sufficient sound absorptive properties to provide noise control in such spaces; i.e., the reverberant sound build-up shall be minimized with the use of sound absorbing materials.

7. Assuming that low-cost housing consumers can still afford furnishings that have sufficient sound absorbing properties, e.g. heavily upholstered furniture, wall-to-wall carpeting, draperies, etc., interior surface finishing materials should provide some sound absorption in dwelling units to help attain a comfortable acoustical environment in them.

8. Certain partitions within individual dwelling units should provide some acoustical privacy for family members.

9. Structural design should include techniques to prevent or minimize the transmission of structure-borne sounds from mechanical equipment and the like.

4.1.3.3 Requirements of Equipment in Buildings

1. Noise control considerations shall be included in the selection of equipment.

2. Installation of equipment shall incorporate noise control measures.

3. With extremely careful planning, usually on an individual-case basis, the sound produced by heating, ventilating and air-conditioning systems may be used advantageously to provide background sound levels that "mask" potentially instrusive noises. Due caustion must be exercised to avoid the noise of HVAC systems from becoming a source of annoying noise in themselves.

4. Installation of plumbing and plumbing fixtures shall provide noise control measures, e.g., rigid connection of piping to large sound radiating areas, partitions, should be avoided.

5. Installation of electrical and telephone services shall not compromise the acoustical integrity of partitions and floor-ceiling assemblies. In addition, planned location of outlets can avoid eventual placement of domestic noise sources, television sets and appliances, on or against party walls.

4.1.4 Present Acoustical Performance Requirements in U. S. Housing

In general, acoustical performance requirements are more prevalent in European housing construction than in the United States. Many European countries have mandatory acoustical isolation requirements and others have recommended codes of practice. With the increased number of multifamily-dwelling units and mass urbanization in recent years, the necessity of providing acoustical privacy and noise control measures has risen in the United States.

The Federal Housing Administration includes some acoustical performance requirements in the Minimum Property Standards (MPS 2600). In addition, a Guide to Airborne, Inpact and Structure-Borne Noise Control in Multifamily Dwellings has been prepared for the FHA, that contains recommended performance levels and criteria, related principally to interior partitions and to floor-ceiling construction.

On the local level, housing authorities and land-use zoning bodies and others have incorporated acoustical performance requirements and noise-control regulations in their building codes and ordinances. It is reported that noise-control regulations and/or acoustical performance requirements are incorporated in, or currently are being proposed, in codes and/or ordinances of the following jurisdictions.

California

Baker's Field
Beverly Hills
Los Angeles
Sacramento
San Francisco

Colorado

Denver

District of Columbia

Florida

Coral Gables
Miami
Miami Beach

Illinois

Chicago
Highland Park
Peoria

Maryland

Montgomery County
Rockville

Michigan

Detroit

Missouri

Glendale

New Jersey

Major cities

New York

Hempstead
Irvington
New York City

Ohio

Cincinnati
Shaker Heights
Toledo
University Heights

Pennsylvania

Montgomery County
Mount Lebannon

Rhode Island

Warwick

Tennessee

Memphis

Virginia

Fairfax County

West Virginia

Charleston

The quality or exact nature of the noise-control regulations and/or acoustical performance requirements of all of the above is not known at this time. Many of these are suspected to be the common "nuisance clause" relating to noise production within the jurisdictional limits.

4.1.5 Summary of U. S. Standard Test Procedures

Standard test methods currently in use, or in development, are:

1. E90-66T : "Tentative Recommended Practice for Laboratory Measurements of Air-Borne Sound Transmission Loss of Building Partitions" - ASTM, Joint E-6 Sub 3 and C20 Sub 6.

2. C423-66 : Standard Method of Test for Sound Absorption of Acoustical Materials in Reverberation Rooms - ASTM, C-20.

3. E-336-67T : "Tentative Recommended Practice for Measurement of Air-Borne Sound Insulation in Buildings" - ASTM, Joint E-6 and C-20. (Accepted for publication in 1968 Book of Standards)

4. (In ballot) : "Recommended Laboratory Method for Measuring Impact Sound Transmission through Floor-Ceiling Assemblies" - ASTM, Joint E-6 and C-20.

5. ISO R140 : "Field and Laboratory Measurement of Air-Borne and Impact Sound Transmission".

6. ASHRAE Standard 36-62	:	"Standard for Measurement of Sound Power of Heating Refrigerating and Air-Conditioning Equipment, Criteria for Testing" - ASHRAE.
7. ASHRAE Standard 36A-63	:	"Standard Method of Determining Sound Power of Room Air Conditioners and Other Ductless, Through-the-Wall Equipment" - ASHRAE.
8. ASHRAE Standard 36B-63	:	"Standard Method of Testing for Rating the Acoustic Performance of Air Control and Terminal Devices and Similar Equipment - ASHRAE.
9. AMCA Bull. 300	:	"Standard Test Code for Sound Rating Air Moving Devices" (Revised April 1965) - AMCA.
10. Standard AD-63	:	"Measurement of Room-to-Room Sound Transmission Through Plenum Air Systems" - ADC.

4.1.6 Summary of Foreign Codes and Recommendations

Another approach to the development of suitable criteria for acoustical privacy is to examine what has been done in other countries coping with similar problems. An extensive survey of codes and recommendations in existence, as well as those presently under consideration, has been conducted, and a summary is presented here.

Most countries have requirements or recommendations for both air-borne and impact sound insulation, although a few deal only with air-borne sound insulation. Generally, the methods of test are quite similar throughout the various countries, although the presentation of data and the insulation criteria understandably differ from country to country.

Airborne sound insulation measurements are made using bands of random noise or frequency-modulated sinusoidal tones, and the results are presented as sound transmission loss or normalized level differences according to the following equations:

Sound Transmission Loss $STL = L_1 - L_2 + 10 \log_{10} S/A$ (9.1)

Ref. Reverberation Time Normalization: $D_{To} = L_1 - L_2 + 10 \log_{10} T/To$ (9.2)

Ref. Absorption Normalization: $D_{Ao} = L_1 - L_2 + 10 \log_{10} Ao/A$ (9.3) where, in all three equations, L_1 and L_2 are the time-space average sound pressure levels, in decibels, measured in the source and receiving rooms respectively. The difference, L_1-L_2, is also known as the Noise Reduction (NR). In equation 9.1, S is the total radiating surface area of the partition, and A is the total sound absorption in the receiving room. In equation 9.2, T is the measured reverberation time of the receiving room, and T_o= 0.5 second is the normalizing reference reverberation time. Similarly, in equation 9.3, A is the total sound absorption in the receiving room, and $A_o = 10m^2$ is the normalizing reference room absorption.

Impact sound insulation measurements are generally performed utilizing a tapping machine which by operating on the floor serves as a repeatable standard source of impact excitation. The resulting impact sound pressure levels are measured in the receiving room located directly below. The presentation of data and the insulation criteria differ among the various countries. The results of the measurements are presented according to one of the following equations of normalized impact sound pressure levels, (ISPL):

$$ISPL_{A_o} = SPL + 10 \log_{10} A/A_o \qquad (9.4)$$

$$ISPL_{T_o} = SPL - 10 \log_{10} T/T_o \qquad (9.5)$$

where SPL is the time-space average sound pressure level, in decibels re: 0.0002 dyne/cm^2, measured in the receiving room. A is the total sound absorption of that room and $A_o = 10m^2$ is the normalizing reference room absorption. Similarly, T is the measured reverberation time of the receiving room and T_o = 0.5 second is the normalizing reference reverberation time. In addition to the matter of normalization, there is inconsistency in the frequency bandwidth of the measurement of sound pressure levels. Measurements are usually made in 1/3-octave or 1/1-octave frequency bands. Confusion arises when the resultant measured levels are compared for compliance with required or recommended criterion contours. The problem simply is that of comparing like quantities. In the early days, the electrical filters used for analyzing the sound were octave frequency band filters which separated the audible frequency sound into components, each encompassing one full octave. The resultant values were plotted at the center frequency of each band and labeled "octave-band sound pressure levels". More recently, it was recognized that a greater refinement or "definition" of the sound spectra was necessary, and consequently 1/3-octave frequency band filters were developed. Obviously, the total sound energy in a given octave band should be the same, whether measured in ten 1/10-octave bands, three 1/3-octave bands, or one 1/1-octave band. In other words, the sum of the energy contributions of each of the three 1/3-octave bands comprising a full octave band should result in the value that would be obtained from a single measurement of that full octave band. It follows that the observed single value in each of the 1/3-octave bands will be less than the single value observed for the full octave band.

A problem arose when the existing criterion contours based upon octave band sound pressure level measurements were applied to the 1/3-octave band measurements. To resolve the problem, it was agreed* that measurements should be made in frequency bands not greater than 1/1-octave wide and not less than 1/3-octave wide, and the values should be corrected to correspond to those of full octave bands by the addition of 10 $\log_{10}$ n (dB) to the average level when (1/n) octave band filters are used. In the case of 1/3-octave bands, n = 3; therefore 10 $\log_{10}$ (3) = 4.77 dB or 5 dB when rounded to the nearest whole number. Some countries plot impact sound pressure level data in octave bands, some plot 1/3-octave band data after adding the 5 dB octave band "correction" to the data and others plot 1/3-octave band data without applying the "correction". As a consequence, the literature contains information which may be confusing and perhaps contradictory. It is scientifically more pleasant and logical to present the data as measured. When comparison with criteria or recommended contours is necessary, these theoretical and sometimes arbitrary reference curves can be adjusted readily to correspond with the measured data. In other words for use with 1/3-octave band data, it is easier to adjust a reference contour by subtracting the value of 10 $\log_{10}$ n from it, rather than adding that value to the measured data. Likewise, if the reference contours are based upon 1/3-octave band data, the value of 10 $\log_{10}$ n can be added to the contour for comparison with 1/1-octave data. This practice avoids the contradictory situation where exactly the same noise is characterized by octave band data and 1/3-octave band data (adjusting by adding 5 dB), but when computed yield total energies which are not the same.

From a scientific point of view, it is technically correct and permissible to convert or express data obtained from 1/3-octave band measurements in terms of 1/1-octave band data, but the converse requires making an assumption about the distribution of sound with frequency which may not agree with the distribution in the particular case considered.

In view of the desirability of 1/3-octave band analysis of noise and the current trend toward standardization of such analyses, the data will be presented as measured in this publication and the reference contours for obtaining single-figure ratings will be adjusted accordingly. Further, it is recommended that future measurements include 1/3-octave band analyses and that subsequent criteria contours be based directly on such data.

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* By the International Organization for Standardization

The following list gives capsular descriptions of required or recommended airborne and impact sound insulation criteria of various foreign countries. Graphic illustrations of these criteria are given at the end of this chapter.

1. AUSTRIA

(a) Airborne Sound Insulation: Single-figure ratings are obtained from a reference contour (Figure 9.6) allowing an average unfavorable deviation* of 2 dB. The STL measurements use either swept frequency-modulated sinusoids with octave-band analysis, or white noise with 1/3-octave band analysis.

(b) Impact Sound Insulation: Single figure ratings are obtained from a reference contour (Figure 9.7) allowing an average unfavorable deviation* of 2 dB. 1/1-octave band analysis of impact sound pressure levels, normalized to $A_0 = 10m^2$, is made in the receiving room with the ISO type tapping machine operating on the floor above.

Recommendations for both airborne and impact sound insulation are based upon four sound insulation groups, by building types, with criteria for various individual partition functions within each group. In addition there are three reference curves for assessing impact noise reduction (ΔL) achieved by modifying the basic floor-ceiling structures with additional floor or ceiling assemblies. Although this standard is not a legal requirement, it is observed by most planners, builders, customers and housing authorities in Austria.

Reference: O NORM B 8115 "Hochbau Schallschutz und Horsamkeit", April 27, 1959.

2. BELGIUM

As far as we know, there are no national requirements, however, British, French and German standards are applied in certain areas, and in some cases more stringently than in the countries of origin.

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* Generally throughout these capsular descriptions, the "average unfavorable deviation" ($\bar{d}$) is computed as follows:

$$\bar{d} = \frac{\sum_n d_n}{n} = \frac{d_1 + d_2 + \ldots + d_n}{n} \qquad (9.6)$$

where d_n are the deviations from the reference contour. The deviations in the unfavorable sense are entered at their full value and those in the favorable sense are entered with a value of zero.

3. BULGARIA

As far as we know, the Bulgarian requirements are quite similar to those of Czechoslovakia.

4. CANADA

(a) Airborne Sound Insulation: "Construction shall provide a sound transmission class rating* of not less than 45 between dwelling units in the same building and between a dwelling unit and any space common to two or more dwelling units." Quoted from Section 5 "Sound Control" (Residential Standards, Canada, 1965, NRC. No. 8251) Supplement No. 5 to the National Building Code of Canada, 1960, NRC. No. 5800.

(b) Impact Sound Insulation: There are no requirements in current use, but it is understood that a new code is in preparation.

5. CZECHOSLOVAKIA

(a) Airborne Sound Insulation: Requirements are based upon reference contours (Figure 9.8) with different contours applicable to laboratory and field measurements, allowing an average unfavorable deviation of 2 dB, providing that no single unfavorable deviation may exceed 8 dB, based upon octave bands. STL measurements are conducted in the laboratory and sound level difference measurements which are normalized to ($A = 10m^2$) are performed in the field.

Reference: O. Brandt, "Sound Insulation Requirements between Dwellings". An invited paper presented at the Fourth International Congress on Acoustics, Copenhagen, Denmark, 1962.

(b) Impact Sound Insulation: As far as we know, the measurements and the reference contour follow the German standard (DIN 4109); however, the requirements are about 10 dB more stringent.

6. DENMARK

(a) Airborne Sound Insulation: The requirements are based upon reference contours (Figure 9.6) with a distinction between isolation provided by a partition alone and isolation between two rooms. The sum total of unfavorable deviations may not exceed 16 dB. Measurements are reported as sound pressure level differences normalized to $T_o = 0.5$ second.

*As prescribed in ASTM Specification E90-61T "Tentative Recommended Practice for Laboratory Measurement of Airborne Sound Transmission Loss of Building Floors and Walls", 1961.

(b) Impact Sound Insulation: Similarly, these requirements are based upon a reference contour (Figure 9.9) with the same restriction on unfavorable deviations. 1/3-octave band measurements of impact sound pressure levels, normalized to T_o = 0.5 second, are made in the receiving room with the ISO type tapping machine operating on the floor above.

Reference: Bygningsreglement for Kobstaederne og landit (Building Regulations) Chapter 9, "Sound Isolation", Copenhagen, Denmark (1961).

7. ENGLAND

(a) Airborne Sound Insulation: Three grading contours (Figure 9.10) - House Party Wall Grade, Grade I and Grade II are specified as recommended requirements; a small allowance is permitted which is equal to an average unfavorable deviation of 1 dB. If the mean deficiency exceeds 1 dB of Grade II, the structure is classified as x dB worse than Grade II. This quantity is not defined for structures rating better than Grade II. 1/3-octave band measurements are made in accordance with British Standard 2750: 1956*, and results are reported as STL or sound pressure level differences normalized to T_o = 0.5 second for laboratory and field respectively. Frequency-modulated sinusoids or random noise may be used.

(b) Impact Sound Insulation: Likewise, two grading contours, (Figure 9.11) Grade I and Grade II, are specified as recommended requirements with similar allowances as above. Impact sound pressure levels are measured either in octave or 1/3-octave bands and normalized to $A_o = 10m^2$ in the field. Measurements are made in the receiving room with an ISO type tapping machine operating on the floor above. If the analysis is made in bands less than a full octave, results are to be "corrected" by adding $10 \log_{10} n$, where 1/n is the bandwidth used.

Although the code represents a standard of good practice, and thus takes the form of recommendations, some local areas require compliance with certain sections of the code; there are indications of the future emergence of regulations throughout the United Kingdom.

Reference: British Standard Code of Practice, CP3: Chapter III, "Sound Insulation and Noise Reduction" (1960).

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* Recommendations for Field and Laboratory Measurement of Airborne and Impact Sound Transmission in Buildings", British Standard 2750: 1956, British Standards Institution.

8. FINLAND

(a) Airborne Sound Insulation: Contours (Figure 9.12) associated with three sound insulation classes are specified as recommended requirements. The classes are based upon maximum permissible noise levels in a given space, as well as the necessary sound isolation obtainable from a partition or between two rooms. The sum total of the unfavorable deviations may not exceed 16 dB. STL measurements are conducted in the laboratory, and sound pressure level differences normalized to $T_o = 0.5$ second are performed in the field; all data are reported in 1/3-octave bands.

(b) Impact Sound Insulation: Likewise, contours (Figure 9.13) associated with the three sound insulation classes are specified as recommended requirements. These carry the same restriction on unfavorable deviations as above. 1/3-octave band measurements of impact sound pressure levels are made in the receiving room with the ISO tapping machine in operation on the floor above. Laboratory and field results are normalized to $A_o = 10m^2$ and T = 0.5 second, respectively.

There is no legislation yet in Finland regarding mandatory requirements of sound insulation; therefore, the above are considered to be recommendations.

Reference: EHDOTUS ÄÄNENERISTYSMÄÄRÄYSIKSI, "Suggestion for Requirements of Sound Insulation", Valtion Teknillinen Tutkimuslaitos, Tiedotus. Sarja III - Rakennus 42, Helsinki (1960).

9. FRANCE

The French have had standards since 1958; however, it is understood that new regulations are being prepared. Single-figure ratings are derived from comparison of measured values with specified average sound pressure level differences normalized to $T_o = 0.5$ second for airborne sound insulation. Similarly, ratings for impact sound insulation are obtained by comparison of measured 1/3-octave band impact sound pressure levels, adjusted to "correspond" to octave band levels, with specified sound pressure levels normalized to $T_o = 0.5$ second. An ISO type tapping machine is used as a source of impact excitation.

10. GERMANY

(a) Airborne Sound Insulation: Single-figure ratings are obtained from reference contours* (Figure 9.6); separate curves are used for the comparison of field and laboratory data. An average unfavorable deviation of 2 dB is permitted when computed as follows:

$$d = \frac{\frac{d_1}{2} + d_2 + \ldots d_{n-1} + \frac{d_n}{2}}{(n-1)} \leq 2 \text{ dB} \qquad (9.7)$$

where d_n are the deviations from the reference contour; deviations in the favorable sense are assumed to lie on the contour and are entered as zero in the computation. n is equal to the number of measured values, usually at sixteen 1/3-octave bands. Measurements are made in accordance with DIN 52210**, and results are reported as R(STL) and R' for laboratory and field measurement respectively.

(b) Impact Sound Insulation: Single-figure ratings are obtained from reference contours (Figure 9.7) in a similar manner as for airborne sound insulation; the average unfavorable deviation is computed analogously. The 1/3-octave band analysis of impact sound pressure levels is made in the receiving room with the ISO tapping machine operating on the floor above. The sound pressure levels are normalized to $A_o = 10m^2$ and "corrected to correspond" with octave band data.

Germany was among the first countries to include provisions for acoustical privacy and noise control in building codes; and the present standard (DIN 4109) is perhaps one of the most comprehensive documents of its kind.

Reference: Schallschutz in Hochbau (Sound Insulation in Buildings), DIN 4109, (5 parts dated September 1962 - April 1963).

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* The theory of requirement contours is given by L. Cremer, in "Der Sinn der Sollkurven", Schallschutz von Bauteilen, Berlin, 1960. (Published by Wilhelm Ernst & Son.)

** Messungen zur Bestimmung des Luft - und Trittschallschutzes, (Measurements for the Determination of Airborne and Impact Sound Insulation), DIN 52210, March 1960.

11. NETHERLANDS

(a) Airborne Sound Insulation: There are two quality classes of sound insulation, "fair" and "good", based mainly upon the comparison of measured insulation values with reference values (Figure 9.14).

From that comparison, three specific rules are used for obtaining the Insulation Index of a structure. Measurements are made in four octave bands with center frequencies ranging from 250 to 2000 Hz; the laboratory results are reported as STL and field results as sound pressure level differences normalized to $A_o = 10m^2$.

(b) Impact Sound Insulation: Similarly, there are two quality classes of sound insulation and the ratings are based upon comparison with reference values (Figure 9.15) with three specific rules analogous to the airborne sound insulation rating system. Impact sound pressure level measurements are made in the receiving room with an ISO type tapping machine operating on the floor above. The measurements are made in the same four octave bands and are normalized to $A_o = 10m^2$.

Reference: Natuurkundige Grondslagen voor Bouwvoorschriften, Deel III, Geluidwering in Woningen (Noise Control and Sound Insulation in Dwellings), NEN 1070, December 1962, Nederlands Normalisatie-Instituut.

12. NORWAY

(a) Airborne Sound Insulation: Single-figure ratings are obtained by comparison of measured data with reference contours (Figure 9.16) allowing an average unfavorable deviation of 1 dB. Measurements are made in accordance with ISO/R 140-1960*, and results are reported as sound pressure level differences normalized to $T_o = 0.5$ second. The codes are based upon an effective airborne sound insulation number which takes into account the insulation qualities of the partition, its area, the volume and the reverberation time of the receiving room and the estimated degree of flanking transmission.

* International Organization for Standardization, ISO Recommendation R140, "Field and Laboratory Measurements of Airborne and Impact Sound Transmission", ISO/R 140-1960 (E).

(b) Impact Sound Insulation: Similarly, single-figure ratings are obtained by comparison with reference contours (Figure 9.17), allowing the same average unfavorable deviation. A 1/3-octave band analysis of impact sound pressure levels, normalized to T_o = 0.5 second, is made in the receiving room with the ISO tapping machine operating on the floor above. The codes also are based upon an effective impact sound number system, which yields positive numbers such that the larger values indicate increased impact sound insulation.

Reference: "Proposed Norwegian Building Code for Sound Insulation", Norges Byggforskinngsinstitut Rapport 38, Oslo 1963.

13. SCOTLAND

(a) Airborne Sound Insulation: The Scottish building standards are based upon the "House Party Wall Grade" and "Grade I" contours of the British Standard Code of Practice (Figure 9.10), CP3: Chapter III, "Sound Insulation and Noise Reduction", 1960; the measurements are conducted in accordance with B.S. 2750: 1956, (See 7. ENGLAND).

(b) Impact Sound Insulation: Likewise, the "Grade I" reference contour (Figure 9.11) for impact sound pressure levels is used. The 1/3-octave band analysis is normalized to T = 0.5 second, and "corrected to correspond" with octave band data.

This differs significantly from the British case because the Scottish building standards constitute a legal requirement, effective June 15, 1964, as opposed to a recommendation. Although not applicable to existing buildings prior to that date, local authorities have the power to require conformation in all new buildings.

Reference: Building Standards (Scotland) Regulations, Part VIII, 1963, as presented by G. Berry in an article entitled "Sound Insulation in Houses and Flats - Effect of New Scottish Building Standards", INSULATION, January 1964.

14. SWEDEN

(a) Airborne Sound Insulation: There are three grading contours (Figure 9.18) to which measured 1/3-octave band data are compared. The data are reported as sound pressure level differences normalized to $A_o = 10m^2$. The total sum of the unfavorable deviations may not exceed 16 dB. The requirements, which are stated in terms of functional application of the wall structures, thus determine which one of the three contours must be satisfied in a specific case.

(b) Impact Sound Insulation: Two grading contours (Figure 9.19) are specified for the required comparisons; these are based upon a 1/3-octave band analysis of impact sound pressure levels measured in the receiving room with an ISO type tapping machine operating on the floor above. The results are normalized to $A_o = 10m^2$ and are reported as measured, i.e. without the "correction" to octave bands. In this case, the total sum of the unfavorable deviations may not exceed 32 dB.

Reference: Swedish Building Code: BABS 1960. Anvisnigar Till Byggnadsstadgan, Kungl. Byggnadsstyrelsens Publikationer, Stockholm, Sweden (1960).

15. SWITZERLAND

(a) Airborne Sound Insulation: An unofficial draft recommendation exists, in which "minimum" and "maximum" requirements of average sound transmission loss are specified, which are based upon both laboratory and field measurements according to type of building and wall function. In the case of multifamily dwellings, the following is applicable:

Building Component	Laboratory		Field	
	Min.	Max.	Min.	Max.
Dividing walls and ceilings in flats, staircase wall	52 dB	57 dB	50 dB	55 dB
Dividing walls between flats and restaurant, cinema, garage, workshop and other business premises	57 dB	67 dB	55 dB	65 dB

(b) Impact Sound Insulation: There are no explicit requirements.

Reference: W. Furrer, "Room and Building Acoustics and Noise Abatement", p. 203, English Translation (Butterworth & Co. Ltd., London, 1964).

16. U.S.S.R.

(a) Airborne Sound Insulation: There are three reference contours (Figure 9.20) with which sound transmission loss measurements are to be compared. In the comparison, unfavorable deviations are computed as follows:

$$\bar{d} = \frac{\frac{d_1}{2} + d_2 + \ldots + d_5 + \frac{d_6}{2}}{6} \leq 2 \text{ dB} \qquad (9.8)$$

where d_n are the deviation from a reference contour based upon the six 1/1-octave bands with center frequencies in the range 100-3200 Hz. In addition, no single unfavorable deviation may exceed 8 dB.

(b) Impact Sound Insulation: Similarly, there are two reference contours (Figure 9.21) which specify maximum impact sound pressure levels permissible in the receiving room with a tapping machine operating on the floor above. Unfavorable deviations from the specification contours are computed analogously, as above, according to equation 9.8.

Reference: Advisory Code for Sound Insulation in Housing and Community Buildings, (CH39-58) State Publishing Office for Building Architecture and Building Materials Literature, Moscow, 1959.

In general, most of the requirements imply minimal sound insulation; however, the foregoing cursory review of codes, standards and recommendations obviously does not include all the information contained in such documents. For example, many codes specify criteria for partitions within dwelling units, maximum sound pressure levels permissible in a given space, criteria for doors and windows, means to minimize flanking transmission and structure-borne noise, and other pertinent information. In fact, some documents approach textbook status on the subject of acoustical privacy and noise control rather than codes.

In summary, the review shows several prevalent techniques for specifying adequate acoustical privacy, which essentially are as follows:

(1) Single-figure rating requirements or recommendations formulated on the basis of a single reference contour or upon a family of reference contours, with accompanying rules for computing such ratings. The code requirements are not necessarily consonant with, or the same as, the values of the reference contour; or in other words, the required insulation, for a given installation, may be x dB more stringent than the values of the reference contour. (This point has been often overlooked in similar studies, of existing codes and criteria, appearing in the literature.)

This system affords the greatest flexibility for the code writer because he can revise the single-figure requirements, if need be, without disrupting the basic rating scheme.

(2) Grading curves for minimum airborne sound insulation and maximum impact sound pressure levels. This system affords the simplicity of a "go or no go" decision on the part of the appropriate authorities; but if revision of the requirements becomes necessary, the change is usually difficult to accomplish.

(3) Requirements based upon the single-figure arithmetic average of sound transmission loss values. Although this system is the simplest, there have been technical questions raised regarding its suitability.

Figure 9.22 shows the range of minimum airborne sound insulation requirements and recommendations of other countries and the range of suggested values* for particular cases requiring better sound insulation performance.

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* These generally pertain to areas where better than minimal sound insulation is usually necessary, such as separation of dwelling units in quiet or suburban locations; separation of dwelling units from small business shops within a building, or from noisy areas such as mechanical equipment rooms, restaurants, and for application to hospitals, hotels, etc.

Technically speaking, sound transmission loss, STL, and normalized level difference, D_n, values should not be plotted on the same graph; however, for purposes of convenience, they are shown together and labeled "Airborne Sound Insulation". It can be shown that STL = D_{A_o} when the partition area S is approximately 107.6 ft^2; also, STL = D_{T_o} when S/V->0.1 ft^{-1}, where S is the partition area and V is the volume of the receiving room in the English system of units**.

Similarly, the shaded areas in Figure 9.23 show, analogously, the range of minimum impact sound insulation requirements or recommendations of other countries and the range of suggested values for particular cases requiring better sound insulation performance. These values are plotted to be consistent with 1/3-octave band analyses; i.e., reference contours which were established for comparison with octave band data have been lowered 5 dB for comparison with 1/3-octave band data. In addition, reference values for use with data normalized to both A_o = $10m^2$ and T_o = 0.5 second are shown together. It can be shown that the two normalization schemes yield equivalent results for measurements in rooms which have a volume of approximately 1100 ft^3 or $31m^3$.

** In metric units:

$$STL = D_{A_o} \text{ when } S = 10m^2$$

$$STL = D_{T_o} \text{ when } S/V \rightarrow 0.33m^{-1}$$

4.1.7 Research Need in Architectural Acoustics

The following research programs are necessary to improve the "state-of-the-art" related to the acoustical performance of all housing, not only of low-cost housing.

1. A comprehensive study, evaluation and understanding of the subjective response to the acoustical environment--"What is necessary?", "What is desirable?", or as it is often stated, "How much noise intrusion will people tolerate?"

2. Development of a correlation or relation between field and laboratory measurement results. Devise practical and realistic means for predicting acoustical performance actually achieved in buildings from the results of laboratory measurements.

3. Development or improvement of "standard" methods of measurement, evaluation, and criteria formulation suitable for performance specifications of:

    a. the acoustical properties of exterior wall components individually and compositely that are necessary to provide protection from noise intrusions of exterior sources, e.g., aircraft, rapid-rail-transit systems, motor vehicles, etc.,

    b. the acoustical properties of party walls, separating dwelling units, when they are a part of the total building system,

    c. surface noise radiation generated by people and objects in dynamic contact with floor-surfacing materials,

    d. impact sound transmission through floor-ceiling assemblies generated by dynamic contact with the floor,

    e. structure-borne sound transmission generated by natural sources (earth vibrations) and electro-mechanical equipment,

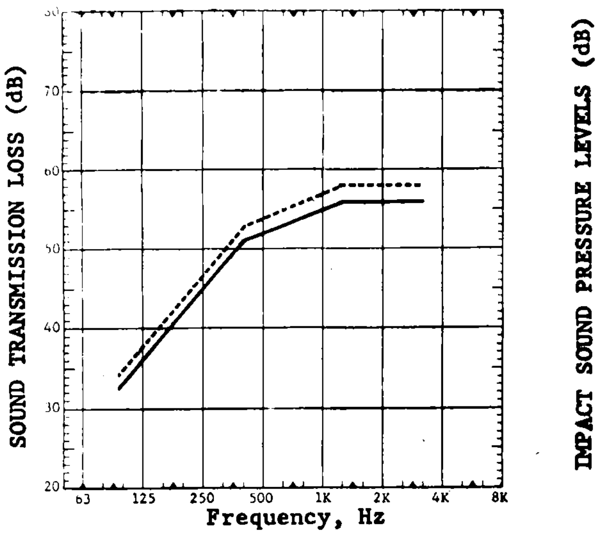
    f. noise production associated with plumbing and fixtures,

    g. noise production associated with appliances and electro-mechanical (HVAC) equipment.

4. The study and evaluation of the acoustical performance of the total building system as it is affected by the interaction and connection of all components, materials and equipment. The full integration of building acoustics technology with all other building science technology is essential.

Figure 9.6

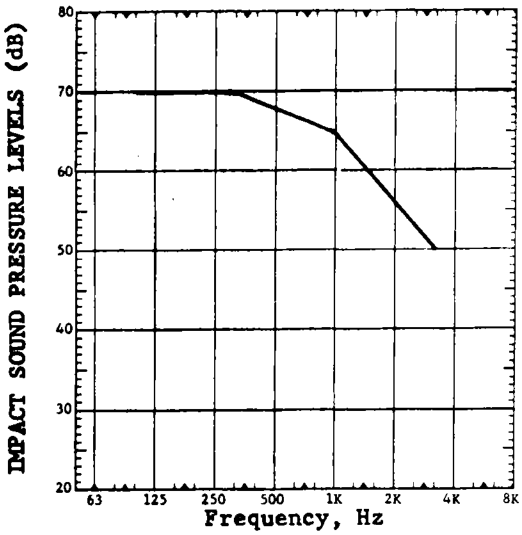
Reference Contours



—— Austria, Denmark, Germany (Field)
------ Germany (Lab)

Figure 9.7

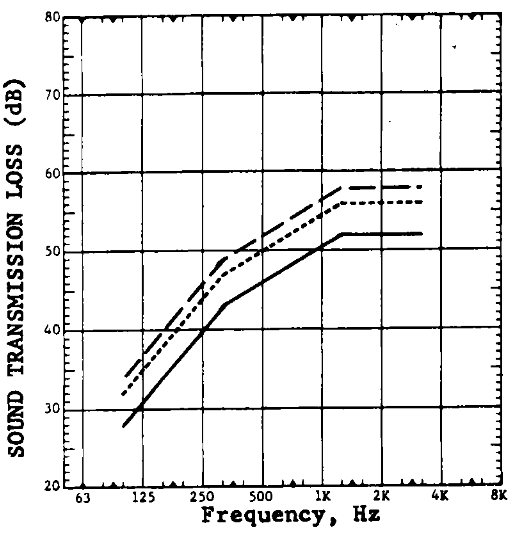
Reference Contour



—— Austria, Germany

Figure 9.8

Reference Contours

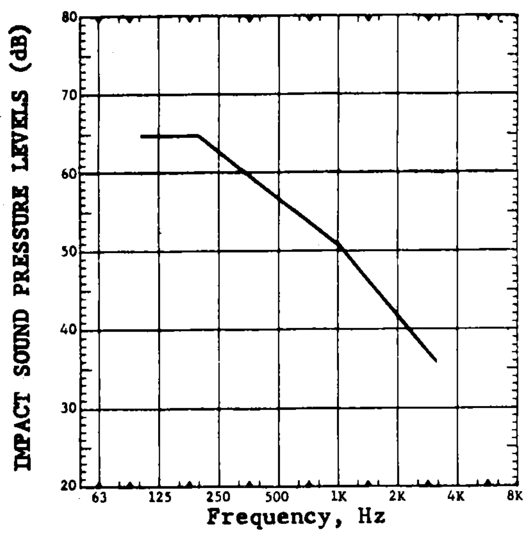


CZECHOSLOVAKIA

—— Field Measurements
------ Walls - Lab. Measurements
— — Floors

Figure 9.9

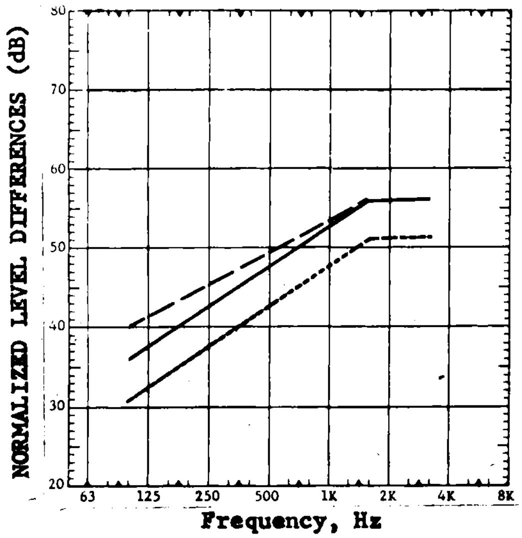
Reference Contour



—— Denmark

Figure 9.10

Grading Contours

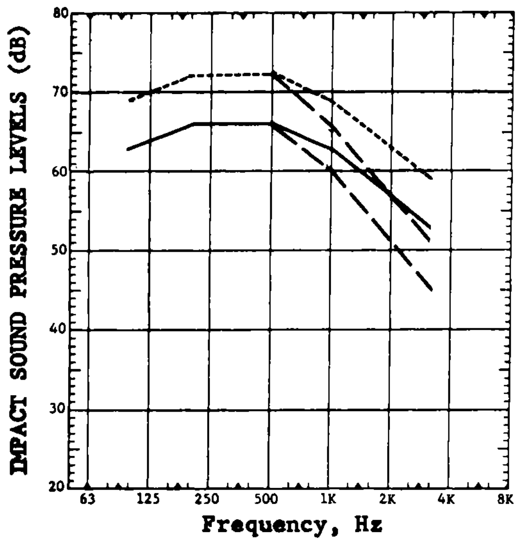


ENGLAND

——Grade I (Flats)
——Grade II (Flats)
— — House Standard (House Party Wall Grade)

Figure 9.11

Grading Contours

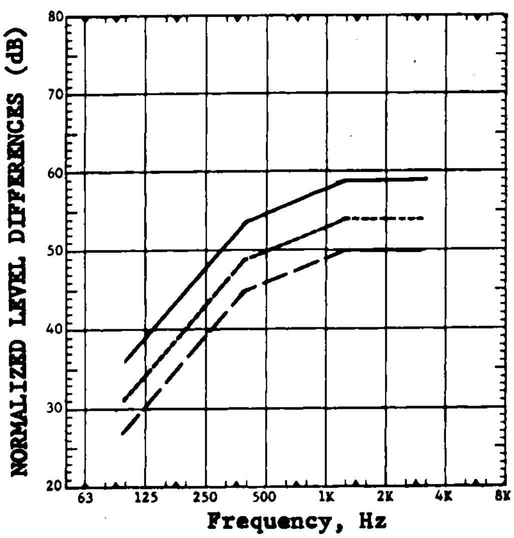


ENGLAND

——Grade I
------Grade II
— —With linoleum

Figure 9.12

Recommended Contours

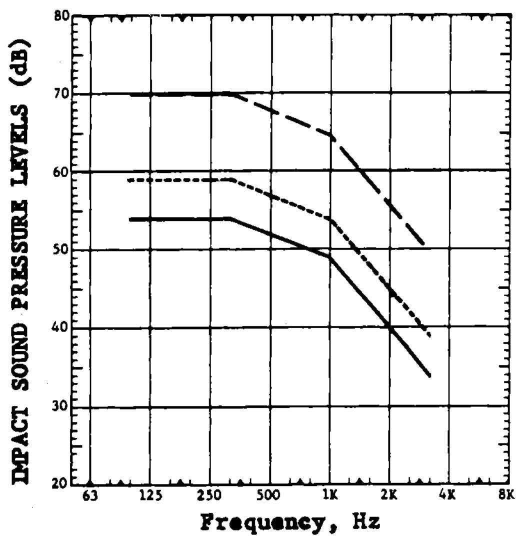


FINLAND (Field Measurements)

——Class I
------Class II
— —Class III

Figure 9.13

Recommended Contours

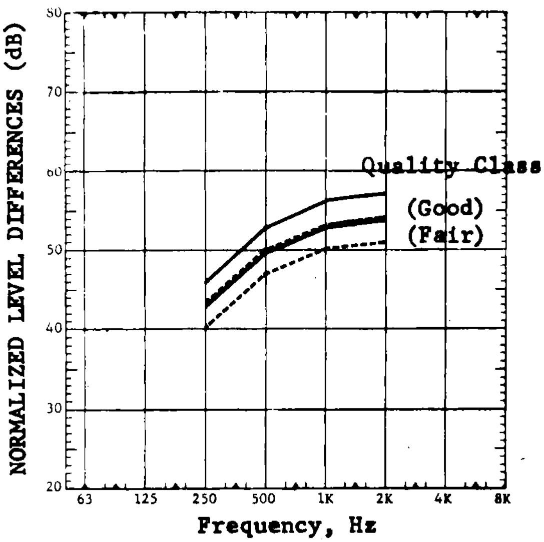


FINLAND

——Class I
------Class II
- — -Class III

Figure 9.14

Reference Values

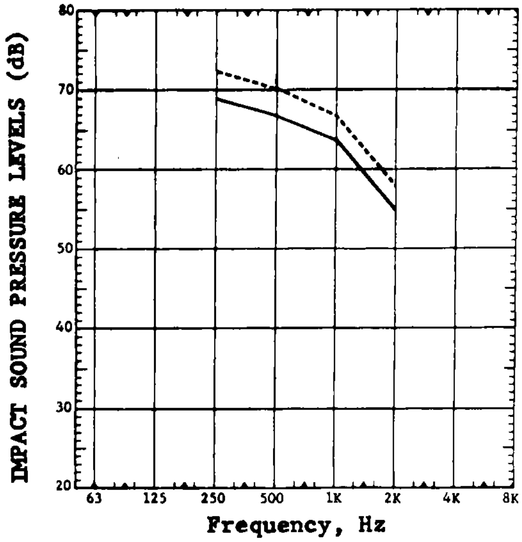


NETHERLANDS

——To Protect Sensitive Room
------To Protect Non-sensitive Room

Figure 9.15

Reference Values

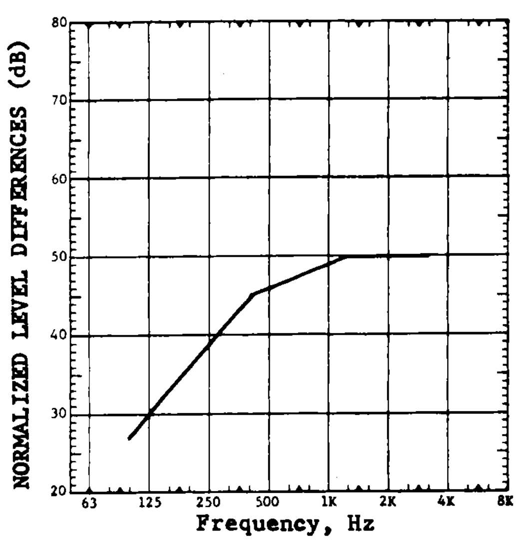


NETHERLANDS

——Quality Class - (Good)
------Quality Class - (Fair)

Figure 9.16

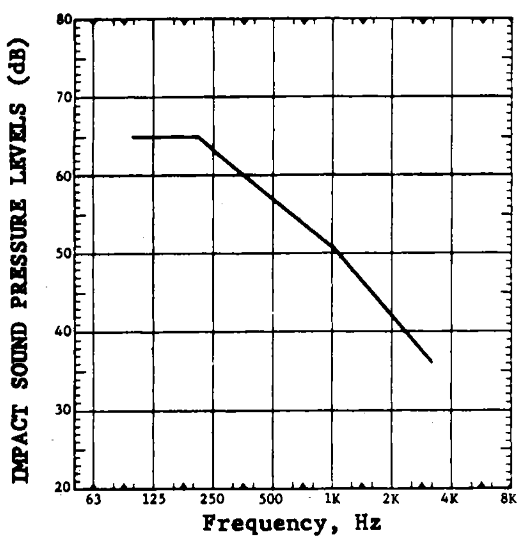
Reference Contour



——Norway

Figure 9.17

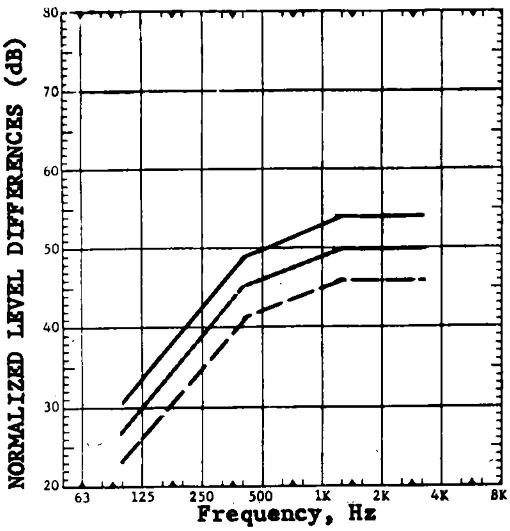
Reference Contour



——Norway

Figure 9.18

Grading Contours

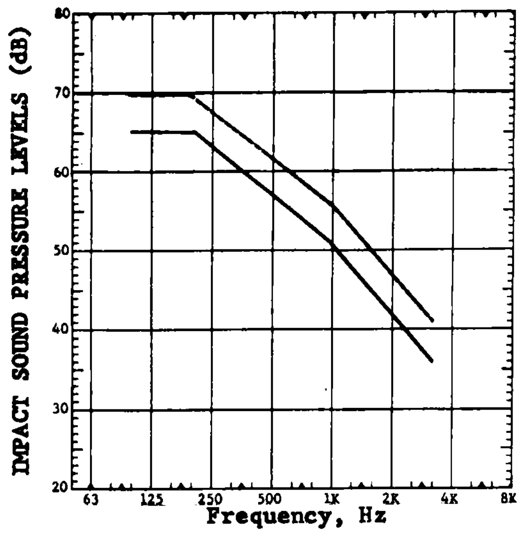


SWEDEN

——Grade I
——Grade II
- — -Grade III

Figure 9.19

Grading Contours

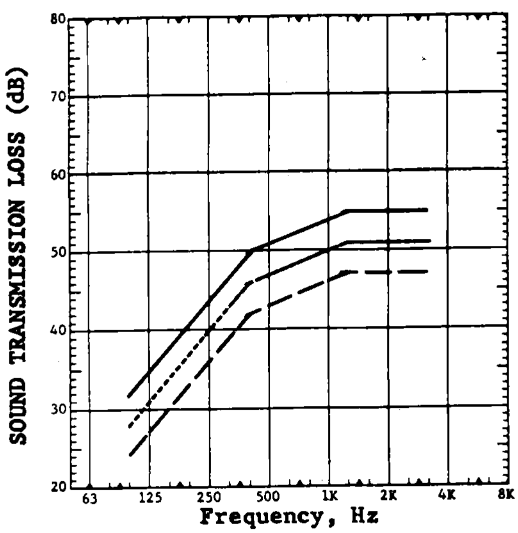


SWEDEN

——Grade I
——Grade II

Figure 9.20

Reference Contours

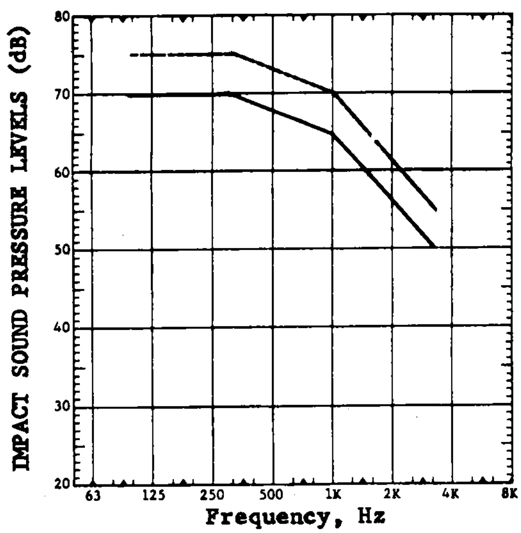


U.S.S.R.

——Standard Curve I
-------Standard Curve II
— —Standard Curve III

Figure 9.21

Reference Contours



U.S.S.R.

——Standard Curve IV
------Standard Curve V

GRAPHIC SUMMARY OF FOREIGN CODES

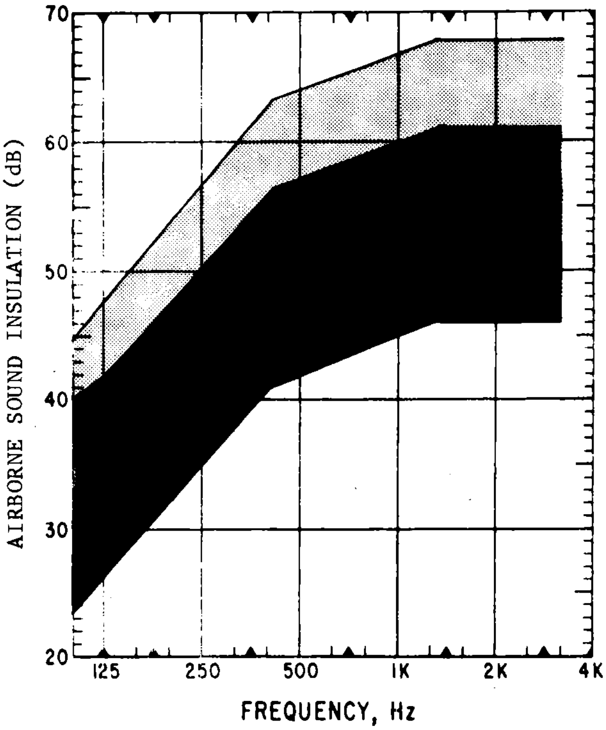


Fig. 9.22. AIRBORNE

Range of minimum airborne sound insulation requirements or recommendations.

Suggested range of values for particular cases where better airborne sound insulation is required.

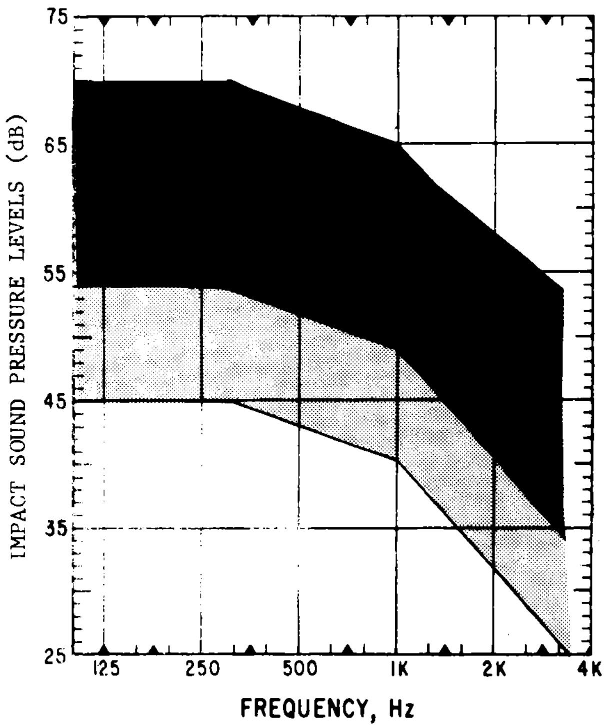


Fig. 9.23. IMPACT

Range of minimum impact sound insulation requirements or recommendations.

Suggested range of values for particular cases where better impact sound insulation is required.

4.2 AIR CLEANING AND ODOR CONTROL

4.2.0 Executive Summary

Because of the state of development of air-cleaning for residential structures and for large buildings where the cleaning is accomplished by mechanical and electrostatic filters, existing specifications do not give assurance that the air will be sufficiently clean. The filters are usually placed in air streams that represent only a part of the air in the building and the particulate matter in the remaining air never experiences filtering. These specifications are not performance specifications in the truest sense; since performance specifications, if fulfilled, would give assurance that the occupants of the building would be subjected to clean air for the promotion of well-being and good health.

They are performance-based, however, in that they measure the amount of particulate matter the filters remove from an air stream. They include minimum limits of weight of particulate matter and of arrestance (loosely defined as efficiency), which is measured indirectly. One can describe these limits as performance criteria.

Examples of these specifications are discussed later in section 4.2.2 of this report. Two specifications which are used extensively by industry and the government are:

1) General Services Administration Standard Air Conditioning Specification published in December of 1964.

2) MIL-F-16552B (Ships), February, 1964.

Both of these documents require that testing be done at the National Bureau of Standards.

Another example is the Standard now being prepared by the American Society of Heating, Refrigerating and Air Conditioning Engineers. This Standard does not require that the testing be done at NBS, but can be done by a qualified independent testing laboratory.

There are other factors besides filtering involved in obtaining clean air. These factors include ventilation, exhaust of air, the number of occupants in a building and the nature of their activities, and the number of cracks and openings in a building which supply fresh air. There are no standards or code requirements for limiting the number of cracks or amount of air leakage in a building. But there are requirements in specifications, standards, and codes which assure adequate performance of single systems such as ventilating systems, exhaust hoods over stoves, exhaust fans in bathrooms, and limitations on the number of occupants in a house. The most important of these are listed in section 4.4.2 of this report.

What is eventually needed is a requirement that limits the particulate matter in the air as well as development of a device which will better clean the air than do present methods. Although the requirement for limiting the particulate matter could be resolved with some research and study of clean-room specifications or possibly by the use of mountain air for a reference, basic new methods for cleaning the air do not appear to be possible in the foreseeable future.

Meanwhile it seems judicious to direct research toward establishing a Standard that limits the particulate matter in the air, and paralleling this effort, to determine the best means for determining the relation between filter methods, ventilation, and occupancy of a dwelling. Quantitative data would be valuable. Control of odor should be considered in this program also.

The control of odor is accomplished now by means of activated charcoal. The operation works well. Yet there may be other methods for reducing odor to an acceptable level which are less expensive and more efficient. Until better methods are obtained, it is recommended that research efforts be directed towards preparation of a performance specification which assures operation of the banks of charcoal filters usually used in buildings. As it stands now, there are only performance specifications for the activated charcoal itself -- Specification MIL 1706B is an example.

Meanwhile research should be started for finding a reliable method of determining whether the air in a dwelling meets performance requirements relating to user needs of health and comfort. The scentometer described later may suffice as a method for odor measurement.

4.2.1 Rationale for Using Performance Requirements

The purpose of air cleaning and odor control is to maintain a clean atmosphere in a living space where occupants live, eat, and sleep. A clean atmosphere is needed to promote a feeling of well being of the occupants, but more than that it aids in maintaining the good health of the individual and adds to the economy in the upkeep of the buildings and furnishings by minimizing the deposit of dirt from outside air and from within the heating system.

The air cleaners used should remove undesirable particulate matter, odors and other harmful pollutants which might be mixed with the intake air or with the air used for transfer ring heat in a heating or cooling system. Air cleaning can be accomplished in a number of ways, in combination or independently. Air filtering is one of the most common ways, another is ventilation. Both of these can be employed with odor absorption devices. Present techniques involve a judicious balance of the different methods, such balance depending a great deal on the size of the buildings, on the level of the occupancy, on the method of construction, and on the economics of the heating and cooling systems.

Health is one important consideration in the need for air cleanliness. There are a number of debilitating yet relatively mild diseases that are known to be related to breathing of air that is not pure. Asthma and other allergy-type diseases such as hay fever are examples. Bronchitis is another. Air cleaners in the return air system of a heating or air-conditioning system are not properly located to remove the major part of the dust present in a house. A filter in the furnace duct only filters out particles from the air that passes through the furnace. The primary effect of this filter, contrary to popular opinion, is to keep heat exchangers or other heating elements clean so they function at maximum efficiency. If a central cooling system is used, an important function of the filter is to keep the coils clean for optimum efficiency. A window air-conditioner is more strategically located than a central system, with respect to the source of dust, but the filters on these devices are of very low efficiency except in the removal of lint.

The other important function of a filter is to remove the dust from the air in the occupied space. The problem of air cleanliness is also aggravated by the fact that in houses today there are air-leaks through the cracks around the doors and windows, below the eaves into the attic space, and through other channels depending on the construction of the house. Modern houses experience air change rates ranging from about one-half air change per hour to two and one-half air changes per hour. Another performance objective for air cleaners is a reduction in house cleaning. Only a small fraction (on the order of 10%) of the dust generated in an occupied space passes into the return air system, and thence to the filter in a central heating or air-conditioning system. Thus most of the dust and other particulate matter in a house is either removed by the cleaning operations of the occupant, by passing out of the house through doors, windows and cracks, or it remains in the house and moves from one place to another by air currents, traffic, etc. Improved cleaning of the air in the occupied space would result in less deterioration of furnishings, less frequent redecoration, and in many cases a lower odor level. All of these considerations for the need of clean air are economically important as well as important to the health of the user.

The same problems which exist for residences in obtaining clean air exist to some extent in obtaining clean air for large buildings. However, in large buildings the amount of fresh air is not dependent nearly as much upon the air that leaks through the cracks of the building. Fresh air is often supplied by duct work from the outside in controlled amounts. Consequently, air cleaning devices can be placed into the inlet ductwork and will filter both the outdoor air and recirculated air.

Clearly, new approaches to air cleaning in residences should be considered. Air cleaners for each room, if strategically located, could remove a much higher percentage of the total dust load. If random air leakage could be essentially eliminated by supplying fresh air through a blower and duct system, both air cleanliness and humidity level could be kept under better control.

In such case, odor control devices and devices for removing particulate matter can be placed at the inlet for the outdoor air. Of course, adequate means for exhaust should be provided. The use of this latter method also entails economic advantages. With the inlet air under control, the amount of fresh air can be better matched to the needs of the occupant instead of supplying him with an overabundance of fresh air which probably occurs when there is an unnecessarily high infiltration rate.

There is little reference in the literature giving technical information on limits of cleanliness in living quarters related to human capabilities, resistance to disease, or comfort. It would require a long-range effort, therefore, to establish a performance type of specification based directly on user needs. It should be entirely feasible, nevertheless, to establish a performance test procedure for particulate matter in a room using an adaptation of the National Bureau of Standards Dust Spot Method for testing air filters. In this method the air in a room to be tested for cleanliness is drawn by means of a vacuum pump through a filter paper held firmly in a special adapter. A dust spot, the size of a dime, forms on the upstream side of the filter paper, the opacity and darkness of the spot giving a measure of the amount of particulate matter in the room where the test is being performed. The opacity can be read with relatively simple instrumentation using photometric techniques. There are devices on the market which produce these dust spots on a moving paper tape. Such devices can be left in a space for relatively long periods of time without attendance by a technician, and the opacity determined at a later date. They also lend themselves to automatic data acquisition techniques.

Limits, by necessity, would be related only roughly to human requirements and would be somewhat arbitrary. An opacity limit could be that which would obtain in a clean atmosphere such as might occur in the Colorado mountains in the open on a clear day, a condition which is known to be healthful. Or the opacity limit could be set at a value intermediate between the mountain environment and the observed levels in the center of a large city.

It appears that there is no well-developed instrumentation available for testing odoriferous air, nor are there limits. One device, the scentometer, however, which is described later, offers some possibility for determining odor acceptability by a single observer. ASTM publishes a standard, "Standard Method of Measurement of Odor in Atmospheres," designation D1391-57, but this employs the complicated technique of a panel of sniffers. It appears to be unsuitable for a performance test.

4.2.2 Generalized Performance Requirements

1) The air-cleaner units shall be readily maintained.
2) The units shall be amenable to renewal or replacement.

3) The cleaners shall be easy to install.

4) All parts shall be free of chemicals which are toxic or lethal to the occupants of the building when the intake air is drawn through them.

5) Regardless of whether the air-cleaners are for single dwellings or for multi-family dwellings, they shall be capable of removing odors. Odors can emanate from neighbors dwellings, or even more probably from industrial processes which so often take place in low income neighborhoods.

6) Air cleaners shall be capable of preventing smudging or any soiling from contaminated air on ceilings, walls and floors.

7) The devices employed shall be free of hazard from fire, electrical mishaps, or mechanical danger.

8) The devices shall be sturdy and resistant to hard usage.

9) Cleaners shall not be offensive to the dwelling occupants from the point of noise.

10) Cleaners shall be capable of removing offensive odors from the living spaces.

11) All requirements apply for both heating and cooling of the dwelling place.

4.2.3 Additional Performance Requirements for Currently-Used Types of Air Cleaners

1) Presently-used air cleaners can be divided principally into the following three categories:

a. Mechanical Types
b. Electrostatic Types
c. Odor-adsorption Devices

Often in present day contracts, mechanical types required in FHA Minimum Property Standards require that all supply air should be filtered to remove dust.

2) A brief description of each type and some of the applicable specifications, performance or otherwise, are presented below:

a. Description of Mechanical Type Filters

This category includes principally:

(a) Filters that employ a dry media (without oil) for trapping the particulate matter in the air that passes through the filter. A panel filter with a fiber-glass media that can be placed in the air-intake to a heating or cooling system, and which can be thrown away, is an example. This category also includes filters of extended surface media of pleated or deep-folded configuration which because of the large media area, arrests more particulate material than does a filter with media of normal area. This general type of filter is known as a Class C filter by the General Services Administration of the U. S. Government, an agency which buys many filters for U. S. Government Buildings. When a manufacturer proposes the use of a filter type, it must be tested at the National Bureau of Standards by the G.S.A. Standard Air Conditioning Specification published in December, 1964. The tests to be made at NBS and the requirements are given in this document.

There are no Federal Specifications (with an F-F designation) for this type of filter.

(b) Another mechanical type which is of importance and which might be useful in low-cost housing, is the automatic-renewable media type in which a roll of media is unwound across the air stream by a mechanism controlled by a timer or a differential pressure control. This timer or control activates the device so that the used or soiled media is moved up and a new, clean section of media is exposed to the air stream. The media on this type of filter is covered with a thin layer of oily-like substance to entrap the particles as they impinge on this media. Test requirements for this type of filter are given in the 1964 G.S.A. Document.

(c) Still another mechanical type is the viscous impingement type, a panel filter made of a metallic or plastic meshwork which also is covered with the oily-like substance. It is a cleanable filter that can be used over and over a number of times. It is sturdy and might be highly suitable for low cost housing. Federal Specification F-F310 includes some performance requirements for this filter. The 1964 G.S.A. publication references this filter as type D, and requires use of the Federal Specification for testing. Testing is to be done at NBS. The Armed Forces uses large quantities of these filters and there is a specification MIL-F-16552B (Ships), February, 1964.

b. Electrostatic Type of Air Cleaners

(a) This type of cleaner, known sometimes as Electronic Air Cleaner type, requires a high d-c potential. Typically about 10,000 volts is used to create an ionizing field so that the particles are charged. The device has plates which are charged positively and negatively and when the stream of air which is to be cleaned passes through them, the ionized particles are attracted. These plates accumulate particulate matter and must be cleaned frequently. To minimize such cleaning the device often employs a pre-filter with a media of some kind to arrest some of the particulate matter before it gets to the charged plates.

Federal Specification, F-F 320, Filter, Air, Electrostatic Precipitator covers this type of air cleaner. It includes performance tests based on the use of the National Bureau of Standards Dust Spot Test Method.

These cleaners are designated as Type B filters in the 1964 G.S.A. specification. The device, according to the document, must conform to the requirements of Federal Specification F-F320.

c. Description of Odor Adsorption Filters

(a) The odor adsorption device usually employs activated carbon (charcoal) to adsorb the odorous and offending vapors or particles. The activated carbon after a period of use can be removed and reactivated so the device is about as efficient as when it was first installed. Most manufacturers of the filters offer various plans for replacing the charcoal or exchanging the equipment during its service period.

A search of the literature and discussions with engineers has revealed that a scentometer is the only instrument available which gives any reliable quantitative information on odor level in a living space. The instrument requires the use of the nose. The method essentially makes an odor comparison with clean air as a reference. The clean air is obtained by filtering it through charcoal. The observer makes the comparison by sniffing methods and judges an odor level. The device is sophisticated enough to be useful with one observer, but it gives better results if a panel of sniffers is used. Preliminary evidence indicates that it will be useful for quantitative measuring of odors generated in low-cost housing.

Discussions with engineers have led to the conclusion that odor level can be kept to an acceptable minimum by ventilation if the outdoor air is sufficiently pure. However, if a building is small and has a high occupancy level it is often more economical to provide an odor absorption device than to circulate large amounts of outdoor air which may require heating or cooling. For an example, office buildings sometimes keep their expenses down by using low ventilation rates and employing activated charcoal. The Electric Power and Light Company buildings in Los Angeles are an example. In this building, heat is obtained only from the lights in the building and other natural heat sources. Another example is the O'Hare Airport in Chicago.

There are no Federal specifications for the assembled charcoal filters. As a result, purchases are made by catalog number and the reputation of the company. One company advised that they use MIL specification 17065B for the test methods in accepting activated charcoal from their own production line. But they do not use the acceptance limits of this specification because they are too rigid. The test method uses the gas chloropicrin for a reference odor. The use of this gas has given satisfactory and reproducible results and it is possible that this test method or use of the scentometer can be used for compliance to performance requirements in low-cost housing.

Charcoal filters in toilet or water closet areas are used frequently in buildings and by the Navy in ships and submarines. The International Conference of Building Officials, 50 S. Robles Ave., Pasadena, California, approves or disapproves of the use of filters submitted to them by manufacturers. Their method for giving acceptance is not known. MIL Specification F-15919C (Ships) Amendment 2, 12 April 1967, covers the requirements of activated carbon filters for submarine use for the Bureau of Ships, Department of the Navy.

4.2.4 Additional Standards and References

The Air Filter Institute has in the past developed test methods and requirements that are different from those developed by NBS. Recently, however, through activities of the Standards Committee of ASHRAE, a new standard was developed which describes an apparatus and test methods incorporating the best features of both methods. The Standard has not been finally approved but it is estimated that final approval and its adoption as an ASHRAE Standard will come within the next six months. It will include test methods and requirements applicable to the mechanical and electrostatic types of filters previously described.

The ASHRAE Handbook includes much valuable information about air cleaners.

4.2.5 Exhaust Fans and Ventilation

1) Exhaust fans contribute significantly to the removal of odors or particulate matter generated at specific locations in a house, such as kitchen and bathrooms. Used hand-in-hand with air filters and odor adsorption devices they serve as a significant component in the ventilating-air cleaning system.

Exhaust fan performance is spelled out indirectly as exhaust ventilation requirements in FHA Minimum Property Standards as indicated by the following table:

EXHAUST VENTILATION REQUIREMENTS
IN FHA MINIMUM PROPERTY STANDARDS

FOR ONE AND TWO SERVING UNITS		FOR MULTIFAMILY HOUSING	
Room or Space	No. of Air Changes per Hr	Room or Space	No. of Air Changes per Hr
Kitchen	15	Kitchen	8
Bathroom	8	Bathroom	8
	----	Public Corridors	2

FHA requires that ventilation equipment shall comply with, and be tested and rated in accordance with, the applicable Standards of the Air Moving and Air Conditioning Association (AMCA) or the Home Ventilating Institute (HVI).

2) A good reference on Ventilation Criteria follows:

"Performance Criteria, Heating, Ventilating and Cooling for Buildings of the State University of New York," prepared by Research Department, School of Architecture, Pratt Institute, Brooklyn, New York.

Such factors as health, comfort, glass area, air conditioning, recommended air changes in cu. ft. per person under various conditions are discussed.

4.2.6 Summary of Important Standards, Specifications, and Papers Related to Air Cleaning

The Standards and Specifications metioned in the foregoing paragraphs together with papers or other valuable information which might help in the design of low-cost housing are listed as follows:

1) Mechanical Types of Air Filters

   a. Dry media, panel type

      G.S.A. Standard Air Conditioning Specification (1964) which includes a section on air filters.

   b. Automatic renewable type

      Ibid

   c. Metallic or plastic viscous impingement type

      Ibid
      Federal Specification FF-310
      MIL-F-16552B

2) Electrostatic Type of Air Filters

   a. G.S.A. Standard Air Conditioning Specification (1964) which includes a section on air filters.

   b. Federal Specification F-F 320 includes performance tests based on the use of NBS Dust Spot Method.

3) Odor Adsorption Type Filters

   a. MIL Specification 17065B gives usable test methods for accepting activated charcoal before being assembled into the filter.

   b. MIL Specification F-15919C (Ships) Covers the requirements of activated carbon filter for use in toilet or water closet areas in submarines.

   c. "ASTM Standard Method for Measurement of Odors in Atmospheres." This standard requires the use of a panel of sniffers.

Pertinent papers and reports on the odor control are listed below:

   a. Odor Determination Techniques for Air Pollution Control

      Chas. W. Gruber, George Jutze and Norman A. Huey (Bureau of Air Pollution Control and Heating Inspection, Cincinnati, Ohio) J. Air Pollution Control Association 10:327-330 (1960). This paper deals with odor evaluation and discusses the scentometer.

b. Process Applications of Activated Carbon

Harold H. Todd, Jr. (Connor Engineering) Air Eng. 4 (8), 26-27, 44 (1962). The paper states that O_2 and CO_2 requirements are generally met with an outdoor ventilation rate of less than 4 cfm/person. Cities that have allowed for recirculatory systems in their municipal building codes are Chicago and St. Louis (85 and 95 percent recirculated air, respectively).

Indiana, Wisconsin and Maryland are studying their codes with respect to activated carbon.

c. Odor Control in Air Conditioned Spaces

Warren Viessman (Air Research and Development Command Andrews Air Force Base) Ind. Refrig. 16, 17, 20, 24 (Aug 60). The author reviews the sources, evaluation methods, and methods for removing odors encountered in air conditioned spaces. Some information is given on the effect of tobacco smoke in the space on humans, and the effect of CO_2 on lung action.

d. Odor and Its Measurement

Elmer R. Kaiser (New York University) Air Pollution, ec. by A. C. Stern, Vol. I, Chapter 15, Academic Press (New York and London) (1962). The author describes methods for measuring and controlling odors. The use of the scentometer is described.

e. Odor Control with Activated Carbon

Norman R. Rowe (Barneby Chaney Co., Columbus, Ohio) J. Air Pollution Control Association 13 (4), 150-3 (1963). Examples of the use of activated carbon in buildings, airports, and render plants is given. Effectiveness of the charcoal is described.

f. Methods of Air Deodorization

W. Summer, Observer Publishing Co., New York (1963). This book offers an excellent coverage of the current knowledge of odors.

g. Odor Abstracts - published Quarterly from 1962 to 1967 by the American Society of Refrigerating, Heating and Air Conditioning Engineers, and subsequently by the Barneby and Cheney Co., North Cassidy at Eighth Ave.,Columbus, Ohio 43219.

h. Air Pollution Manual Part II, Control Equipment

Published by American Industrial Hygiene Association. Includes a good chapter on adsorption of gases.

4) Exhaust Fans and Ventilation

a. FHA Minimum Property Standards for One and Two Serving Units.
b. FHA Minimum Property Standards for Multi-family Housing.
c. Standards for testing and rating of ventilation equipment of the Air Moving and Air Conditioning Association(AMCA).
d. Standards for testing and rating of ventilating equipment of the Home Ventilating Institute (HVI).

Pertinent papers and reports on the testing and evaluation of exhaust fans or hoods or ventilation requirements are listed below:

a. Design criteria for Kitchen Exhaust Hoods

C. B. Rowe (Research Products Corp.) Air Eng. 4 (3), 50-2 (1962). The author gives specific and detailed recommendation for design of commercial kitchen exhaust hoods.

b. Final Report to the United States Housing Administration on Kitchen Range Hood Evaluation

A detailed report giving methods of testing and results for tests on kitchen hoods.

c. State and Municipal Codes

Almost all codes spell out the ventilation rates required in buildings. These rates are dictated principally by safety considerations rather than by performance. Examples are the New York State Building Code and the California State Building Code.

d. Performance Criteria, Heating, Ventilating and Cooling for Buildings of the State University of New York. Prepared by the Research Department, School of Architecture, Pratt Institute. Brooklyn. N.Y.

4.2.7 Possible Projects Relating to Air Cleaning

1) Evaluate existing information showing the relationship between air cleanliness and respiratory problems of asthma, hay-fever, bronchitis, etc.
2) Develop a test apparatus and procedure for evaluating the air purity in the occupied spaces of residental structures.

3) Study the relationship between air purity and the soiling rate of room surfaces, furnishings, etc.

4) Study the technical and economic feasibility of reducing random air leakage in dwellings sufficiently to allow small pressurization of occupied space and permit control of air leakage, air cleanliness, odor, humidity, etc.

5) Develop user needs and performance requirements for air cleaning and odor control systems in residential structures.

6) Conduct research to develop performance requirements for ventilation in kitchens and bathrooms, taking into account odor, moisture, particulates, vapors, temperature, and soiling.

7) Conduct laboratory and field research on the interrelationship of outdoor air purity and indoor air quality and the effectiveness of various air cleaning techniques, by type, on the air cleanliness in the occupied spaces of dwellings.

8) Develop one or more representative test dusts and suitable testing techniques that can be used to realistically relate the performance of air cleaning systems in the laboratory and in residential use.

4.3 THE THERMAL ENVIRONMENT IN BUILDINGS

4.3.0 Executive Summary

Thermal Performance Requirements of Building Codes

The ASHRAE Thermal Comfort Standard 55-66 is almost the sole source that has been found that gives recommendations for thermal conditions for comfort based on extensive testing and with intent to provide uniform standards. Nevertheless, a number of building codes give requirements for temperatures to be maintained in buildings in winter. An assessment of how these requirements in several such documents compare with those of the ASHRAE Standard 55-66 may be of interest.

Indoor Temperature Requirements of Some Building Codes

	Air Temp. F	Season	Max. U-value, Btu/hr ft^2 deg F
ASHRAE Standard 55-66	73 - 77*	w, s	0.1 to 0.15**
New York State Building Code, 1964	≮ 70	w	No. max.
New York City Building Code, 1967	≮ 70	w	" "
First California Commission on School Construction System (SCSD)	≮ 73	w	" "
	≮ 75	s	" "
	or ≮ (0 ΔT-20deg)	s	" "
Canadian Building Code, Residential Standards, Suppl. No. 5 (1967)	≮ 72	w	0.15 to 0.08
British Building Regulations, 1965	(None)	w	0.30
Building Standards (Scotland) Regulations, 1963	(None)	w	0.42 average

* "Adiabatic condition temperature", i.e., air dry bulb and occupied space (MRT) temperatures are equal (see 4.3.2.1)

** In effect, due to MRT restrictions. (See 4.3.2.1, tables T.1 to T.3)

To make efficient comparison possible, it is necessary to appreciate that Standard 55-66 restricts not only the air dry bulb temperature, but also the concomitant mean radiant temperature (MRT) in the occupied space, which is tantamount to a restriction on the average U-value of the exterior walls. The U-values estimated here as corresponding to Standard 55-66 conditions are based on 0 °F outdoor temperature.

Only the Canadian Building Code contains requirements that in effect govern both dry bulb temperature and MRT, the latter being accomplished by its requirements on maximum U-values. The Canadian requirements are less stringent than those of Standard 55-66, but they approach the lower range of the latter--to a degree estimated roughly as comparable to an ASHRAE "adiabatic condition temperature" of about 69 F.

The California SCSD requirements also make a near approach to Standard 55-66 in respect to winter conditions, considering the relatively mild winter climate of California, but no estimate can be made because there is no limitation on U-value.

Pivotal Opportunities for Research

The sections of this report in Part 4.3 develop needs and possibilities for advances in regard to a satisfactory thermal environment in buildings.

Of the three advances discussed in Part 4.3, the one of greatest potential is that of a computer capability for calculation of cyclical characteristics of walls (section 4.3.3.4). The reasons for this are that answers difficult for intuitive analysis and response can be provided on fairly rigorous grounds by computer methods, almost without limit, and that a building-designer's decisions, which rest ultimately on economic costs, cannot be wisely taken without energy-usage and cost figures which depend on realistic evaluation of building-zone heat exchanges with the outdoors, within the constraints imposed by provision of a satisfactory thermal environment.

The development of an apparatus suitable for determining the cyclical thermal characteristics of complex walls, or of complex components of wall constructions (section 4.3.3.3.2), is essential for many, now-not-available inputs required in applications of a computer calculation program. It is the most time-consuming of all the advances proposed, simply for its development; conducting tests and acquiring needed data will take even longer. For this reason, immediate activity in this direction is recommended. Emphasis is added because of the present tendencies toward light-weight exterior wall and interior partition designs which militate against interior temperature stability.

The importance of exploratory development and trial of the method proposed for evaluating the thermal response index of existing buildings, and types of building construction (section 4.3.3.5), is believed to warrant immediate action. A computer program can evaluate a proposed building design, in terms of its blue-printed details, but the proof must depend upon actual performance of the building as it was constructed. In a fundamental way, an evaluative test of the kind proposed is the only basis on which a thermal performance specification can be realistically established and used.

The ASHRAE Thermal Comfort Conditions Standard 55-66 provides a much-needed basis for assessing or establishing environmental conditions that are thermally comfortable or acceptable to most normally clothed people. The concept here termed "adiabatic condition temperature" is a convenient way to express a variety of thermal conditions of differing dry bulb and mean radiant temperatures in an occupied space, all of which presumably yield approximately equal feelings of thermal comfort. The accuracy of their equivalence depends, however, on the correctness of the factor for compensating for departures of MRT from dry bulb temperature. In Standard 55-66, it is considered that if MRT is one degree less than an adiabatic condition temperature, a dry bulb temperature 1.4 deg higher than the adiabatic condition temperature will produce a comfort condition equivalent to that of the adiabatic condition temperature, and vice-versa. In view of the importance, and utility of being able to express the equivalence of various conditions, it is believed that specific confirmation of the compensation factor 1.4, or its improvement, should be sought as soon as possible.

Research on thermal comfort conditions under asymmetrical conditions is also needed. The thermal environment in a room is directional with respect to radiant conditions and involves air temperature gradients both horizontally and vertically under actual operating conditions. There are no standards or specifications describing acceptable comfort under such conditions and only a limited amount of research has been done on these subjects. It is known that a human being does respond to the directional mean radiant temperature gradients surrounding his body. Thus a study of human comfort under realistic conditions of exposure to non-uniform thermal environment is essential as a basis for performance requirements related to the degree of thermal insulation of exterior walls and the permissible air temperature gradients in dwellings.

4.3.1 User Needs

From the viewpoint of the occupant of a building, his needs in respect to the thermal environment are

1 - Reasonably uniform, controlled, air temperature in the occupied space.

2 - Reasonably uniform mean radiant temperature (MRT) in all occupied space.

3 - Reasonable limits of relative humidity in the occupied space.

4 - Avoidance of extreme drafts or air motion.

5 - Ability of the occupant to modify 1, 2 and 3 to taste.

User needs expressed in these terms cannot be controverted, chiefly because of the fifth item: that the occupant be able to modify the thermal conditions to taste. The owner of a single dwelling can do this, within the limits of his purse. In multi-family housing, it can be done only if the installed heating or cooling plant and appliances are capable of satisfying the demands that might be made, which in the absence of a priori information would require probable overdesign of the plant and appliances.

4.3.2 Standards for Thermal Environment

4.3.2.1 ASHRAE Standard 55-66

A description of environmental conditions for thermal comfort indoors, as based on the current state of knowledge, is given by ASHRAE Standard 55-66, Thermal Comfort Conditions, a copy of which is attached. The purpose of the standard is to specify desirable and generally acceptable thermal environmental conditions for comfort of sedentary and slightly active, healthy and normally clothed people in the United States and Canada.

It defines an occupied zone as the region within a space from 3 in. to 72 in. above the floor and more than 2 ft from walls or fixed air conditioning equipment. The standard sets ranges of dry-bulb temperature, relative humidity, mean radiant temperature (MRT), and air motion, to be maintained within the occupied zone, and sets limits for the time-rates of change of the first three.

In effect, the standard states that acceptable comfort is provided by conditions in the range from 73 F dry-bulb, with a concomitant 73 F MRT, to 77 F dry-bulb and concomitant 77 F MRT. It is evident that the second condition is warmer than the first, probably perceptibly, but it is considered that both, and intermediate, conditions are acceptably comfortable to most people.

A condition in which the dry-bulb temperature and MRT are equal can be referred to as an adiabatic condition, since it can be obtained only in a room in which the net heat exchange through its boundaries is zero. In an actual room exposed to an exterior differing temperature, there will be a net heat exchange, and the dry-bulb temperature and MRT must differ. For this reason, the standard provides for compensation of a lower MRT by raising the dry bulb temperature, and vice-versa. The limits of compensation are indicated in table T.1.

T.1 Values of compensating dry-bulb temperature, °F:

Adiabatic condition temp.:	73	75	77
MRT			
70	77.2	82.0	86.8
73	73.0	77.8	82.6
75	70.2	75.0	79.8
77	67.4	72.2	77.0
80	63.2	68.0	72.8

What are the building characteristics that are required to satisfy these comfort conditions? Assuming that for a person within the occupied zone, but only 2 ft from an exterior wall, the comfort condition is dominated by radiant heat exchange with that wall, it is possible to calculate the max. U-value allowable for the wall, for 0 F outdoor temperature, as follows:

T.2 Max. U-value of wall, Btu/hr ft^2 deg F: (Winter, 0 F)

Adiabatic condition temp.:	73	75	77
MRT			
70	0.15	0.24	0.32
73	0	.10	.19
75	< 0	0	.10
77	< 0	< 0	0

Excluding the values above 0.15, because of the extraordinarily high dry-bulb temperatures they require (above 82 F, see T.1.), the required U-values are less than those generally provided in buildings common today. Even these require dry-bulb temperatures above 77 F when the outdoor temperature is 0 F.

It is evident also that the ASHRAE comfort conditions cannot be satisfied (in winter) near large windows, if radiant compensation is not provided.

Similarly, maximum U-values allowable for summer comfort (95 F outdoor temperature) are shown in table T.3.

T.3 Max. U-value of wall, Btu/hr ft^2 deg F: (Summer, 95 F)

Adiabatic condition temp.:	73	75	77
MRT			
73	0	< 0	< 0
75	0.32	0	0
77	.57	.35	0
80	.87	.73	.53

Excluding the values greater than 0.56, because they require dry-bulb temperatures lower than 70 F, it is seen that U-values from 0.32 to 0.53 are possible if the dry-bulb temperature is between 70 and 73 F (see T.1). However, as tables T.3 and T.1 show, the U-values needed to allow dry-bulb temperatures between 73 and 77 F go rapidly toward zero. In short, the ASHRAE comfort conditions require quite low U-values for the building, if dry-bulb temperatures indoors are to be in the range 73 to 77 F when the outdoor temperature is 95 F.

The assumption made regarding comfort in developing Tables T.2 and T.3, if valid. leads to the conclusion that buildings must have U-values considerably lower than those in common use now, to meet the thermal comfort conditions set forth in ASHRAE Standard 55-66.

4.3.2.2 FHA Minimum Property Standards

Requirements for the insulation of buildings to restrict heat loss are given in FHA Minimum Property Standards for Multi-Family Housing (MPS 714.3, 1965). An evaluation of the impact of these requirements in promoting improved insulation of buildings was made in National Bureau of Standards Report 9817, Performance Criteria for Exterior Wall Systems, rendered to the Federal Housing Administration. It was concluded (page 69) "that the steady-state wall heat loss limitation of 30 Btu/hr per sq ft of building floor area is not low enough, since it hardly requires addition of insulation in exterior walls even in cold areas of the country, although such insulation can be most readily and satisfactorily installed when the building is built, at a minimum cost which is soon returned to the home-owner by fuel savings. In addition, a more stringent limitation is needed to avoid appreciably uncomfortable radiation to cold exterior wall surfaces".

Similarly, MPS 714.5, giving requirements for the insulation of living units for cooling, was examined. It was concluded (page 69) "that the maximum heat gain requirement of MPS 714.5 does not limit the U-value (of an exterior wall) even as much as does the winter maximum heat loss requirement." It was suggested (page 70) "that for exterior wall systems, consideration should be given to a suitable insulation requirement aimed at better insulation for fuel savings and comfort in cold areas, and for air conditioning needs and comfort in less severe, and warm climates."

The earlier discussion suggests that the FHA Minimum Property Standards may not require insulation of buildings to nearly the extent that is required to meet the ASHRAE Thermal Comfort Condition Standard.

4.3.3 Thermal Characteristics of Buildings

4.3.3.1 Introduction

Buildings are exposed to cyclically-changing exterior temperature conditions, due to daily air temperature variations and solar heating, and to seasonal weather extremes. As a result, over a period of a few days or so, a building is subject to heat exchanges that can be divided into two different categories. One category covers the steady-state effect, and comprises the heat transferred by means of a steady temperature difference between the mean temperature of the outdoor weather cycle, and the mean temperature indoors during the time period. The second category covers the heat transferred by means of the time-varying temperature fluctuations occurring during weather cycles, and according to the nature of the weather cycle this category can be termed the transient or cyclical effect. The sum of the steady-state effect and the cyclical effect will give the total heat transferred at a specific time.

The steady-state effect is the best understood method of heat transfer and is presently used for estimating the heat transfer characteristics of exterior walls because only the thermal resistance effect of a wall needs to be determined either by computation or by testing. This characteristic (known as the U-value) is of major importance, because it is the fundamental characteristic that determines the seasonal heat loss or gain of a wall. It is also the predominating characteristic that determines the average temperature difference between the indoor air and the indoor wall surface, which in turn controls the MRT of the occupied zone for a given dry-bulb temperature.

On the other hand, the cyclical effect has not been given widespread practical application in the past. Several reasons may be advanced for this, namely: the mathematical solutions which include these effects are quite complicated, usually requiring a digital computer to obtain numerical results; representative weather cycles are not well-defined or generally available for given localities, seasons, etc.; the thermal diffusivities of the components of an exterior wall must be known, and such data are not available for many non-homogeneous components.

The cyclical effect is dependent on both the thermal resistance and the heat capacity of the components of a wall, and more than that, on their relative distributions in the wall. There are two important consequences stemming from the cyclical thermal characteristics of a wall. They control the magnitude of interior surface temperature variations as a result of outdoor temperature cyclical fluctuations; they also control the time-lag between a change of exterior temperature and the arrival of its attenuated effect at the indoor surface. The greater the heat capacity of a wall of a given U-value, the greater is the degree of attenuation at the interior surface of an exterior temperature change, and the greater the time-lag.

4.3.3.2 Illustration of Cyclical Thermal Characteristics of Walls

The practical importance of the cyclical thermal characteristics of a wall is illustrated by comparing two walls having the same low U-value (the steady-state characteristic), but differing considerably in thickness and heat capacity. The walls might be, for example, a sandwich panel three inches thick, and an 8 in. brick wall with two inches of thermal insulation, both having a U-value of about 0.1 Btu/hr ft^2 deg F. Assuming that the interior of the building, and the contents of the room, represent a heat capacity equivalent to about 5 lb of water per sq ft of exterior wall area (a conservatively low value), the total daily cyclical change of interior wall surface, and room air, temperature, in February weather in Bismarck, North Dakota, would be about 4.4 deg F for the panel wall, and 1.3 deg F for the brick wall. These daily fluctuations would be superimposed on the steady-state air to wall temperature difference of about 3.6 deg F. In view of the importance of MRT in affecting thermal comfort, as indicated in the ASHRAE Standard for comfort conditions, this difference between the two walls could be critical.

There is another aspect of the cyclical characteristics that warrants attention - namely, the time-lag. For the two walls described, the time-lags for cooling are about 3 hr and 8 hr, respectively, so that the panel wall reaches its minimum interior temperature at about 8 AM, and the brick wall at 1 PM (assuming the walls face south-east). Similarly, for heating, the time lags are 5 hr and 13 hr, respectively, so that the maximum temperatures are reached at 3 PM and 11 PM, respectively. The distribution in time of the minimum and maximum temperatures in doors can have additional importance. The cases discussed were for the walls without windows. Had the walls both had windows representing 15 percent of the wall area, exposed to solar radiation at the same times as the walls, the instantaneous solar heat gain through the windows, which in February would reach its maximum at 10 AM, would have been augmented 7 hours later by the maximum heat gain through the panel wall, and 10 hours later in the case of the brick wall. This difference between the walls could be critical as regards the comfort conditions indoors, and also could materially affect the size of cooling plant needed for the room in summer.

The comparison above of two walls is based on the results of an analytical calculation of the thermal performance of the walls, given the stated interior building heat capacity, and using weather data for Bismarck, North Dakota, taken from Weather Bureau records for a 9-day period in February. The characteristics presented are the results for the eighth day of the 9-day period. Although these results were obtained for the locality of Bismarck, the performance would have been similar for other localities in winter.

4.3.3.3 Test Methods for Determining Thermal Characteristics of Walls

4.3.3.3.1 Steady-state characteristic - U-value

Two standardized test methods are available for determining the U-value of walls. ASTM C177, Guarded Hot Plate Method, enables measurement of the thermal conductivity of the components of a wall construction, from which for relatively simple walls the U-value can be readily calculated. For more complicated walls, the U-value can be obtained by measurements by ASTM C236, Guarded Hot Box Method, provided that a representative specimen of the construction can be made to fit the dimensions of the hot box apparatus. In some instances, there is difficulty in achieving this fit, or in including the effect of edge framings of large panels.

4.3.3.3.2 Cyclical Thermal Characteristics

At present there is no well-developed test method for dynamic thermal tests of wall sections. Pulse- or step-function temperature changes have been used by investigators to evaluate dynamic thermal properties of homogeneous materials, but for complex constructions such as most building exterior walls, the appropriate data need to be ascertained under cyclical conditions of the kind to which they are exposed in service.

As mentioned in 4.3.3.4 below, it is possible to calculate the cyclical dynamic thermal response of walls composed of successive layers of homogeneous materials of known thermal properties. It is not possible to calculate with assurance if the geometry of the components is complex, or involves heat flow laterally as well as directly through the wall. Nevertheless, many types of wall constructions are of the latter kind, and a suitable test method is needed if such walls are to be evaluated for cyclical performance.

To examine the possibility of developing a suitable test method, a mathematical analysis of a multi-layer wall was developed. A report of the results of this analysis under the title "Dynamic Thermal Performance of Exterior Walls" was furnished to FHA.* The findings given in the report indicate (a) that the dynamic thermal performance of a composite wall depends sharply on the spatial distribution of thermal mass and thermal resistance in the wall; (b) that it depends also upon the time period of the cyclical outdoor weather variation, but that the diurnal 24-hour period would suffice for most purposes; (c) that for a given cyclical period, the performance of a wall can be expressed in terms of an "effective thermal conductivity" and an "effective thermal diffusivity" for a homogeneous one-material wall of equal thickness; and (d) that a test method and apparatus for making dynamic thermal performance tests of full-scale wall sections is feasible, and would serve for intercomparing one wall with another and for establishing criteria for dynamic thermal performance. It was further noted that the parameters that would be obtained from the tests could be used to calculate mathematically the thermal response at any time of the indoor side of the wall to periodic outdoor variations of conditions -- provided that as an essential input for such calculations there was available a statement of the exterior variable climatic condition appropriate for a given case as a design condition. At present, such design conditions are not available in general.

The apparatus needed would be fairly large (approximately the size of a C236 Guarded Hot Box apparatus) to enable testing full-scale prototypes of building wall sections. Nevertheless, there seems no alternative if needed cyclical data are to be obtained for many constructions, or even for certain common components of walls such as hollow-core masonry units.

* NBS Report 9817 entitled "Performance Criteria for Exterior Wall Systems."

4.3.3.4 Calculation of Cyclical Characteristics of Walls

For walls consisting of successive layers of homogeneous materials of known thermal properties, mathematical calculation of cyclical (and steady-state) thermal characteristics is feasible, using digital computers. Such computations can take into account not only the heat capacity of the wall itself, but also the effect of the heat capacity of the interior of the building and its contents, to yield the hourly heating or cooling requirements of rooms or zones of buildings.

At present, there are several computer programs for calculating the hourly heating and cooling requirements of rooms or zones of buildings. For the most part, they are based on the methodology of the ASHRAE Guide and Data Book, itself based on steady-state thermal factors with approximations to adjust for dynamic weather conditions. They do not take into account the thermal mass or heat capacity of the interior of the building, or of its contents. If a building is not maintained at a steady indoor temperature (as it can be if maximum-design heating or cooling is provided) the neglect of thermal mass can seriously affect calculated results. There is therefore an important need to develop a more rigorous method for calculations, based on dynamic thermal conditions and taking heat capacity into account. With such a method, the temperature extremes in a non-air-conditioned space, or the temperature extremes for a moderate or limited amount of air-conditioning, can be more reliably estimated, and give a better basis for decisions as to whether air-conditioning, and how much, should be provided. The question obviously depends on the climatic conditions at the site of the building, and on the building itself, and therefore can be answered in a large program for buildings only by a digital computer program which takes these conditions into account for the particular building in question.

Several concomitant steps are necessary for developing and providing the predictive capability that is needed for these purposes without loss of time:

a) Developing the mathematical machinery for calculating hourly data on energy interchanges between the exterior and interior of building spaces, and incorporating it in a digital computer program for calculations.

b) Preparing a means for introducing data describing a particular building into the computer program with minimal human effort and cost -- as for example, by use of FOSDIC (a film optical sensing device for input to a computer) developed for the Bureau of the Census.

c) Preparing, with the aid of the Weather Bureau, standard weather data tapes for computer input on the variations of weather conditions throughout the year, or in periods of extremes, for selected areas of the country.

Two further steps are desirable:

d) Conducting a trial of the predictive capability of the program, either in a selected building, or by means of laboratory tests of a prototype building. (See 4.5.3.5, below)

e) Preparing, in a form suitable for use, the developed computer program, building data input methodology, and standard weather data, with recommendations for its specific applications in analysis and design of buildings.

The computer program will provide a means for building designers to calculate, at the design stage, and on a dynamic basis that takes into account the heat capacity of the building and its contents, the indoor temperature variations to be expected, on an hourly basis, in a proposed building as a result of weather variations and indoor loads, without heating or cooling, or with prescribed heating or cooling. Thus, it will enable decisions to be made as to the need for heating or cooling, for example, and as to the amount needed, if unacceptable extremes of temperature are to be avoided in a particular building.

One feature of the computer program is that it would relate the magnitude of the variation of indoor temperature, for a proposed building space and exterior daily weather variation, to the heating or cooling input to that space, and thus afford designers flexibility in making trade-offs between them. It would also enable designers to compare realistically on a dynamic basis the performances of two alternative designs of a building, in terms of indoor temperature variations for equivalent heating or cooling input.

A further, and quite important, output to be considered is that the proposed program for calculating heating or cooling requirements for given building spaces is a prerequisite for a larger computer program for calculating energy-usage demands and operating costs for an entire building and its selected heating and cooling system. The latter program is of the kind needed for making economic analyses and comparisons of alternative buildings and systems and fuels. Nevertheless, to develop the latter program, it is essential first to have accurate data as to the heating or cooling requirements for the various spaces of a proposed building, which would be the output of the proposed computer program.

4.3.3.5 Measurement of the Dynamic Thermal Response of an Actual Building -- Response Index

The predominating importance of the building thermal characteristics -- in controlling the task to be accomplished by the systems used for heating or cooling the building and satisfying the thermal environmental needs of its occupants -- calls for, and justifies, an inquiry as to how the thermal characteristics of a building can be defined and measured.

In theory, the dynamic thermal behavior of a given building subject to the variations of weather can be predicted by means of a complex computer program. Even with a number of simplifying assumptions, however, such programs are at present expensive to develop and use, partly because of the great amount of detail needed for computer input. In addition, some uncertainty as to input data is bound to exist -- for example, as to the actual details of construction and workmanship, or as to the extent and location of air exchange between the building interior and exterior.

Nevertheless, it appears possible to evaluate the dynamic thermal performance of an existing building by relatively simple means. In brief, it calls for letting a building with its contents (but with no internal heating, cooling or energy input) "float" in response to weather changes, over a period of several days. Hourly observations would be made of the air temperature within the building or its various rooms, and of the outdoor air temperature including the effects of solar radiation at various points around the building. During a typical 24-hr. period, outdoor temperatures could be expected to vary by 20 to 40 degrees F; interior temperature variations would be moderated to some degree, depending on the thermal characteristics of the building.

One use of the data would be to calculate the standard deviation of the hourly temperatures observed in a day or in a longer period for the set of indoor temperatures, and for the corresponding set of outdoor temperatures. The ratio of the standard deviation indoors to that outdoors would be a "response index" of the dynamic thermal shielding action of the building. It obviously would include the effects of the thermal mass of the building and its contents, and be influenced by air exchange rates, and therefore by wind and stack action. Solar radiation also would play its important part.

At present, it is thought that observations should be continued for perhaps as long as a week, to assure that the building is fully "floating" on the weather. Under this condition, the mean value of the interior temperatures, and that of the outdoor temperatures, should nearly agree: i.e., the DC component would substantially vanish, and the data would involve only the AC component of the thermal response.

However, it is not essential that the building "float" with zero mean temperature difference indoors and outdoors. If the building were supplied with a constant rate of heat input throughout the period of observation, the DC component would be constant, and the AC component could be determined as before. Observation with a suitable D C component has an added advantage, since it would reproduce the effects of air infiltration and exfiltration due to normal thermal stack action, as well as those due to wind forces. Since infiltration effects may be of material importance, especially in tall buildings, and are not accurately predictable, it is fortunate that the response index can be determined with a DC component operative.

Although there are many technical problems to be worked out in applying the proposed measurements, at this stage their solution appears feasible. It is more important, at the moment, to consider the potential uses and value of the proposed determination of the thermal characteristics of a building.

For example, if the measurements were made on a number and variety of buildings (some of the buildings to be demolished at White Plains, New York, would probably be good candidates), it would be possible, apparently for the first time, to determine by how much buildings of various types and constructions differ in their thermal response characteristics, and possibly to relate the size of the heating and cooling system, and its operating cost, and its operating performance as judged subjectively by former occupants or building managers, to the measured response characteristic. Eventually, empiric information would be available to guide designers in selecting and rating various types and constructions of buildings to achieve optimal thermal performance. Further, the existence of a feasible method of measuring this characteristic of a building can make it possible to write a thermal performance specification for a building.

4.3.3.6 Non-Uniform Thermal Environment

The ASHRAE Thermal Comfort Standard 55-66 and all of the other documents identified in the Executive Summary oversimplify the description of the thermal environment in a house during either the winter or summer season. The thermal environment in a room is asymmetrical with respect to thermal radiation and air temperature. A typical room has one or two exterior walls through which 80%, more or less, of the heat loss occurs in the winter time. This may be nearly 100% if the room is on an intermediate floor of a multi-story building. The effect of this heat loss at one or two sides of the room is to produce (1) large cold surface areas to which the occupant radiates more heat then to the interior walls, and (2) a major movement of cold air toward the floor along the full length of the exterior walls. This downdraft at the exterior wall surfaces is a natural convection pump that produces a vertical air temperature gradient from floor to ceiling and a horizontal air temperature gradient from the cold wall to the warm wall unless the heating system effectively counteracts these effects. In fact, the major performance requirement of the heat distribution system is to compensate for and counteract this asymmetrical air and radiant temperature pattern in a room in a building.

The asymmetry of the thermal environment in a room or building is even greater under summer conditions where air conditioning is contemplated. This unbalanced environment is caused by one or more exterior walls exposed to warm outdoor conditions, to instantaneous entry of solar heat through windows, and to warm ceiling surfaces on a top floor level or single - story building. Thus the task of providing a satisfactory thermal environment during summer conditions is different from that in the winter, and a single heat distribution system will typically not produce optimum results in all seasons.

The ASHRAE Thermal Comfort Standard recognizes the importance of the exterior wall surface temperature on comfort and indicates the need for compensation for this effect. However, none of these codes and standards recognize the significance of horizontal and vertical air temperature gradients or the asymmetry in radiation in a typical environment.

Windows, and to a lesser degree doors, usually constitute the weakest link in the chain of thermal resistance of exterior walls to heat flow, quite apart from their role as regards air infiltration. For example, for single-glass windows aggregating 15 percent of the exterior wall area, the winter night-time heat loss through the windows would equal that through the rest of the wall, if the latter had a U-value of 0.2 Btu/hr ft^2 F. The situation is even less favorable for summer cooling cases, for unshaded windows facing the sun, since the instantaneous solar heat gain through the windows could easily exceed 100 Btu/hr ft^2, as compared with a heat gain of 10 Btu/hr ft^2 or less for non-window areas of the wall.

The chief point made here is that windows militate against the maintenance of a reasonable ambient temperature in the enclosed space, to an important degree. As mentioned in 4.5.2.1, maintenance of the ASHRAE thermal comfort conditions near large windows is virtually not possible in cold winter weather, or when solar radiation is incident on uncurtained windows. Nevertheless, it seems inappropriate to charge this effect of windows against an exterior wall system. Presumably the specification of windows in an exterior wall stems from architectural decisions as to lighting, safety, and aesthetic values, and it would be expected that the decision would be the same for nearly all competing wall systems. Hence, although all concerned should be aware that windows tend to undo efforts made to better comfort conditions in the enclosed space by improving the insulating values of wall systems, it is suggested thatwindows should not be included as a factor in the evaluation of particular wall systems in respect to insulating value. Nevertheless, windows have a major effect on the operating cost for environmental comfort control in a building, and also may have the controlling effect on the average mean radiant temperature of exterior walls and on the relative humidity in the winter time. Therefore it appears impractical to attempt to establish thermal performance criteria for buildings without taking the effects of windows into consideration (See 4.3.3.2). Since windows can themselves be regarded as important parts of exterior wall systems, some consideration might be given to evaluation of different types of windows in regard to insulating value, with a view to test methods and criteria for their evaluation.

4.4 VISUAL ENVIRONMENT

4.4.0 Executive Summary

Existing Standards, Procedures, Test Methods

None of the nineteen existing industry or national standards, Federal or other published specifications, or foreign standards, that were examined have any useful performance tests for existing natural or artificial lighting systems pertinent to recommendations for use in low-cost housing.

Among building codes in the U. S., those that have daylight requirements (some do not) express them in terms of window area, rather than performance with regard to view or light. The objectives of the requirements are not described. For artificial lighting, the range is from no requirements at all to describing what rooms should have lighting; a few list quantity requirements. None of these provide useful guidance as to the purpose and qualitative aspects of the requirements.

Current British thinking, expressing performance requirements in terms of brightness, has similarities with the requirements presented here. The proposals for day-lighting requirements given in the report are a development of the daylight factor recommendations of the Building Research Board, London.

The minimum footcandle recommendations of the Illuminating Engineering Society Handbook are deemed as failing to describe relevant objectives, and as not leading to good visual environments. Quality factors are ignored, and light intensities listed are extremely high, without justification.

Suggested Program for Further Development of Performance Criteria

Two courses of action are suggested:

A. Subjective testing procedures should be used to establish confirmation of the numerical values assigned to the performance requirements proposed, which were based on judgment. Procedures might include 1) developing standard measuring procedures by which to rate existing housing units as meeting, or not meeting, the proposed performance criteria; 2) developing survey questionnaires to measure user satisfaction, and use of artificial lighting in daylight; 3) evaluating the accuracy of the ratings in predicting user satisfaction, as compared to the accuracy of present types of specification requirements.

B. An accurate and inexpensive technique (using scale models) should be developed for testing proposed designs against the performance requirements.

4.4.1 User Needs

An appropriate, comfortable, pleasant visual environment that will allow the performance of desired activities is needed by occupants of multi-family housing.

What are the elements that make up such an environment, and what are the activities to be provided for?

4.4.1.1 The Visual Environment

Satisfaction of the visual sense is important in the feeling of psychological well-being. Such satisfaction cannot be related to the intensity of brightness and darkness, but to the information conveyed by the environment and interpreted by the mind in relation to the other senses, past experiences, etc., and in relation to one's activities as they are constantly changing. While the expectation of an appropriate environment will vary among individuals and cultures, contemporary Americans have some universal expectations that can be identified.

Gloom: Until recently, people expected and accepted that the environment would be gloomy, both indoors and outdoors, under gloomy weather conditions. With today's technical advances and resources, they unconsciously expect, and should be able to get, interior environments that feel bright and cheerful regardless of the exterior conditions.

Gloom results from a sense of deprivation or upsetting of expectation. The presence or absense of gloom is not related to the amount of light present; a gloomy, overcast day may have a very high illumination level, many times that of the most brightly lighted office. Such gloom is a result of the bright sky's dominating one's attention when one is really trying to derive from the landscape and buildings the information he instinctively seeks. Diminishing the gloom outdoors can be achieved by reducing the impact of the bright, but informationless, sky by wearing a visor, by the shade of overhanging trees or enclosing buildings, or by increasing the intensity of desirable information with brightly lighted store windows and signs, strong color, or value contrast to make up for minimal defining shadows under those conditions.

Indoors, gloomy conditions are produced by improperly-designed daylighting. Use of glass blocks or obscure glass (instead of clear glass) generally causes the same kind of unpleasantness as the overcast sky, that of high brightness without meaningful information. Also, improper placement, size and shape of windows will create a brightness balance within the room which leaves room surfaces in such comparative darkness to the windows that maximum artificial lighting is needed to redress the imbalance and bring one's natural focus within the room, where conscious or unconscious visual activities want to be (unless one is primarily occupied with observing the view). The color and reflectance of room surfaces can help or hinder this imbalance. Users should expect not to need artificial lighting when daylight is abundant, unless this lack of economy is obviously being offset by other benefits. Because of the association with the bright overhead condition outdoors, dispelling daytime gloom requires that a substantial part of wall and ceiling surfaces be comparatively well-illuminated, even when these surfaces are not seen in direct contrast to windows (e.g., interior halls). At night, association with the overall darkness overhead outside means that gloom need not be dispelled by brightness overhead, and the absence of daylight for comparison allows much lower brightness levels to seem very adequate.

Gloomy and unpleasant conditions can also be produced by other means: when the environment seems wrong for the activity, when one's natural focus is drawn away from where it wants to be (e.g., as a result of overly bright lighting fixtures overhead when dining, or the glare of a light in the kitchen or hall seen from the living room, or in the kitchen when one is working in his own shadow or that caused by overhanging cabinets). Because of the changing needs with changing activities, the visual environment must allow maximum control by the occupants.

Gloom and unpleasantness are also caused by a disorderly pattern of lights that is unrelated to the activities or the environment, a highly personal decor (e.g., light fixtures), the design and color of which are not to the user's tastes, or by highlighting evidence of poor maintenance (dirty, cracked, discolored light fixtures or windows, etc.).

Orientation: People have an instinctive need for orientation at all levels in locale within the city, neighborhood, and home; in time and to weather conditions; to spaces indoors and to man made and natural features outdoors--and the visual system actively seeks the desired information. Thus, there is a need for windows or skylights that fulfill these needs.

In contradiction to these view requirements, however, is the need for light control and privacy: bedrooms require means for temporary darkening and privacy; bathrooms require the means for temporary privacy; and living rooms and kitchens may require means for temporary privacy. In addition, requirements for reduction of solar overheating and control of sky glare must be met. All of these conflicting demands are temporary, however, and their satisfaction should not be at the expense of not getting the most interesting view for the maximum amount of time. Even the feeling of space achieved by looking at a blank wall or roof overhead is of value and more satisfying than a panel of translucent glass or closed venetian blinds. Daylight with no view (of even a blue sky) has much less value.

In circulation spaces indoors and outside, orientation is enhanced by a visual environment in which building organization, structure, and circulation paths are clear. This can be accomplished by a combination of clear, positive design, utilizing texture, colors, and light. A formless monotony should be avoided. Clarity of circulation paths is particularly important outdoors at night for the feeling of security.

Both in the interior public areas and the exterior circulation paths, the spaces adjacent to the routes of travel should be designed and lighted to be non-threatening, so that one has a sense of assurance that he can't be surprised. A high level of illumination is not necessary, but rather the elimination of shadowed pockets (such as dark areaways, etc.).

<u>The Visual Environment Summarized</u>: People desire a visual environment that looks and feels right for the purpose, and which helps them feel oriented with the interior and exterior environments. They want and should have spaces that are not gloomy. They are comfortable when they can focus on what they consciously or unconsciously want to see, and uncomfortable if involuntarily distracted by unwanted information (such as glaring light fixtures).

4.4.1.2 What are the Activities and Lighting Needs for Their Performance?

In homes more than any other type of building, the range of activities is endless; fortunately, most of these activities can be performed with very little light, such as would be the by-product of providing the amenities of appropriate environments described above. Such activities include the following: circulation, play, bathing, dressing, storing and retrieving, cleaning, casual reading and writing. With an appropriate environment, the glare must be minimal, and the large areas of illuminated room surfaces required to produce a cheerful room would naturally distribute light in all directions and without sharp shadows. In achieving the most appropriate environment, there would be a relationship of the light to the activity: maximum brightness at the points of maximum activity. The exact quantities are unimportant.

Rooms in which there are predominant tasks that can be localized are enhanced by lighting that is related to these activities. Thus, the maximum light in the kitchen should be related to the sink and range top activities, and in the bathroom the maximum light (for shaving and makeup) should illuminate all portions of the face without strong shadows. Other activities which might benefit from additional supplementary lighting include sewing, certain hobbies, and extensive reading of difficult material, etc. However, location of this special lighting must be as variable as the potential locations of those activities themselves, and therefore are best provided for with portable lighting to the extent desired by the individual occupants.

Health and Safety: There is no demonstrated relationship between the visual environment and general health, nor can the eyes be harmed by inadequate light any more than the ear can be by inadequate sound. Illumination required for physical safety and movement is very minimal and deserves consideration only for exterior lighting at dangerous points, such as stairs. In interior spaces, achievement of the appropriate environment automatically insures adequate illumination for safety.

4.4.2 Performance Requirements

Performance requirements for low-cost housing should be evolved to reduce cost or to provide optimum living environments without increasing current cost levels. Even though the needs previously outlined are not currently being consistently fulfilled in housing in any price category, they can be attained easily and economically if architects and builders realize what these needs are and have guidance on how they might be attained. Proper performance specifications can provide such help. In addition to fulfilling the needs previously outlined, performance requirements to follow consider the ultimate cost to the occupants. Thus, even a superficial analysis would demonstrate conclusively that, when needs can be predetermined as universal and fixed in location, well-designed permanent artificial lighting must be more economical and more effective than solutions improvised by the occupants; where needs are not predetermined and universal, electrical services that allow safe and convenient fulfillment of the needs by the occupants are required. It should be emphasized that satisfaction, rather than health and safety requirements, is the primary basis for the performance requirements, and the tentative quantification presented should be confirmed by subjective testing before being specified. Confirmation of these performance requirements should provide a sound basis for performance specifications. In following up these performance specifications, however, governmental agencies should be very aware that, while the specified criteria are desirable, almost none of them is relevant to health, and therefore merits the status of a code or law. These performance requirements have been expressed to achieve the user needs while allowing the maximum design freedom.

4.4.2.1 Daylighting Requirements

Windows or skylights should be clear to allow undistorted view, and positioned in such a manner that the view is available to a maximum degree when privacy and climate control needs are satisfied. All windows should receive direct sunlight or allow occupants to see sunlit surfaces. The unobstructed glazing area for habitable rooms (bedrooms, living room, dining room, kitchen) should average 12% of the floor area of those rooms with a minimum of 8% in any room*. In the kitchen, the 8% can be in the form of an opening to a view window in another room.

Windows and skylights should be of a size, shape, and placement to minimize the need for supplementary artificial lighting during the day. The average brightness of ceiling and wall surfaces in all habitable rooms should be at least 1/50 of the average window brightness**, except in the kitchen, where artificial lighting to meet the nighttime requirements will provide this ratio. This brightness ratio is largely affected by the light reflectance properties of room surfaces***. Compliance with these requirements for proposed buildings should be demonstrated with models.

Daylight and Privacy Control: Means for temporary privacy control should be provided in bathrooms. Temporary means (such as curtains, blinds) should be provided for insuring privacy and screening out at least 80% of the daylight from bedrooms.

4.4.2.2. Artificial Lighting Requirements

Kitchen: Permanent artificial illumination should be provided in the kitchen to provide an average brightness of wall and ceiling surfaces of 10 footlamberts (to be forecasted by calculation, model, or full-scale mock-up demonstration). Sink and range surfaces should be illuminated without conspicuous shadow from overhanging cabinets or by user. Lighting fixtures should be neutral in style. Any light sources visible from normal positions within the room and from seated positions in adjacent living spaces through open doors and pass-throughs should be not more than 10 times the average kitchen brightness.

Concealed lighting is one means of achieving all of these goals most economically, with the further advantage of being permanent and virtually indestructible with light sources out of sight and no lenses to replace.

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* A check with one FHA office indicates that projects now being built average 12-14%.

** For the purpose of evaluation, the glazed surface should be temporarily covered with a translucent diffusing material.

*** For evaluation, paintable surfaces can be considered white; materials meant not to be painted (tile, brick, decorative concrete) should be tested unpainted.

Bathrooms: The average brightness of wall and ceiling surfaces should be 5 footlamberts. Light arriving at the face from light fixtures and room surfaces should reach the head from all frontal directions to eliminate strong shadows. The intensity of light at the face from 45° from the sides, bottom, and top should have a minimum/maximum ratio of 1/10. The styling of the fixture should be neutral in character for universal acceptability.

Corridors: All internal corridors shut off by doors, and corridors not separated from other rooms where the average wall and ceiling brightness during the daytime is less than 1/500 of the window brightness, should be provided with permanent artificial lighting properly shielded for glare* to achieve an average wall and ceiling brightness of 1 footlambert.

Closets, Storage Rooms: Closets and storage rooms which cannot receive light from adjacent lighted spaces should be provided with a light fixture.

Other Rooms: For lighting purposes (considered separately from other electrical requirements), all other rooms should be provided with sufficient electrical outlets to allow use of portable lamps with normal length cords in all probable locations. In dining rooms, when table placement is likely to be in the center of the room, fixed overhead lighting properly shielded for glare* should be provided, or a flexible power outlet-suspension system that would allow hanging of fixtures over the center of the table, wherever placed.

Public Spaces, Interior: A combination of daylighting and artificial lighting in public lobbies should produce an average wall and ceiling brightness of 10 footlamberts; corridor spaces and stairs should have 5 footlamberts. At night, these levels can be reduced to 20% of those amounts. The first of these brightness levels is for the elimination of gloom. Achievement of this objective can also be furthered by clear, understandable organization of spaces, with positive use of light, color, and materials. The appearance of good maintenance can be furthered by maximum use of recessed and concealed lighting of maximum permanence that least invites vandalism.

Site Lighting: The objectives of exterior lighting are to provide a minimal illumination level for seeing obstructions, to provide psychological assurance against surprise attackers, and to provide maximum guidance information for pedestrians and automobiles. The minimum illumination level at any point on active pedestrian areas, plazas, parking areas, and paths**, should be $\frac{1}{4}$ footcandle. Areaways and other likely hiding places should be illuminated. Entrances, signs, and all other key points in the circulation system should be high-lighted to provide guidance in circulation, and the patterns should be arranged to give maximum clarity to circulation. Undisciplined clutter of light sources should be avoided.

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* So that lens or light source is not visible from seated positions in adjacent living spaces.

** Defined as including any area on either side of the path proper large enough for a person to hide.

High intensity lights used for the illumination of grounds and parking lots should be shielded so as not to cause glare in any living unit. For the most part, lamps and lighting glassware should be concealed from view or placed out of easy aim of vandals, or, when in special areas design objectives necessitate their being within reach, they should be selected for maximum durability and low replacement cost.

4.4.3 Existing Standards, Procedures, Test Methods

None of the existing industry or national standards, Federal or other published specifications and foreign standards examined have any useful performance tests for existing natural or artificial lighting systems that would be pertinent to recommendations for use in low-cost housing.

Federal, State, and City Codes: A survey of Federal, state, and city codes reveals that some agencies have no requirements at all, some have daylight requirements alone, and some have daylight and artificial lighting requirements.

Daylight requirements are in terms of window area, rather than performance with regard to view or light. While minimum requirements can produce good environments, they may also produce bad ones, because they are not expressed in performance terms, even to the extent of describing the objectives of the requirements.

For artificial lighting, the range is from no requirements at all to describing what rooms should have lighting; a few list quantity requirements. None of these provide useful guidance as to the purpose and qualitative aspects of the requirements. Among those that provide quantitative requirements, there is no consistency in the type of requirement or the values listed, and none of those listing quantitative requirements uses a relevant criteria. For example, the New Jersey State Housing Code calls for 3 footcandles measured in the center of the bathroom 3 feet off the floor, which, if achieved most directly, would put the face in full shadow. The same code also calls for a minimum of 2 footcandles in the darkest portions of "every portion of each staircase, hall, cellar, basement, landing, furnace room, utility room, and all other similar non-habitable space."* It is unlikely that many existing houses would meet this requirement.

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* New Jersey State Housing Code, New Jersey Department of Conservation and Economic Development, New Jersey State Department of Health.

Foreign Codes: The expression of performance requirements in terms of brightness has some relationship to much of current British thinking (e.g., as expressed by R. G. Hopkinson in "A Proposed Luminance Basis for a Lighting Code," Transactions of the Illuminating Engineering Society, London, Vol. 30, No. 3, 1965.). User survey methods have been devised by the Pilkington Research Unit, Liverpool, and the Building Research Station. The proposals for daylight requirements (Section II-A) are a development of the daylight factor recommendations of the Building Research Board, London.

Industry Recommendations: The Illuminating Engineering Society Handbook lists of minimum footcandle recommendations also fail to describe the relevant objectives and do not lead to good environments; even as task requirements, quality factors are ignored and the numbers listed are extremely high, without justification. None of these levels is common in many residences, nor is the format of the recommendations suitable for use as specifications.

We were unable to find any instances where these recommendations have been adopted as codes in the United States; however, they appear in the National Building Code of Canada (including a blanket provision: "For complete table of current recommended practice of lighting in buildings as published in the Illuminating Engineering Society Lighting Handbook, refer to the Secretary of the Associate Committee on the National Building Code, National Research Council, Ottawa, Canada."), and have been recommended for incorporation into local building codes, adopted by the city of Ottawa.

None of the criteria, government or industry, describe whether their purpose is to meet requirements for health, safety, or satisfaction.

4.4.4 Suggested Program for Further Development of Performance Criteria

4.4.4.1 Confirmation of Performance Requirements

The numerical values assigned to the performance requirements outlined above were based on the judgment of the author. Subjective testing should be used for their confirmation; this might include the following procedures:

1. Develop standard measuring procedures and then rate existing housing units as meeting or not meeting the performance criteria for daylighting and artificial lighting by research staff and traditional administrative personnel.

2. Develop survey questionnaires, and then measure user satisfaction, use of artificial lighting during the day, etc.

3. Evaluate the accuracy of the ratings in predicting satisfaction, and compare with accuracy using present types of specification standards. Adjust the quantities required as indicated.

There seems to be a sufficient range of daylight designs to test this type of criteria, but it may be difficult to find artificial lighting that satisfies the proposed criteria. In this instance, a relatively small expenditure in equipment and design consultation should be sufficient to bring some units up to standard, in order to carry out the evaluation. The procedure should be tested in one project and then extended to a broader geographic and ethnic distribution.

Analysis of Current Lighting Codes and Standards		Daylighting (Windows)											Artificial Lighting														
		Habitable Spaces			Bathrooms			Kitchens					Units												Public Spaces		
													Habitable Spaces			Bathrooms			Kitchens			Other Service Spaces					
Description of Code or Recommendation	Mandatory	Per cent of usable floor area	Minimum size: square feet	Ventilation: per cent of usable floor area	Per cent of usable floor area	Minimum size: square feet	Ventilation: per cent of usable floor area	Per cent of usable floor area	Minimum size: square feet	Ventilation: per cent of usable floor area	View requirements	Daylight control	Minimum foot-candles	Outlets	Fixtures	Minimum foot-candles	Outlets	Fixtures	Minimum foot candles	Outlets	Fixtures	Minimum foot-candles	Outlets	Fixtures	Lobbies, corri-dors: footcandles	Stairs: foot-candles	Site
California Administrative Code	√	12.5	12	6.25	8.35	3	4.17	12.5	12	6.25	---																
Hawaii: Housing Code of the Dept. of Health	√	12.5	12	6.25	5	3	2.5	12.5	12	6.25	---																
Indiana Building Rules & Regulations	√	10[a]		10				10[a]		10																	
Code of Iowa	√	10		4		4[b]		10		4																	
Massachusetts Sanitary Code	√	10		4				10[c]		4				2[d]						1	1			1	2M[e]	2M	
New Jersey State Housing Code	√	10		4.5				10		4.5				2[d]		3[f]				2[d]		2			2M	2M	
Oregon Administrative Rules	√				12.5	3	5.6									10[g]											
Pennsylvania Regulations for Sanitation in Tenements, Lodging & Boarding Houses	√				10																						
Austin, Texas, Housing Code	√	10	8	5		3	5	10	8	5			10[h]	1[h]	1[h]												
Wisconsin Building Code	√	10	12	5																					5	10	
FHA Minimum Property Standards for Multi-Family Housing		10[j]		5	10	2	5							1[k]			1	1			1				√[l]	√[m]	√
Southern Standard Building Code		10		5		3	5	10		5																	
Southern Standard Housing Code		10[n]		4.5	10[n]		4.5	10[n]		4.5																	
Building Officials Conference of America, Inc., Basic Housing Code		10		4.5	10		4.5	10		4.5														1	5[o]	5[o]	
APHA-PHS Recommended Housing Maintenance & Occupancy Ordinance		10		4.5	10		4.5	10		4.5				1[p]				1		2[q]							
Uniform Building Code		12.5	12			3		12.5	12																		
National Building Code of Canada													10			10			30						10	10	
Illuminating Engineering Society Handbook																50[r]			50-70[s]						10	10	
American Public Health Association Committee on the Hygiene of Housing: Construction & Equipment of the Home		√[t]													1[u]			1[v]			1[w]	5[x]			5	5	

a. 12.5 in apartment houses
b. openable in all parts
c. for kitchens over 70 square feet in area
d. or one outlet and one fixture
e. "M" indicates minimum
f. measured 36 inches from floor in center of room
g. over entire floor
h. in rooms without windows
j. increase to 15 if any part of room is more than 20 feet from direct source of natural light
k. or one fixture
l. natural light provided by windows equal to 10% of floor area or 12 square feet; ventilation by windows equal to 5% of floor area; for corridors, natural light provided by windows equal to 5% of floor area
m. natural light provided by windows with area equal to 10 square feet per floor
n. 15 for skylights
o. in darkest portion of normally traveled area
p. and/or fixture(s) capable of providing 3 watts/ft^2 power
q. minimum, or one outlet per 60 square feet of floor area
r. on face at mirror locations
s. range and sink, respectively
t. suggests adoption of British daylight factor or similar standards in place of minimum window areas in terms of per cent of floor area
u. ceiling fixture and outlets in bedrooms; optional ceiling unit in living room, which, if used, should provide 10 footcandles 30 inches from floor below fixture
v. ceiling fixture with vertical tubular bulbs for illumination on mirror
w. ceiling fixture yielding diffuse illumination over central half of room
x. basement stairs, unused storage space

5. SERVICE SYSTEMS WITHIN HOUSING

5.1 PLUMBING

5.1.0 Executive Summary

Plumbing may be considered as comprising (a) pipes and fittings, (b) fixtures, (c) appliances, (d) appurtenances, (e) industrialized units, and (f) installed systems. Pertinent technical characteristics for some of these are given in Section 5.1.2. A general discussion of the performance approach and 18 suggested qualitative performance requirements are given in Section 5.1.1, together with charts showing (1) steps in development of a performance document, starting with a knowledge of user need, and (2) identification of major elements comprising plumbing.

A discussion of the current state of the art is presented in Section 5.1.3, and certain research is recommended in support of the furtherance of performance standards. Several examples illustrating trade-off possibilities are given in Section 5.1.5.

Section 5.1.6 lists user requirements in qualitative terms that might be considered health-oriented and certain building elements are identified as being involved in each instance.

5.1.0.1 Utilization of the Performance Approach in Existing Standards and Codes

Most existing standards contain some requirements and tests designed to assure reasonable in-service performance in one or more ways. However, specification-type or prescription-type language is often used, and quality-control type tests are often specified. Thus, it may often be that the tests do not simulate service conditions very closely. Standards based on this approach are often of little value when applied to new materials, new designs, or new methods of construction: but may be altogether adequate for the familiar materials and constructions for which they were developed. Review indicates that many of the existing standards for piping and fixtures and most codes may be placed in this category.

Tests for leak resistance of installed systems or components thereof, such as prescribed in USASI A40.8, the New York State Plumbing Code, and USASI A119.1 are essentially performance-type and may be considered generally satisfactory. Existing or presently proposed USASI, AGA, ASME, and UL Standards relating to backflow preventers, temperature and pressure-relief devices, refrigerated drinking-water coolers, water heaters, and water-hammer arrestors appear to be based largely on performance concepts; hence need little attention unless serious difficulties begin to develop from attempts to introduce untried materials or unexpected, novel constructions.

The New York State Plumbing Code, the plumbing portion of the National Building Regulations for England and for Scotland, and the USASI A40.8 National Plumbing Code are more nearly performance codes than others surveyed. In the matter of determination of what materials or equipment might satisfy the performance requirements, these documents refer to specification-type standards or prescription-type statements, in the absence of a better solution.

The absence of generally recognized plumbing standards for some appliances and appurtenances, and the prevalence of a certain amount of user dissatisfaction with some aspects of performance of this equipment, particularly in regard to noise, indicates a need for performance-oriented standards in this area. Perhaps sink and lavatory supply appurtenances, food-waste grinders, and automatic dishwashing and laundry machines are the most familiar examples. Current standards efforts in these areas should be speeded up.

To facilitate the evaluation of innovative systems, standards are needed for prefabricated assemblies, industrialized units, and complete plumbing systems. With the exception of leak tests, there appear to be no American criteria for evaluating such constructions, other than by inspection to determine conformance with the prescriptions laid down in plumbing codes and in the standards for the individual pieces. Some of the pertinent technical characteristics are shown in Section 5.1.2. Evidently, performance tests are needed in this area for residual flow pressure at water outlets, hydraulic capacity of soil- and waste-pipe systems, and trap-seal retention under loading, without regard to the particular sizing and geometry used in the construction of the system.

Limited sampling of European plumbing standards and codes indicates that in Europe a broader coverage has been achieved than in America, and at least in some instances, such as in standards for fittings and some appurtenances, test methods are more sophisticated. The recent National Building Regulations in Britain reflect an increased emphasis on performance language. However, many of the provisions in the European standards and codes still appear to be of the specification type so familiar in America.

As to the evaluation of innovations, the Europeans have made notable use of the Agrément scheme. Ideally, this includes the development of acceptable criteria by which a given family of innovations are to be evaluated, as for example, for doors. A limited number of Agrément certificates have been issued for some plumbing pipes and appurtenances, at least in France, but evidently the criteria for evaluation have been of the ad-hoc variety. Better criteria for plumbing seem to be needed in order to evaluate innovations.

A number of codes, such as USASI A40.8 and the New York State Plumbing Code, indicate in some detail the procedure to be followed in sizing various pipes and describe the characteristic geometry of pipe systems that are allowed. For the most part, these requirements are based in part on data from hydraulic and pneumatic research; hence may be looked upon as performance requirements, or at least performance-based requirements, in a broad sense. Unfortunately, some of these requirements are not suitable when applied to constructions unlike the ones on which the research was performed.

5.1.0.2 Recommendations for Long-Range Improvement of Standards and Codes

Perhaps the best chance for considerable cost reductions at little risk of sacrifice of essential performance may be realized through specifications and standards that permit evaluation of the performance of systems with unusually small pipes, of simplified systems, and of systems based on other than hydraulic principles or on novel adaptations of hydraulic principles.

Most of these approaches would involve first the collection of pertinent new data on service loads and use conditions in American housing, and probably on user reaction to various levels of performance. Some of the research programs that might be helpful in this area are indicated in Sections 5.1.3 and 5.1.5.

5.1.0.3 Recommendations for Short-range Programs to Improve Specifications for Low-cost Housing (2 yrs. duration or less, involving relatively little new research).

Cost reduction without serious risk of loss of essential performance seems possible through modification of the FHA Minimum Property Requirements to reflect a number of promising concepts, such as:

a. Incorporate in MPS's a greater use of performance language, following approach utilized in N.Y. State Plumbing Code, with certain necessary exceptions.
b. Incorporate in MPS's the substance of the February 1968 NAS-NRC Special Report on Performance Characteristics of Sanitary Plumbing Fixtures, somewhat as in the URBS project.
c. Incorporate in the MPS's the most recent pipe-sizing criteria developed in USASI A40 Sectional Committee on the National Plumbing Code, some of which originated with NBS.

As a valuable comparison study with evident potential, it is recommended that single-stack drainage systems of two different varieties be installed in one or more multi-story apartment buildings, in addition to systems conforming to the presently applicable code requirements. Design of the single stack systems would be based on extrapolation of European findings to American conditions. Provisions would be made to conduct field evaluations of performance, as well as any essential supporting laboratory evaluations. From the data gained, it might be possible to incorporate single-stack drainage in the MPS's. See NBS Report 9674 and supplement thereto, for detailed recommendations and discussions of European data.

The bathroom component category of URBS demonstrates the feasibility of performance specifications for the bathroom. A short-range program, benefitting from the test procedures developed for the bathroom, should produce comparable performance specifications for the kitchen fixtures (sink, dishwasher, and food waste-grinder) and the wash room area (clothes washer and dryer). Such a program could also introduce needed improvements in the URBS recommendations, with reference to low-cost housing.

A final recommendation is that a "Little Agrément" body be established to advise on suitability of innovations proposed to HUD in response to performance-oriented language in the MPS's as suggested above. This body might be drawn in part from IAT-NBS.

5.1.0.4 Recommended Research Programs

Among the more important research programs needed are the following:

a) Collection of hydraulic load data under service conditions, in order to provide a rational, realistic method for calculating design loads for use in evaluating performance of unusual water distributing systems and drainage systems.

b) Application of data obtained in (a) to the development of test methods for evaluation of the hydraulic performance of unusual or simplified drain-waste-vent (DWV) systems and water-distributing systems.

c) Development or selection of measurement techniques for evaluating plumbing noise, and study of installation techniques for reducing noise.

d) Collection of data on performance aspects in relation to incineration of fecal matter and solid food waste, and the development of criteria for evaluating such equipment.

e) Development of improved test methods for evaluating hydraulic and/or thermal performance of plumbing appliances, appurtenances, fixtures, and pipe fittings.

f) Development of data on corrosion and liming in water distribution piping, and on fouling anddeposition in drain piping. From this, develop recommendations on the management of such deleterious actions to reduce maintenance and replacement costs; and to aid in the selection of materials, in the evaluation of plumbing equipment performance, and in water quality control.

g) Collection of data on behavior of plumbing materials in fires, in order to establish criteria for fire ratings and recommendations for protective measures in installation.

h) A study to provide data on performance of, and test methods for evaluating, joints and connections for piping systems with particular emphasis on applications of industrialized units for multistory work.

i) Development of performance tests for resistance of piping to bursting, fire effects, impact, puncture, crushing, deflection, chemical attack, dimensional stability, and corrosion, without particular reference to the type of material.

j) Development of improved tests for evaluating wear in hydromechanical assemblies utilized in plumbing appurtenances and appliances.

As to relative importance of the recommended programs, items a, b, h, and i are probably of the greatest importance. Perhaps the most difficult and costly would be item i.

5.1.1 Performance Requirements for Plumbing

5.1.1.1 Rationale

The term "plumbing is commonly applied to a broad spectrum of subject matter, encompassing the materials, devices, equipment and the systems utilized for the distribution of water within buildings and for the removal of waste water from the premises. It also refers to the installation or design of plumbing systems. Storm drainage associated with buildings is often regulated under the provisions of plumbing codes. Requirements primarily in the interests of health and safety of users are essential not only in relation to the hardware, but also in relation to design and installation practices for plumbing systems and their components.

Perhaps the most striking illustrations of the need for an improved approach in the development of standards and codes can be found in the experiences of innovators in their relationship with local authorities who administer typical plumbing codes that are largely of the rigid, specification type and that refer to specification-type standards identifying materials, devices, and equipment that are to be deemed acceptable under the code. True, many codes allow the administrative authority to permit exceptions, at his discretion and based on good evidence; however, experience has shown little advantage is taken of this provision by the authorities. For example, codes effectively set the general pattern of design for the sanitary drainage system through various specifications relating to configuration, venting, pipe sizing, etc. This prevents the acceptance of novel systems in which secondary ventilation or the need for gravity drainage is eliminated, although such systems have been in use for some time in Europe, and have been researched there. In another example of difficulties encountered by innovators, the use of bituminized-fibre sewer and drain pipe in plumbing was resisted for many years under the local codes because, among other things, it could not pass some of the tests commonly specified in existing standards for concrete, vitrified clay, and cast iron, although such tests might be considered irrelevant to bituminized fibre pipe in the proposed applications because of its particular properties. More recently, manufacturers of plastic pipe and plumbing fixtures have encountered similar difficulties.

It is altogether proper that local authorities exercise their lawful duty to protect the public health and to minimize dangers to life and property. Thus, it is not correct to criticize local authorities and the specification-type codes and standards which are their tools in the performance of their lawful duties, solely on the basis that innovation and cost reduction are obstructed. Instead, what must be offered are improvements in the identification of essential performance characteristics and the means for their measurement, so that meaningful and reliable systems-design rules and materials standards can be provided that, insofar as possible, will apply regardless of the particular material or system to be considered. Only in this way can enforcing authorities be provided with the tools to evaluate cost-saving proposals and novel approaches quickly and objectively and at the same time not run a serious risk of failure in the protection of the public health and safety. It must be remembered that reasonable standards of health and safety cannot be ignored in the quest for cost reduction and in facilitating the introduction of innovations.

The desirable functional characteristics of plumbing include not only properties such as gas-and-water-tightness, provision of adequate quantities of drinking water not contaminated by disease-producing bacteria, and the ability to carry away waste water quickly and without overflow on the premises, but also more subjective concepts such as cleanability, resistance to aging, deterioration, and long-term resistance to chemical attack and corrosion. Requirements for performance in the more subjective areas are commonly expressed in qualitative terms involving phrases like "acceptable appearance," "normal service life," "no serious deterioration," "typical use," etc., that have no precise definition in physical terms.

The development of meaningful test methods requires conception of procedures that simulate to an acceptable degree the kinds of exposure received by plumbing in actual use. While simulative service testing is not new, simulation of the interactions between human beings and plumbing in a way that will provide a basis for fair competition among materials and systems of a wide variety presents additional complexities. It involves careful analysis of the important use-related processes, such as loading, frequency of use, wear, deterioration, exposure to possible mechanical or bacteriological hazards, etc., and the translation of these processes into a test procedure and/or laboratory equipment that can be described and reproduced and that can measure the effects of these processes in quantitative terms. When such apparatus and procedures are developed, it then becomes possible to obtain test results on available commercial items or specially-made items for comparison with user requirements.

In establishing acceptable performance levels, as well as the essential areas in which performance must be obtained, the evaluation of subjective human response is involved, as well as the frequency and duration of exposure to a variety of human activities. In many instances, valid levels of performance cannot be set without extensive data on use and users' concepts of long-term acceptability. Such data are usually not obtainable because of prohibitive cost. Another complication may arise where measured values for a given property may vary widely between different materials or methods of construction. It may be that under such circumstances a requirement of a single level of performance is not logical.

The acceptable level of performance may be related to previous user experience and social background, in relation to some properties. A further problem is that, probably more often than not, the performance that may be desired may not be attainable in a single material, piece of equipment, or a system where all the various significant performance characteristics are considered. Thus, some compromise will have to be made. In the absence of adequate statistical data on use conditions, performance in use, and tolerance of users, one practical approach to performance levels is to select levels that either upgrade, downgrade or maintain existing quality of products or systems in current use, based on measured performance of a suitable sample. The actual levels set would require the studied judgment of informed, experienced persons as a consensus of experts. This procedure may well be the only practical solution in the case of some innovations. Performance levels set in this way, of course, will be subject to later adjustment as more service data or user reaction data become available.

It is likely that with continued effort in the development of performance standards and specifications based on improved test methods, the state of the art in evaluative technique can be vastly improved. Nonetheless, with acceleration already evident in the innovative field and with the probable quickening of this pace if the performance approach is widely introduced, it appears certain that the ability to evaluate innovation will never be up-to-date in the foreseeable future. For this reason, some mechanism for exercising the best available technical judgment in advance of promulgation of accepted standards is needed. Perhaps a board of informed experts with access to laboratory facilities should be established to perform this function. It may be that something patterned after the current European solution in the form of an Agrément Board with authority to evaluate and issue recommendations and temporary "certificates" could be considered as a practical approach in the case of innovations to which current standards are not suitably applicable. Such a body of informed persons representing the principal interested groups might be the best approach in judging whether a given innovative proposal could be deemed to satisfy pertinent essential performance requirements that are not precisely defined in advance of a generally accepted standard.

5.1.1.2 Performance Requirements for Plumbing

Requirements that might be established without regard to the material, equipment, system, or method used in a particular solution, are listed in the first two columns of Table 1. In the third column are listed some requirements associated with the current, hydraulic-systems solution. While not presently listed, the determination of compliance with these requirements rests upon such evidence as can be found in generally accepted standards. Unfortunately, the format and approach utilized in developing most of the existing standards is far from sufficient in establishing the adequacy of performance of a novel system or piece of equipment, or of a new material.

5.1.2 Technical Characteristics of Plumbing

5.1.2.1 Piping and Fittings

1. Mechanical and Structural
   a. Impact resistance, abrasion resistance.
   b. Resistance to deflection or crushing under external load.
   c. Resistance to swelling or bursting from internal pressure.
   d. Ability of joints to resist pull-out and maintain seal under representative internal and external loading.
   e. Minimum hydraulic resistance.
   f. Absence of leakage under representative conditions.

2. Thermal
   a. Maintenance of essential mechanical properties over a representative range of temperature.
   b. Avoidance of adverse effects of representative expansion or contraction.
   c. Ability to maintain essential properties under representative conditions of thermal shock.
   d. Resistance to excessive softening or collapse from fire, and to generation of toxic gases or excess smoke, and to transfer of fire.

3. Chemical and Electrolytic
   a. Minimization of chemically or electrolytically-induced deleterious effects on essential mechanical properties resulting from representative fluids conveyed. Minimization of corrosion.
   b. Ability to resist deleterious action of representative chemical additives on essential mechanical properties.
   c. Minimization of weakening or penetration from soil corrosion.

Table 1. Performance Requirements for Plumbing

	General Requirements	Essential Criteria or Protection Approach	Special Requirements Pertinent to Present-day Solution
1.	Potability of water for human consumption.	Bacteriological and chemical content, taste, odor, turbidity--to be satisfied at acceptable health levels.	Shall meet Public Health requirements for drinking water.
2.	Provision of sufficient, but not excessive, quantity of water for human consumption and other user needs.	Satisfaction of minimum instantaneous and daily demands essential to health and sanitation of users.	Satisfaction of equipment demands as necessary to achieve sanitary and effective functioning, considering probability of concurrent use at different outlets.
3.	Provision of hot water for essential sanitation.	Satisfaction of minimum instantaneous and daily demands essential to health and sanitation of users, with particular reference to ablutionary, culinary, and laundering activities.	Satisfaction of equipment demands as necessary to achieve sanitary and effective functioning, considering probability of concurrent use at different outlets.
4.	Protection against harmful contamination of potable water, food, and sterile materials.	Separation of potable water supply and sterile materials from potential sources of contamination.	Protective devices shall effectively prevent backsiphonage; cross connections prohibited; adequate air gaps required at outlets where practicable.
5.	Protection against explosion, scalding, or burning from overheated water.	Control of water temperature and pressure at critical points.	Pressure relief valves, energy cut-off devices, and temperature-sensitive relief devices required. Pressure vessels to have adequate strength and resistance to failure at elevated temperature. Mixing devices to maintain adequate temperature and volume control.
6.	Provision of receptacles and equipment essential to ablutionary, culinary, laundering, and excretory functions.	Minimum facilities essential to health, sanitation, and well-being of users.	Provision of sanitary fixtures for essential user needs; adequate sizes for user needs.

(continued)

Table 1. continued (Part 2)

	General Requirements	Essential Criteria or Protection Approach	Special Requirements Pertinent to Present-day Solution
7.	Sanitary removal of excretory, ablutionary, culinary, and laundering wastes from the premises.	Avoidance of unsanitary accumulation, overflow, or spillage of waste matter; capacity for ready transportation of peak waste loads to acceptable point of disposal without causing unsanitary discharge on the premises, or nuisance conditions.	Adequacy of size, shape, and drainability of fixtures and appliances; adequacy of pipe sizes and configuration in gravity, non-pressure drainage system, considering probability of concurrent operation of the various fixtures and appliances.
8.	Protection against emission of toxic, noxious, or explosive gases.	Maintenance of physiologically safe gas concentrations, of gas concentrations safe against explosion, of gas barriers; gas-tightness of joints and connections at critical points.	Adequacy of pipe sizes and configuration in ventilation system to protect against siphoning or blowing trap seals; provision of water-seal traps of depth adequate to maintain essential resistance to gas emission.
9.	Minimization of noise.	Maintenance of physiologically and psychologically acceptable noise levels generated or transmitted by plumbing systems, considering frequency and amplitude.	Secure but resilient supports and attachments of piping to structure, water pressure control, velocity control, water-hammer control, tolerance control in fit of moving parts.
10.	Protection against entry or growth of vermin and rodents.	Maintenance of physical barriers; minimization of accumulation of matter attractive to vermin and rodents; use of repellent or non-attractive materials and forms of construction.	Provision of pipe shields where pipes pass through walls or floors; minimization of concealed spaces conducive to harboring vermin; maintenance of adequate water seals in fixture traps.
11.	Protection against deleterious accumulation of storm water.	Collection and transportation systems adequate to remove peak storm loads without structural overload or deleterious permeation or erosion of fabric of building or adjacent areas.	Adequacy of pipe sizes to avoid excessive accumulation of storm water; location of inlets to facilitate collection, and design to avoid choking by debris; consideration of probability of peak storm loads; avoidance of discharge across surfaces subject to erosion.

(continued)

Table 1. continued (Part 3)

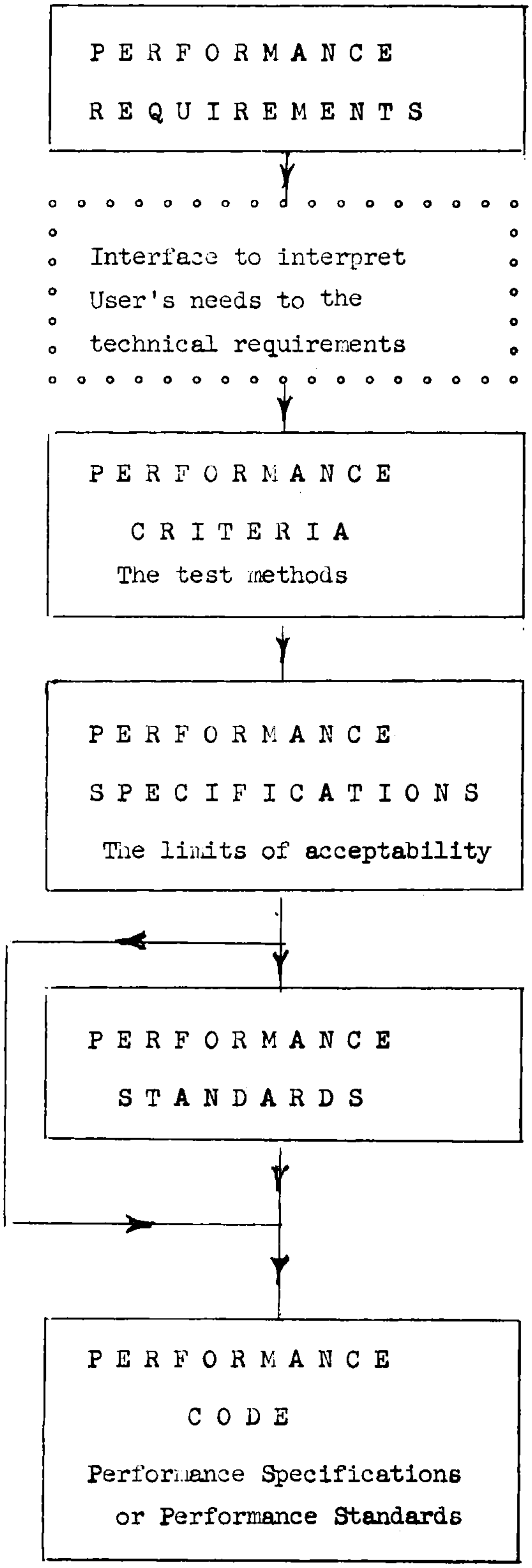
	General Requirements	Essential Criteria or Protection Approach	Special Requirements Pertinent to Present-day Solution
12.	Minimization of contamination of persons and sterile materials by contact with receptacles and equipment.	Design and location of plumbing facilities and appurtenances to minimize physical contact of persons and sterile materials with potentially contaminated surfaces or materials.	Design of manual control devices requiring minimum physical contact by hands; design of fixtures and supply fittings subject to minimum accumulation of fouling matter; design of excretory fixtures to minimize physical contact with users and reduce aerosol generation.
13.	Potential for effective maintenance and servicing in relation to essential functions of system and components.	Provision of cleanability and resistance to soiling or fouling; convenient access to locations requiring cleaning or servicing; design to simplify cleaning or servicing, and to avoid undue accumulation of materials deleterious to essential functioning.	Adequate access for cleaning fouled pipes and eliminating stoppages; provision of drain slopes and fitting shapes that promote self-cleansing of pipes; hardness control to avoid excess liming of water pipes; access and location of equipment to facilitate servicing, replacement, etc.
14.	Durability of materials and essential functioning of components and equipment.	Provision of materials and components possessing adequate resistance to abrasion, chemical attack , corrosion, thermal deterioration, impact, structural collapse, delamination, dimensional instability, staining, deterioration from moisture absorption, from radiant exposure, normal wear, and deleterious physical and chemical changes due to passage of time.	Selection of materials best suited to local conditions in relation to water quality and exposure to use; velocity control in water systems. Rely on adequacy of accepted standards and develop techniques for evaluating new materials, devices, and equipment.
15.	Fire safety	Materials, properties and system design shall be such as to minimize their contribution to fire load, to smoke and toxic gases in case of fire; and to avoid serious contribution to ventilation through collapse in the event of fire.	Require adequate resistance to fire propagation and degradation, smoke generation, and collapse under fire--particularly for organic materials.

(continued)

Table 1. continued (Part 4).

	General Requirements	Essential Criteria or Protection Approach	Special Requirements Pertinent to Present-day Solution
16.	Security	Design and location of equipment and exposed parts of plumbing systems shall be considered in relation to degree of exposure to and access by users likely to impose hard use conditions or to commit acts of vandalism or malicious mischief.	
17.	Structural safety, structural strength, and stability	Installation to avoid weakening of building structural elements; provide structurally safe support of plumbing services; minimize likelihood of structural failure of plumbing services due to shrinkage, settlement, and thermal expansion or contraction; dimensional stability of materials.	Structural adequacy of pipe and fixture hangers and supports; avoidance of excessive cutting and notching of structural elements to provide for passage of pipes; provision for linear movement of pipes; sound trenching and backfill practice.
18.	Compatibility with other building subsystems	Design and installation to avoid imposition of unreasonable requirements on other building elements, to avoid reducing effectiveness of other elements, and to share common space with other elements.	Minimize space requirements for plumbing services; avoid installation of plumbing in a manner that would interfere with doors, windows, etc.

THE PERFORMANCE BUILDING CODE STARTING FROM A DEFINITION OF THE USER'S NEEDS



What functions or services does the User want the particular building component to provide ?

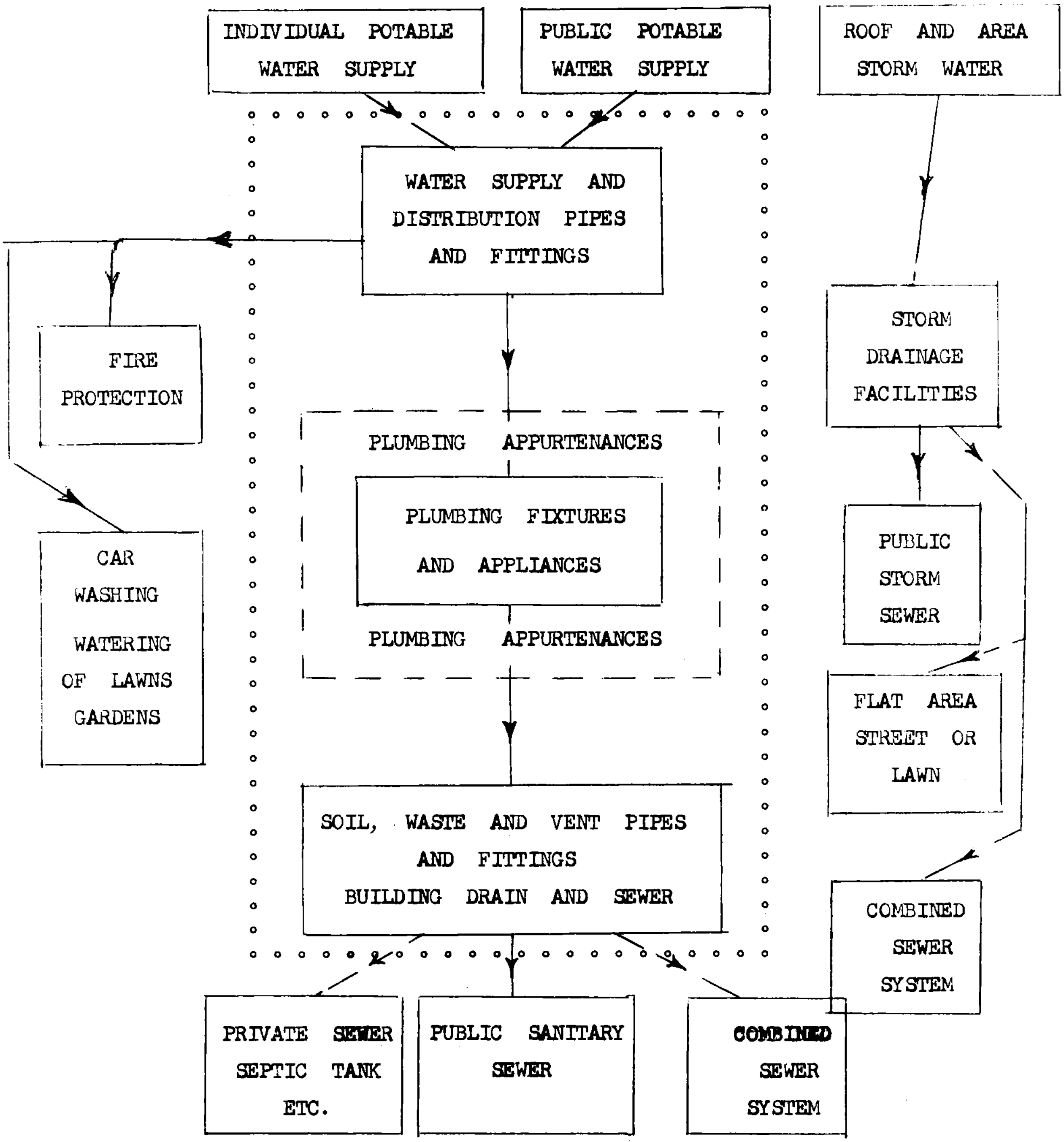
By developing suitable testing techniques that provide measurments, we can determine how well the component meets the performance requirements.

If we then define acceptable limits or tolerances for performance as measured by the test methods , we have performance specifications.

The Performance Standard may develope as the result of (a) being a standard test procedure in a performance specification or(b) frequent and widespread use of a performance specification and approval by standards-generating organization

The Code exists when adopted by a regulating body and put into practice in the legal sense.

THE PLUMBING SYSTEM OF
PUBLIC OR PRIVATE HOUSING



Performance Requirements of Plumbing Systems and Components to Meet Users Needs

	Pipe and Fittings	Plumbing Fixtures	Plumbing Appliances	Plumbing Appurtenances	Industrialized Units	Installed Systems
1. Provision for potable water (safe for human consumption)	X			X	X	X
2. Provision for quantity of water (sufficient in volume and pressure)	X	X	X	X	X	X
3. Provision for hot water to meet essential sanitation needs	X		X		X	X
4. Protection against contamination of water, food, and sterile materials			X	X	X	X
5. Protection against explosion, scalding or burning from overheated water	X			X	X	X
6. Provision of facilities for ablutionary, culinary, laundering, and excretory functions		X	X		X	X
7. Provision for removal from premise of wastes from facilities of #6	X	X	X		X	X
8. Protection against emission of toxic, noxious, or explosive gases				X	X	X
9. Minimization of noise	X	X	X	X	X	X
10. Protection against entry or growth of vermin and rodents	X		X		X	X
11. Protection against deleterious accumulation of storm water	X			X	X	X
12. Minimization of contamination from contact with receptacles & equipment		X			X	X
13. Potential for effective maintenance and servicing of system & components	X	X	X	X	X	X
14. Durability of materials and dependability of equipment	X	X	X	X	X	X
15. Safety of Plumbing system against hazards of fire	X	X	X		X	X
16. Security of plumbing system against hard use or vandalism		X	X		X	X
17. Structural strength, and structural safety (stability)	X				X	X
18. Compatibility with other building subsystems					X	X

4. Durability and Maintenance Potential

   a. Aging--stability of essential properties on long-term exposure to representative environmental conditions involving moisture, heat, light, etc.
   b. Resistance to mechanical or chemical deterioration from microbes, insects, vermin, or rodents.
   c. Resistance to deleterious effects of normal mechanical or chemical pipe-cleaning techniques.
   d. Resistance to excessive fouling, liming, or deposition from fluids transported.

5.1.2.2 Plumbing Fixtures[1/]

1. Structural

   Ability to resist representative uniform and concentrated loads without excessive deflection, deformation, or breaking.

2. Mechanical
   a. Resistance to surface impact, abrasion, and scratching.
   b. Surface smoothness, cleanability, soiling-resistance, slip resistance.
   c. Bond maintenance, dimensional stability.
   d. Minimization of noise.
   e. Drainability.

3. Thermal
   a. Hot water resistance.
   b. Cigarette burn resistance.
   c. Resistance to thermal shock.
   d. Radiant-heater resistance.

4. Chemical
   a. Resistance to deterioration of essential properties from exposure to representative fluids and household chemicals.
   b. Stain resistance.
   c. Color stability.
   d. Corrosion resistance.

5. Durability or maintenance potential
   a. Aging--maintenance of essential properties on exposure to normal environmental conditions such as moisture, temperature, light, etc.
   b. Resistance to chemical or mechanical deterioration from microbes, insects, vermin, or rodents.
   c. Potential for repairing or replacement; design and installation to facilitate access and ease of cleaning, repair, and replacement.

1/ Defined in Nov. 1966 proposed revision of USASI National Plumbing Code. Examples: Water closets, lavatories, bathtubs or shower receptors, kitchen sinks, laundry tubs.

5.1.2.3 Plumbing Appliances[1/]

1. Structural
Ability to resist representative stresses and strains associated with installation, maintenance, and use without breakage, excessive deformation, or adverse effect on essential functions of the appliance.

2. Mechanical
   a. Impact resistance, and resistance to deformation or breakage by representative forces, pressures, etc.
   b. Minimization of noise and water hammer.
   c. Ability to control or regulate fluid flow, where pertinent.
   d. Ability to maintain uniformity of automatic operating cycle, where pertinent.
   e. Ability to permit passage of an adequate rate of discharge, where pertinent.
   f. Ability to resist or prevent backflow of contaminated or otherwise deleterious liquids under representative adverse pressure differentials, where pertinent.
   g. Ability to intercept deleterious materials in suspension, where pertinent.
   h. Ability to function without overflow or discharge of unwanted liquids on the premises.
   i. Ability to reduce waste solids to particle sizes and consistencies that will not cause malfunction of the waste transportation system.

3. Thermal
   a. Maintenance of essential mechanical properties over a representative range of temperature and thermal shock.
   b. Ability to control or regulate fluid temperature at desired, safe levels, where pertinent.

4. Chemical and Electrolytic
   a. Resistance to chemically or electrolytically-induced deterioration from exposure to representative fluids.
   b. Ability to control chemical content of water at acceptable levels at outlets, where pertinent.

5. Durability and Maintenance
   a. Aging--stability of essential properties on long-term exposure to representative environmental conditions involving moisture, heat, light, etc.
   b. Resistance to excessive fouling, liming, or deposition from fluids. Corrosion resistance.
   c. Ability to perform essential repetitive functioning over a period of time without undue deleterious wear.
   d. Design and installation to facilitate access and ease of cleaning, repair, and replacement.

1/ Defined in Nov. 1966 proposed revision of USASI National Plumbing Code.
Examples: Automatic laundry machines, dishwashers, food-waste grinders, water heaters and softeners, mechanical water coolers and filters, automatic ice-making machines.

5.1.2.4 Plumbing Appurtenances [1/]

1. Structural
   Ability to resist representative stresses and strains associated with installation, maintenance, thermal expansion or contraction, and building shrinkage or settlement without breakage, excessive deformation, or adverse effect on essential functions of the appurtenance.

2. Mechanical
   a. Impact resistance, and resistance to deformation of breakage by representative forces, pressures, etc.
   b. Minimization of noise and water hammer.
   c. Ability to control or regulate fluid flow, where pertinent.
   d. Ability to control fluid pressure at safe levels, where pertinent.
   e. Ability to permit passage of an adequate rate of discharge where pertinent.
   f. Ability to resist or prevent backflow of contaminated or otherwise deleterious liquids under representative adverse pressure differentials, where pertinent.
   g. Ability to intercept deleterious materials in suspension, where pertinent.

3. Thermal
   a. Maintenance of essential mechanical properties over a representative range of temperature and thermal shock.
   b. Ability to control or regulate fluid temperature at desired, safe levels, where pertinent.

4. Chemical and Electrolytic
   a. Resistance to chemically-induced or electrolytically-induced deterioration of essential properties and functions from exposure to representative fluids.
   b. Ability to control chemical content of water at acceptable levels at outlets, where pertinent.

5. Durability and Maintenance
   a. Aging -- stability of essential properties on long-term exposure to representative environmental conditions involving moisture, heat, light, etc.
   b. Resistance to excessive fouling, liming, or depostion from fluids. Corrosion resistance.
   c. Ability to perform essential repetitive functioning over a period of time without undue, deleterious wear.
   d. Design and installation to facilitate access and ease of cleaning, repair, and replacement.

1/ Defined in Nov., 1966 proposed revision of USASI National Plumbing Code.
Examples: Supply and waste fittings for plumbing fixtures, fixture traps, pressure and temperature relief valves for hot-water systems, backflow preventers, grease intercepters, water-hammer arrestors.

5.1.2.5 Performance Characteristics of Installed Systems for Water Distribution and Plumbing Drainage

1. Structural

   Adequacy of supports, attachments, joints, and connections to secure system against excessive deformation, collapse, or vibration; and to avoid undue weakening of structural elements of the building through drilling, notching, cutting, or boring; to avoid buildup of excessive stresses through thermal forces or shrinkage or settlement of building elements; and to avoid unnecessary contribution to noise transmission.

   Adequacy of strength of components when properly secured, to enable system to resist excessive deformation, deflection, or breakage due to normally imposed stresses as indicated above.

2. Mechanical
   a. Adequacy of gas barriers and, where pertinent, of ventilation system to prevent transmission of unacceptable quantities of toxic, noxious, or explosive gases into building under normal conditions of use.
   b. Adequacy of waste transportation system to remove characteristic peak loads of sanitary and rainwater wastes to an acceptable point of disposal with sufficient dispatch and without contaminating or flooding the premises or creating a nuisance.
   c. Adequacy of water distribution system to deliver sufficient water to outlets under characteristic peak demand conditions to meet essential user needs for water and to assure satisfactory, sanitary operation of plumbing fixtures and plumbing appliances.
   d. Adequacy of installed systems in avoiding contamination of potable water supply through backflow or cross connection, and in minimizing danger of explosion, burning or scalding from overheated water.
   e. Ability of installed systems to perform without excessive noise or water-hammer.
   f. Ability of installed system, including piping and joints and connections to fixtures, appliances, and appurtenances, to resist leakage of gases and liquids normally transported at representative pressures.

3. Thermal

   Adequacy of installed systems to resist adverse structural or mechanical deterioration from prevailing thermal forces; and to minimize hazards from fire in relation to materials, installation methods, smoke, and toxic gases.

4. <u>Chemical and electrolytic</u>
   Adequacy of installed systems to avoid excessive deterioration from chemical or electrolytic reactions associated with the materials used in relation to fluids conveyed, soil conditions, etc.

5. <u>Durability and Maintenance</u>
   a. Adequacy of design and installation of systems to facilitate normal maintenance, repair, and replacement of components.
   b. Adequacy of choice of materials and quality levels of components in relation to intended useful life of systems or the building in which they are installed. This also involves considerations of:
      i. Aging properties of components.
      ii. Resistance to fouling, liming, deposition, and corrosion.
      iii. Design and installation to facilitate access and ease of cleaning, repair, and replacement.
   c. Adequacy of design and installation in minimizing entry and/or growth of rodents and vermin.

5.1.3. <u>Review of Plumbing Codes, Specifications and Standards</u>

A limited review of model, state, and local plumbing codes was made to gain knowledge of the means utilized to achieve satisfactory performance of installed plumbing systems. From this review, and from general knowledge of specifications and standards for plumbing materials and equipment, the following statements can be made:

1. Some, but by no means all, codes give broad, general qualitative statements of performance requirements or objectives. These are in large measure described in the context of the current hydraulics system solution, hence would need some modification to apply to non-hydraulic systems or to radically different types of hydraulic systems.

2. Specific requirements as to performance are inadequate or lacking for numerous properties or characteristics, among which are various ones affecting durability such as corrosion resistance, chemical resistance, resistance to thermally induced failure, aging, etc. Performance tests for the hydraulics of equipment and systems are lacking in many instances.

3. The bases for specification-type statements frequently found in codes are, more often than not, not given.

4. The local administrative authority is ordinarily authorized to approve alternate materials, equipment, or constructions if they can be shown as equal to or better than specified items. Unfortunately, the methods by which he is to make this decision are not adequately identified in most instances.

5. All the codes examined restrict the use of certain materials, or require the use of certain materials or constructions to the exclusion of others.* Presumably these restrictions or exclusive requirements are not part of any recognized standards on the materials or equipment involved, and ordinarily are related to installation, use, or environmental factors.

6. Some local authorities who maintain laboratory facilities, issue an "accepted products" list, and require listing of certain plumbing materials and equipment as a prerequisite to its general use in the particular locality. Evidently many items on such listings are those for which no generally recognized standards have been issued.

7. Removal of all code statements that require or limit the use of specific materials, and their replacement by adequate performance language would be very desirable. However, this could be satisfactorily accomplished only if a suitable substitute were offered. Ideally, adequate evaluative techniques in the form of performance requirements and associated test methods should be provided to the maximum degree possible. However, this solution would be expensive and time consuming and probably could never entirely suffice for innovations. Thus, it might be necessary to establish a recognized body of experts and generally knowledgeable persons having access to recognized competent laboratories, authorized to develop the best possible judgment as to acceptability of new materials and other innovations that are too new to have achieved the fully-developed standards status ordinarily associated with conventional items. Recommendations from such a body would be quite valuable and probably essential to authorities administering plumbing codes of the performance type.

* subject to the provisions indicated in 4 above.

8. This review provides the basis for general recommendations for several specific, needed technical investigations. The most important of these follow:

   a. An investigation to establish the patterns of user-imposed loads in relation to demand for water distribution and sanitary waste transportation, and for hot-water supply. From this, recommended methods of estimating peak loads for design purposes could be improved.

   b. An investigation to formulate and standardize criteria for design of rainwater collection and drainage systems, taking into account the utilization of peak rainfall data and applicable hydraulic phenomena.

   c. An investigation to develop techniques for evaluating the hydraulic adequacy of installed water distributing and sanitary drainage systems without particular regard to pipe sizes or system configuration. Development of these techniques or test methods would require trials on simulated systems in the laboratory, and on installed systems in the field.

   d. An investigation of hydraulic and pneumatic performance of novel, simplified sanitary drainage systems, including development of recommended critical design rules for the guidance of plumbing designers, installation contractors and inspectors.

   e. An investigation to develop recommended methods of evaluating and minimizing noise in plumbing, and of evaluating noise-reducing devices.

   f. An investigation to develop new or improved test methods to evaluate hydraulic and thermal performance of plumbing equipment, materials, and devices, with due attention to water conservation, safety, and avoidance of contamination of potable water supplies.

   g. A study on the feasibility of non-hydraulic means for disposal of fecal matter and food wastes, and to develop recommended test methods.

   h. An investigation to develop recommended procedures to minimize the effects of corrosion, liming, or deposition in pipes.

   i. An investigation to develop recommended test methods relating to fire safety of plumbing materials.

   j. A study to develop essential design criteria and installation rules for industrialized plumbing units.

k. A study to establish design and installation recommendations that would reduce long-term maintenance, and facilitate servicing or replacement. This might also include development of methods for evaluation of additive substances.

l. A series of investigations to develop new or improved methods for simulative testing that would permit realistic estimates of probable durability of materials and durability of essential functional characteristics of systems, devices, and equipment.

m. A study of the feasibility of developing "function-oriented" standards for plumbing fixtures, piping, and fittings, without particular regard to materials. For example, a single standard for piping for use in sanitary drain-waste-vent systems might be considered. Another standard for sanitary plumbing fixtures of any material might be considered.

5.1.4 Partial Listing of Published Sources of Information on Present State of the Art for Plumbing.

1. U. S. Public Health Service Drinking Water Standards, PHS Publication 956, U. S. Public Health Service, Washington, D. C.

2. Water Supply and Plumbing Cross Connections - Hazards in Household and Community Systems, PHS Publication 957, Government Printing Office, Washington, D. C.

3. Performance Characteristics for Sanitary Plumbing Fixtures, BRAB-NAS-NRC, in process as a NAS Publication obtainable from The National Academy of Sciences, Washington, D. C.

4. American Standard National Plumbing Code, USASI A40.8-1955, U.S.A. Standards Institute, 10 East 40th Street, New York, N.Y.

5. State Building Construction Code Applicable to Plumbing, Bull. No. 23, New York State Building Code Bureau, 393 Seventh Avenue, New York, N. Y.

6. Southern Standard Building Code - Part III, Plumbing, Southern Building Congress, Brown-Marx Building, Birmingham, Alabama.

7. Uniform Plumbing Code, International Association of Mechanical and Plumbing Officials, Los Angeles, California.

8. Recommended Minimum Requirements for Plumbing, BH 13, U. S. Department of Commerce, Washington, D. C.

9. Plumbing Manual, BMS 66, U. S. Department of Commerce, Washington, D. C.

10. Code of Practice for Building Drainage CP 301, British Standards Institution, London, England.

11. Code of Practice for Soil and Waste Pipes above Ground, CP 304, ibid.

12. Code of Practice for Water Supply CP 310, ibid.

13. Code of Practice for Durability CP 3 - Ch. IX, ibid.

14. Code of Practice for Sound Insulation and Noise Reduction CP 3 - Ch. III, ibid.

15. Code of Practice for Precautions Against Dirt and Vermin CP 3 - Ch. X, ibid.

16. Frost Precautions for Water Services CP 99, ibid.

17. The Building Standards Regulations (Scotland) - 1963, No. 1897, HMSO, London, England.

18. The Building Regulations - 1965, No. 1373, ibid.

19. National Building Code of Canada - Part 7, Plumbing Services, Nat. Research Council, Ottawa, Canada.

20. Trinkwasser-Leitungen in Grundstucken-Technische Bestimmungen fur Bau und Detrief, DIN 1988, Deutschen Normenausschuss, Beuth-Vertrieb Gmb H, Berlin, Germany.

21. Grundstucksentwasseringsanlagen - Technische Bestimmungen fur die Bau, ibid.

22. Amer. Standard Approval Requirements of Gas Water Heaters, USASI Z21.10.1 - 1966, U.S.A. Standards Institute, 10 E. 40th Street, New York, N. Y.

23. Amer. Standard Listing Requirements of Relief Values and Automatic Gas Shut-off Services for Hot-Water Supply Systems, USASI Z21.22-1964, ibid.

24. Approval Requirements of Electric Water Heaters, UL-174, Underwriters Laboratories, Inc., 207 E. Ohio Street, Chicago, Illinois.

25. Sources for Standards and criteria relating to various materials, devices, and equipment forming portions of plumbing systems:

    a. National Sanitation Foundation, Ann Arbor, Michigan
    b. U.S.A. Standards Institute, 10 E. 40th Street, New York, N. Y.

c. Amer. Soc. for Testing and Materials, 1916 Race Street, Philadelphia, Penna.
d. Canadian Standards Assoc., 77 Spencer Street, Ottawa 3, Canada.
e. British Standards Institution, Newton House, 101/113 Pentonville Road, London, N. 1, England.
f. Deutschen Normanausschuss, Beuth-Vertrief, GmbH, Berlin 30, Germany.
g. International Association of Mechanical and Plumbing Officials, Los Angeles, California.
h. American Society of Sanitary Engineering, 228 Standard Building, Cleveland, Ohio.
i. U. S. General Services Administration, Federal Specifications Branch, Washington, D. C.
j. Office of Products Standards, National Bureau of Standards, Washington, D. C.
k. American Waterworks Association, 2 Park Avenue, New York, N. Y.
l. Federal Housing Administration, H.U.D. Department, Washington, D. C.

26. Miscellaneous Sources of Information pertaining to Plumbing and/or Sanitation in housing:

a. U. S. Public Health Service
b. State Department of Health
c. Amer. Public Health Association
d. Amer. Soc. of Sanitary Engrg.
e. National Sanitation Foundation
f. U. S. Department of Agriculture
g. U. S. Department of the Army
h. U. S. Department of the Navy
i. U. S. Department of the Air Force
j. National Bureau of Standards
k. British Building Research Station
l. Swedish Building Research Institute
m. Amer.Waterworks Assn.
n. University of Iowa
o. U. S. Department of Labor
p. National Safety Council

5.1.5. <u>Possible Trade-Offs or Compromise Between Performance Requirements in Relation to Plumbing</u>

5.1.5.1 <u>Trade-off possibilities between plumbing requirements</u>.

1) <u>Exchange between requirements for Venting and Water consumption</u>. That is, more stringent requirements in relation to water demand or consumption based on more efficient utilization might permit a relaxation of requirements for venting, with consequent overall cost reduction, conservation of resources, and a contribution to pollution abatement. Also more stringent requirements for water demand or consumption should yield benefits in noise control.

2) <u>Exchange between requirements for waste transportation system (drainage system) and gas-relief system (venting system)</u>. That is, more stringent requirements on sizing and configuration of drainage system might permit a relaxation of requirements for the venting system, with the strong possibility of overall cost reduction in tall buildings for low-cost housing.

3) <u>Exchange between plumbing requirements for sanitary drainage above ground and underground, so as to permit the use of oxidizing, recirculating, waste-disposal systems that would not require public, sanitary sewerage systems</u>. Such systems might be entirely self-contained on the premises, or limited to on-site installation to serve a small number of buildings. Surplus waste water rendered safe by on-premises or on-site oxidation might be discharged to the soil on-site, or to a public storm sewer or local stream. Reduced quantity of waste water and reduced BOD of the effluent would reduce cost of public sewerage works, and contribute to water conservation and water-pollution abatement. Surplus waste water might be used for irrigation purposes.

4) <u>Modification of plumbing requirements so as to permit the use of incineration techniques for fecal and solid kitchen wastes</u>. This would require an exchange between requirements based on certain plumbing criteria, as well as between requirements for plumbing versus requirements for fire safety and air pollution control. A net saving might be achieved in terms of construction cost, water conservation, and water-pollution abatement.

5.1.5.2 <u>Trade-off possibilities between plumbing requirements and other building requirements</u>.

1) <u>Modification of plumbing-system design requirements to avoid the necessity for piping within walls</u> might be advantageous in regard to simplification of wall-system requirements, yielding a more economical solution overall. Depending on the building construction method employed, it might be more advantageous to modify piping system design requirements to avoid piping both within wall panels and floor panels. In either approach, resort might be had to exposed branch pipes, with risers enclosed within adjacent pipe shafts not a part of the wall or floor system. Decorative removable shields could easily be provided to cover the otherwise exposed piping after fixtures were set.

2) <u>Modification of plumbing requirements to avoid necessity for circular conduits</u> of the larger diameters in favor of oval or rectangular conduits might permit relaxation of thickness requirements for wall and floor panels in which conduits may be have to be placed.

3) <u>Modification of plumbing requirements to avoid the necessity for gravity drainage</u>, in favor of vacuum or pressure drainage, might make it feasible to relax architectural requirements relating to space allowance for drain pitch. This might also permit the relaxation of requirements for wall and floor panel thickness in respect to panels that must include drainage piping, due to the smaller diameter of drain piping required for pressure or vacuum drainage.

4) <u>Modification of plumbing requirements to permit the use of mechanical, illumination, electrical, wall, floor, and ceiling systems that provide for "core" units</u> constructed either on-site or manufactured in modular form and assembled on-site.

5) <u>Modification of plumbing requirements to permit the use of other sub-systems of building to provide for a modular approach using complete manufactured bathrooms, kitchens, and laundry-utility rooms that could be assembled on-site</u>. The trade-offs might be as between plumbing requirements for jointing, pipe sizes, secondary ventilation, etc., and other building sub-system requirements for panel design, joining and sealant methods, and dimensional control.

Recommended Research Programs

Among the more important research programs needed are the following:

a. Collection of hydraulic load data under service conditions, in order to provide a rational, realistic method for calculating design loads and formulating test loads for use in evaluating performance of unusual water distributing systems and drainage systems.

b. Application of data obtained in (a) to the development of test methods for evaluation of the hydraulic performance of unusual or simplified drain-waste-vent (DWV) systems and water-distributing systems.

c. Development or selection of measurement techniques for evaluating plumbing noise, and study of installation techniques for reducing noise.

d. Collection of data on performance aspects in relation to incineration of fecal matter and solid food waste, and the development of criteria for evaluating such equipment.

e. Development of improved test methods for evaluating hydraulic and/or thermal performance of plumbing appliances, appurtenances, fixtures, and pipe fittings

f. Development of data on corrosion and liming in water distribution piping, and on fouling and deposition in drain piping. From this, develop recommendations on the management of such deleterious actions to reduce maintenance and replacement costs; and to aid in the selection of materials, in the evaluation of plumbing equipment performance, and in water control.

g. Collection of data on behaviour of plumbing materials in fires, in order to establish criteria for fire ratings and recommendations for protective measures in installation.

h. A study to provide data on performance of, and test methods for evaluating, joints and connections for piping systems with particular emphasis on applications of industrialized units for multi-story work.

i. Development of performance tests for resistance of piping to bursting, fire effects, impact, puncture, crushing, deflection, chemical attack, dimensional stability, and corrosion, without particular reference to the type of material.

j. Development of improved tests for evaluating wear in hydro-mechanical assemblies utilized in plumbing appurtenances and appliances.

As to relative importance of the recommended programs, items a, b, h, and i are probably of the greatest importance. Perhaps the most difficult and costly item would be item i.

AREAS OF NEEDED WORK IN RELATION TO PLUMBING RESEARCH AND TEST DEVELOPMENT, IN SUPPORT OF ADEQUATE STANDARDS*

Essential Require-ments**	Need	Explanation or Example
2	Standards for water consumption efficiency of fixtures, appliances, etc.; Standard procedure for sizing water piping; Standard method for determining residual pressure in in-situ evaluations, or in mock-up installations.	Sanitary operation with minimum representative consumption and min. peak demand of water; size on representative basis of probable user demands, velocity, temperature, and chemical content of water; field tests needed to establish ability of installation to satisfy essential requirements of sanitary functioning of equipment.
3	Standard procedure for sizing water-heating equipment and hot-water distribution piping.	User demand for hot water (peak instantaneous and hourly) is important element of procedure for selecting water heaters and sizes of hot-water piping.
4	Updating and expansion of stds. for devices to protect against backflow; Std. procedure for backflow and cross-connection control.	Rules for installation and tests for evaluation of devices not adequate for new devices and installations; USASI Stds. over 20 years old.
5	Standard procedure to evaluate volume and temperature control of hot-and-cold water mixing faucets and valves.	No test method in general use in America; essential to rational evaluation of safety aspects of these devices.
7	Std. procedure to evaluate flooding or overflow potential of sanitary drainage systems in-situ, or in mock-up installations.	No test method having general acceptance; essential to evaluate unusual designs of DWV systems.

NOTES: * The term "standards" is used herein to refer broadly to specifications and codes-of-practice, as well as generally accepted standards on materials, devices, and equipment; and may refer to test methods also.

** Numbers in this column refer to the correspondingly numbered essential performance requirements listed in Table 1 of Section 5.1.

8	Standard procedure to evaluate adequacy of gas barriers in-situ, or in mock-up installations.	No test method having general acceptance; essential to evaluate unusual design of DWV systems.
7, 8	Stds. for design and installation of sanitary drainage systems with simplified venting.	No code-of-practice recommendations in America relating to special, cost-saving simplified vent systems.
9	Standards for noise control in plumbing.	No detailed, std. installation rules prescribed in American practice; control of noise needed through installation and design rules, use of special shock-arresting or pressure-reducing devices; stds. for performance and installation of devices needed.
11	Std. procedures for hydraulic sizing of gutters, leaders, conductors, and flat roof collection systems.	Updating of hydraulic capacity basis needed, along with greater utilization of Weather Bureau data; utilization of storage for leveling out of temporary storm peaks, for flat roofs.
12	Stds. for plumbing equipment and installation to minimize physical contact with potentially contaminated surfaces.	Need for design of bathroom and kitchen facilities, laundry room facilities, to reduce chance of physical contact between users and potentially contaminated or contaminable surfaces; concerns fixture shapes and types, work surfaces and their location, door hardware, water control valves, etc.
13	Stds. for installation and design that provide for convenient access for maintenance and servicing, and that avoid excessive need for maintenance.	Present-day code prescription specifications need reworking and up-dating, so that they might take the form of a separate code-of-practice or a standard for maintenance and servicing potential.

14	Std. procedures for simulative testing in relation to evaluation for durability of materials or functioning of systems or equipment. Evaluation of probable effects of abrasion, impact, corrosion, chemical attack, thermal failure, delamination, radiation, dimensional instability, staining aging, wear.	Approach: Develop essential requirements relating to durability without particular regard to materials - for example, a single type of test for chemical resistance of drain-waste-vent (DWV) pipe should be applied to all candidate materials, and should suitably simulate service exposure conditions, with an allowance for accelerative effect if a satisfactory time-effect correlation can be established. Other needs in this area include: test methods for evaluating resistance to thermally-induced breakdown; corrosion; aging; dimensional instability; and wear.
15	Std. procedures for simulative testing in relation to fire safety of plumbing materials.	Devise tests to evaluate fire-load contribution; smoke and toxic-gas contribution; resistance to collapse in fire; develop a code of practice for installation that will reduce hazards due to fire exposure of plumbing.
17	Std. rules of installation to assure structural adequacy of plumbing system and avoid undue weakening of other subsystems of building.	Concerns hangers and supports; trenching and excavation procedures; attachment means; cutting, boring, or notching of structural members; allowances for settlement, thermal movement, etc. A standard code-of-practice for installation seems needed here.

5.1.6 ESSENTIAL PERFORMANCE REQUIREMENTS OF BUILDINGS THAT HAVE RELATIONSHIP TO HEALTH

Requirement	Pertinent Building System Elements
Potability of water.	Drainage, plumbing equipment, water source, water distribution in building.
Control of generation, emission or transmission of harmful gases and particulate matter.	Plumbing, heating, ventilating, air-conditioning, service shafts, access systems, fire and smoke-control management.
Drainability.	Plumbing, waste disposal, rainwater disposal.
Adequacy of water quantity and rate at outlets.	Plumbing, heating.
Avail. of hot water.	Plumbing, heating.
Cross connection and back flow control.	Plumbing, heating, air-cond., waste disp., storm drainage.
Vermin and rodent management.	Plumbing, heating, air-cond., waste disp., ventilating, service shafts, access systems, walls, floors, ceilings, roofs.
Illumination.	Lighting (artifical and natural)
User comfort and convenience compatibility--dimensional and configuration aspects.	Plumbing, walls, floors, access systems.
--thermal, psychometric, and air movement aspects.	Heating, air-cond., ventilating.
Control of Moisture condensation.	Plumbing, floors, walls, ceilings, roofs, air-cond., ventilating.

ESSENTIAL REQUIREMENTS - Continued

Requirement	Pertinent Building System Elements
Control of leakage, spillage, or overflow of deleterious liquids; aerosol generation control.	Plumbing, waste disp., air-cond., heating, rainwater disposal.
Resistance to soiling.	Plumbing, floors, walls, waste disposal.
Cleanability.	Plumbing, floors, walls, waste disposal.
Minimization of contamination by contact with unsanitary surfaces.	Plumbing, waste disp., food-services systems, access systems.
Durability and maintenance potential.	All systems named above, insofar as their functional characteristics are pertinent to health.

NOTE: While primarily safety-related rather than health-related, the following requirements are recommended:

1. Snow and ice management, in relation to roofs, access systems, and site links.

2. Slipperiness control in relation to plumbing, floors, and access systems.

5.2 FOOD SERVICES

5.2.0 Executive Summary

Present Standards

Food service equipment and facilities for low-income housing differs from that for speculator housing in that the equipment to be furnished must respond to actual needs rather than to buyer appeal to help sell the house. This creates a problem in that there are no recognized standards describing actual user needs for food service equipment. Present practice in guide specifications such as FHA Minimum Property Standards is to spell out specific items to be furnished. Similarly many building codes require minimum equipment items. Trade association standards, USA standards, and federal specifications for specific equipment items are available for reference which offer performance requirements and test procedures in varying degrees, but do not indicate what sizes, capacities or performance levels are needed by a range of occupancy groups. For example, USA Standard B38, now under revision, contains test procedures, methods of measuring size, etc. of refrigerators, but does not suggest what size or type is required; AHAM Standard HS-1 for automatic dishwashers does suggest capacity ratings in terms of defined "place settings" but includes only limited test procedures; Federal Specification W-R-101e(3) describes tests for electric ranges, but does not indicate how many elements, or how much oven space is needed; similar variations in technical coverage are typical of most other item standards now in use.

Suggested Short-Term Investigations

Existing capability of home economics personnel, equipment designers, and housing planners should be convened to prepare guidelines, based on available information and expert judgment, describing user needs in low-income housing for the following elements of food service:

1. Adequate cooking facilities
2. Food preparation surfaces
3. Basic utensils and storage for utensils
4. Water supply
5. Adequate food storage
6. Food serving, dispensing, dining facilities
7. Cleaning facilities
8. Waste removal facilities
9. Protection from rodents and vermin
10. Optimum physical arrangement
11. Adequate lighting and ventilation

Another program which can be started promptly is the systematic revision and analysis of the many available specifications and standards for food service items to determine immediate needs for revision and improved test methods to meet the user requirements now recognized and those to be established.

Consideration should be given to the feasibility and acceptability of using community food services to minimize individual equipment needs.

5.2.1 Rationale for Performance Requirements - User Needs

The need for food in adequate quantity, quality and variety to nourish life is basic. The user needs to which attention is directed in this discussion relate to only one part of the process of providing food for occupants of low-income housing, that of describing the requirements for the elements of housing needed to effect the storage, preparation, and serving of food and maintenance of such facilities in a safe and effective manner. Not included are requirements for the selection of food (for variety, food value, nutrition, vitamin content, etc.) or for its preparation (cooking, flavoring, seasoning, etc.), these factors being controlled by the predilections and capabilities of the occupant.

It is recognized that there are many customs and desires of different groups or varieties of people which may alter the requirements for food service facilities, and other parts of this broad study (such as rural poor, Indian, etc.) may identify some of these special desires.

The question of group or community food services as compared with individual food services in each dwelling unit must be considered. It seems likely that the majority of dwelling units for low-income housing for the near future at least will be oriented around the family group and that individual food service facilities will be the present option. Many community-type feeding arrangements already exist, however, and the designer of future housing should not ignore this concept. Day-care centers, central-kitchen meal services for young, old or dependent persons, cafeteria-type facilities for dormitory housing, are examples of such food services for existing group housing. Particularly if large structures with many dwelling units, such as high-rise apartments, are considered, the opportunity is present to provide central food-service facilities, with possible attendant reduction in the multiplicity of individual facilities. The feasibility, and acceptability, of central vs. individual food-services needs to be studied before devoting much effort to the specialized needs of a central facility.

While the purposes of food-service systems are the same for central vs. individual kitchens, i.e., to provide food for the occupants, the responsibilities and involvement of the occupants is quite different. For example, in the central facility, all equipment and labor must be provided by the operator, whereas in the individual facility, each occupant usually provides much of the food service equipment and the building operator only the major items.

5.2.2 Generalized Performance Requirements

During the prospective useful life of the housing, the food service system must provide the following facilities for the occupants of the housing to use in satisfying their needs and hospitalities:

1. A means for cooking food by simmering, boiling, frying, baking, and broiling.
2. A means for preparation of food for cooking or serving.
3. A means for serving food and drink.
4. A means for cleaning and washing food service equipment.
5. A means for disposal of associated waste materials.
6. A means for storing and preserving the food supplies before use, and the leftovers of meals.
7. A means for storing dishes, flatware, utensils, and other related food equipment when not in use.

5.2.3 Additional Performance Requirements for Currently Used or Known Solution

Expanding on the general requirements in 5.2.2, and considering currently-used solutions, the performance requirements must incorporate at least the following.

1. Adequate cooking facilities.
   a. stove
   b. oven

2. Food preparation surfaces.
3. Basic utensils, and storage-space for all utensils.
4. Potable water supply.
5. Adequate food storage
   a. refrigerator
   b. freezer
   c. dry storage
   d. liquid storage

6. Food serving and dispensing facility.
   Dining facility and utensils.
7. Cleaning facilities.
8. Waste removal facilities
   a. garbage
   b. kitchen trash
   c. liquid wastes

9. Protection from vermin and rodents.
10. Optimum physical location of food storage, preparation, dispensing areas, and optimum arrangement of food service items to minimize lost motion.
11. Adequate lighting.
12. Adequate ventilation.
13. Other

1.* For all practical purposes, cooking of food refers to a heating process. The principal variant is the type of fuel--wood, coal, gas, oil, electricity (resistance, induction or microwave)--and fuel selection will be made on the basis of overall project design considerations. Regardless of the type of heating, safety of the user is a specific requirement and must include protection from burns, scalds, cuts, impact, shock, contamination, fire, toxicity, and others. Performance requirements to meet user needs for temperature control, temperature distribution, durability, appearance, cleanability, and size (capacity) should be described, with regard to the type of heating appliance. A stove and oven is customarily furnished with housing.

2,3 Preparation of food involves utilization of equipment of many degrees of sophistication. A determination has to be made of the devices and facilities to be furnished as a part of the dwelling unit. In current practice this is done rather arbitrarily, usually along "customary practice" lines. Minimum food-preparation surfaces and utensil-storage areas are normally specified in the building design but are seldom described in performance language.

4. Kitchen water supply, both hot and cold, along with a sink, is normally required by an applicable housing or plumbing code, as well as being included because of customary practice. Performance requirements should be developed for these items, as for many other food service elements, based on better analysis of real user needs than exists at present.

5. Adequate food storage is one of the major kitchen needs and is seldom described in performance language. It is customary to furnish a refrigerator, usually with a freezer section, and some minimum shelves and cabinets based on guide specifications which have usually been developed along "customary practice" lines.

6. Food dispensing and serving facility and dining facility are usually developed by the occupant utilizing furniture and utensils of his own. The need for improved performance requirements in this area relative to the building relates to space, and equipment orientation. For community-feeding facilities specialized requirements for dispensing and serving equipment must be developed in relation to the size of the facility.

7. Cleaning facilities in relation to food service normally relate to means for washing food, utensils, dishes and food serving and

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*These numbers refer to listed items above.

and handling equipment. It is difficult to determine whether a well-designed sink with hot and cold water adequately meets this need, or whether performance requirements should require, for low-income housing, such devices as automatic dish washers. In any event performance requirements need to be developed. One aspect of kitchen design for which performance requirements are needed is that of means for keeping the kitchen itself clean--walls, floors, shelves, work surfaces, etc. Protection from vermin and rodents must be considered in developing performance requirements for kitchens.

8. Adequate waste removal facilities are vital to effective kitchen operation. The waste removal process must be convenient to use, free from odor, readily maintained, and adequate for the demand. Automatic garbage disposal units connected to the building sewer may appear to be a luxury item for low-income housing but may be an effective means of minimizing the garbage disposal problems. Incinerators or other refuse collecting means must be convenient to use, safe, effective, and not be a nuisance or hazard to the surrounding property or atmosphere. If trash and garbage receptables with scheduled pick-up are employed the performance requirements for the system must recognize the separate responsibilities of both the occupant and community.

9. See No. 7

10. See No. 6

11,12. With regard to lighting and ventilation of kitchens, customary solutions are entirely empirical. In other sections of this report, needs for development of performance requirements in these areas are discussed in more detail.

5.2.4 Existing Standards

A number of organizations considered to be likely sources of existing standards for food-service requirements for low-income housing were contacted as a part of this limited investigation. Some of the contacts were:

American Home Economic Association
U. S. Department of Agriculture
Farm Housing
Home Economics
National Association of Home Builders
Cornell Center for Housing and Environmental Studies
University Home Economics Groups
Appliance Manufacturers
Consumer Testing Groups

In general the reply from these and other individuals, after the distinction between performance requirements based on the user's needs and performance requirements for systems or devices which are solutions for these needs was emphasized, was that, in effect, no standards or recognized performance requirements directly based on user needs could be singled out for reference.

Many standards or guides such as FHA Minimum Property Standards, DOD Family Housing Guides, etc., were cited, as were numbers of local or state codes, and others. All of these, on examination, are in fact specifications for minimum devices or facilities to be provided, not performance expressions of user needs. This is not to say that these specifications lack basis in good judgement or that they were not based on analysis of user needs. It is likely that, if the needed research is undertaken to determine or define user needs, many of these traditional or empirical developments of specification solutions may well be shown to meet the user needs or performance requirements. Appliance manufacturers and home builders claim to have criteria for determining what is needed in the way of food-service equipment but acknowledge that commercial sales features exert the major effect on design, sizing, appearance, etc.

Many standards, specifications, recommended practices, test methods, rating procedures, etc., exist for equipment and are in use. It must be emphasized that in practically every case, these standards address themselves to the performance or construction of a given device or system, not to the evaluation of the degree to which the device or system meets a user need. For example, test procedures are available for and in use to evaluate size, performance, and other characteristics of refrigerators, but not to determine what size or temperatures are required to meet the needs of various family groups.

Organizations producing standards, etc., for devices used in food service systems include

- American Gas Association
- Edison Electric Institute
- USA Standards Institute
- U. S. Department of Agriculture
- U. S. General Services Administration - Federal Standards and Specification
- U. S. Department of Commerce - Product Standards
- Association of Home Appliance Manufacturers
- National Fire Protection Association] Safety of
- Underwriters Laboratories] Devices
- Gas Appliance Manufacturers Association
- Institute of Appliance Manufacturers
- American Society of Heating, Refrigerating and Air Conditioning Engineers

National LP-Gas Association
State and Local Codes
National Sanitation Foundation

Other groups such as

National Association of Home Builders
Mobile Home Manufacturers' Association and
Trailer Coach Association

include reference to food service equipment in documents referring to the overall dwelling design.

Many of the standards-producing groups coordinate efforts. For example, many documents are issued both by a sponsoring group and also as a USA Standard.

Because lists of these documents are readily available from the various groups or can be supplied by NBS, the titles are not given here.

5.2.5 Standards Needed

From the preceding discussion it follows that standards, expressed in performance language, and directly relating to user needs must be developed for practically all aspects of the food service system. From comments of the several organizations identified above, it seems likely that many of the necessary studies, surveys, analyses, etc., needed have been made and if coordinated could produce valid performance requirements which will satisfy user needs.

5.2.6 Future Research

1. Determination of existing research and coordination to produce performance requirements directly expressing user needs for food-service systems in low-income housing.

   It has been suggested by some of the organizations contacted during this investigation that a conference of individuals with background in the home facilities design field should be called to explore the development of performance requirements. Mr. Alexander Kira, of the Cornell Center for Housing and Environmental Studies, whose book, "The Bathroom-Criteria for Design" deals with research leading to user performance requirements for the bathroom, expressed the opinion that such a conference, perhaps under HUD sponsorhip, would be a good starting point. He confirmed the apparent lack of research-based performance requirements for many elements of housing design, including food services.

2. Review and analysis of the value of the many equipment standards, specifications, etc., available and in current use. Time limitations of this investigation precluded such review and analysis for this report.

3. Development of test procedures to support new performance requirements for both direct relation to user needs and for performance requirements for devices and systems.

5.2.7 Possible Trade-offs

Combination of functions in kitchen area of the dwelling unit, such as laundry and food services, increased use of "built-in" devices may result in improved utility with lower cost and space requirements. Many research projects in home economics, schools and extension services groups can be examined for such innovation possibilities. Such review and coordination may be a justified area for future research. Extensive bibliographic material has been cited by the organizations contacted and can be made available if such a review is implemented.

5.3 ENERGY SOURCES

5.3.0 Executive Summary

There are approximately a dozen different types of fuel or sources of energy available for use in buildings. However, the predominant types used in houses are gas, fuel oil, coal, and electricity. There are existing test methods and specifications for measuring and describing the requirements for these fuels that are related to safety, convertibility, controllability, ease of distribution, cleanliness, reliability, combustion and disposal of waste products. These are already in use.

The use of other fuels or energy sources such as wood, gasoline, solar energy, nuclear energy, and pressurized fluids is confined to special applications or circumstances that have revealed an economic benefit.

The most promising avenues for research are in more efficient utilization of fuels based on (a) more economical central generation, (b) more economical distribution from a central source or within a building, (c) developing more efficient combination systems using more than one energy source, (d) combining all energy production into one on-site piece of apparatus or (e) improving the diversity of usage among many appliances or many buildings.

Objective techniques for evaluating the overall cost of energy generation, distribution, and usage in a large building have not been standardized so the economy of different fuels or energy systems could be effectively compared. Such an evaluation system is needed for design purposes.

5.3.1 Rationale for Performance Requirements

In connection with the study for this project of use of electricity in low-cost housing, it was pointed out that the user does not, in fact, need electricity--he needs heat, light, power, etc.--which may be obtained through the use of electricity. As a practical matter, it is recognized that electricity will be used in most, if not all, housing.

Other energy sources must be considered. These other sources, in company with suitable mechanical systems can meet definable user needs. These other energy sources include:

1. Wood (and other fibrous natural materials)
2. Waste materials
3. Coal (of numerous grades and quality)
4. Oil (of numerous grades and quality)

The different grades identify quickly with specific groups of user needs; for example, kerosene may be used in stoves or small space heaters, No. 6 fuel oil is normally adaptable only to larger, complex energy conversion systems.

5. Gasoline
6. Gas, natural or manufactured
7. Gas, liquified petroleum, such as propane, butane, etc.
8. Solar
9. Water, wind
10. Nuclear
11. Electricity. In the sense that electricity is usually delivered from an off-site utility source to the user on his demand, it can be considered as an energy source. Depending on the nature and type of housing involved (urban, remote rural, high-rise, etc.) electricity will be produced on- or off-site through utilization of one of these other energy sources. In this sense electricity serves primarily as an energy-transfer or energy-conversion stage to perform some directly-related user need.
12. Fluids under pressure for power, motion, heat transfer, such as hot or cold brine, steam, compressed air, etc., as could be distributed from a central facility. (Most of these will result from on-site conversion from another energy source).

5.3.2 Generalized Performance Requirements

The performance requirements relating to energy (or fuel) usage become directly involved with the devices or mechanisms for converting the energy into the form or effect desired by the user.

Recognizing this, the generalized performance requirements for the various energy forms can be described. In many cases, two or more forms of energy may be combined within the housing environment to accomplish a needed function. For example, oil burned in a boiler heats water which is then circulated through a number of individual dwelling units to provide heat. Depending on the point of reference, the oil or the hot water may be considered as the energy source.

Regardless of the means for utilizing energy, the energy to be used for housing, taking into account the devices for utilizing it, must meet the following requirements.

1) Safety. It must be capable of being supplied (or stored) and used in such a manner as to not cause harm to persons or property by temperature, flame, toxicity, contamination, explosion, shock (electrical), impact, weight, radiation, excessive noise, vibration, cutting or macerating action.

2) Availability. It must be available on demand (either from on-site storage or off-site source), in adequate quantity, at acceptable levels to meet the minimum need. The source of supply must be dependable both in terms of quantity and quality, and in response to demand.

3) Convertibility. Because the energy, in most cases, is not needed as energy but as some function of energy, it must be capable of effective, safe, efficient conversion to produce the desired function.

4) Controllability. Together with the related converting devices it must be controllable as to rate, safety limits, force limits, capacity for performance of the desired function, and effectiveness.

5) Distribution. Assuming adequate availability at the entrance to a building, it must be capable of effective and safe distribution to the points of use within the building.

6) Cleanliness. The use of energy must be accomplished in such a manner that the supply, storage or use of the energy, or disposal of waste products, is clean enough to be acceptable from safety, maintenance, aesthetic, or legal standpoints.

7) Cost. When all factors are considered--raw fuel cost, transportation, storage, distribution, equipment cost, operational efficiency, etc.--it is possible that a number of energy forms or conversions may be utilized within a single structure to achieve the best cost effectiveness.

5.3.3 Specialized Performance Requirements

Each different form of energy, or combination of energy forms, presents special requirements for safe, effective use. In most instances the overall acceptance cannot be evaluated without simultaneous consideration of the devices for storage, transmission or conversion of the energy into an effect in direct or indirect response to a user need.

All forms of energy which require on-site storage must be capable of safe storage. The material must not deteriorate in storage so as to become unusable or dangerous. Procedures for replenishing the supply must be practical and safe.

Energy forms which involve on-site combustion must be capable of safe containment of the combustion process and the combustion waste products must be handled in a manner which does not endanger the surrounding persons, property or environment. If the waste products are discharged into the atmosphere, the effluent must not contain elements of radioactive, chemical, or particulate nature detrimental to the environment or in excess of legal requirements which may be applicable. The energy conversion systems which have liquid or solid wastes must provide for safe, practical removal from the site.

Energy conversion systems, including the devices required, must be capable of responding to both normal and abnormal conditions (overload, overtemperature, overpressure, failure of one component, etc.) without violating acceptable safety limits.

Energy utilizing systems which involve distribution within the normally-occupied portions of the housing unit must provide for adequate transmission, proper safety to occupants and the building, and effective control. The special needs for electrical distribution are described in another part of this report.

It is recognized that all available forms of energy can conceivably be used somewhere in the broad range of multi-family housing but in the sense of state-of-the-art, a few energy forms predominate. These will be described in more detail in the following special-requirements reference to the previously listed forms of energy:

1) Wood (and other fibrous natural materials). Use of these materials will probably be limited for most multi-family housing. In some rural areas, ready availability and local custom may result in its use. Storage, reasonably protected from weather and infestation by rodents, is needed. Wood-burning systems are usually manually-controlled which requires protection from overtemperature and proper venting of combustion products. If fireplaces are provided suitable stacks must be included.

2) Waste materials. As used here this refers to large-scale systems such as gas generation from sewage treatment plants, solid fuels prepared from community trash collection, etc. As such they may be of marginal interest to this project.

3) Coal. Many factors indicate only limited use of coal for new multi-family housing. Delivery and storage problems, cost of air pollution protection equipment, cleanliness of storage and ash removal facilities, fire-rate controllability are among these factors. For small manually-controlled systems the same safety precautions are required as for wood.

4) Oil. The several grades of oil constitute a major energy form for use in multi-family housing. While kerosene may have limited application, it must be considered with concern for safety, particularly where manual filling of small tanks is required. Fuel oil grade Nos. 1 and 2 are widely used in residential oil-burning equipment (No. 1 used primarily in pot-type or vaporizing burners) and can be used in larger systems. Safe vented storage must be provided with provision for minimizing storage deterioration of the fuel. Protection against corrosion or other deterioration of the storage vessels must be provided. Means for removing water and other contaminants (resulting from handling and storage) from the fuel must be included in the system. Burners and burning systems must be equipped with means for protection of persons and property against fire, explosions, toxicity, shock, chemical damage due to fuel leakage, odor, smoke, noise, vibration, dirt, and air pollution. Fuel must be selected from acceptable specification grades to obtain adequate performance. Proper storage temperature must be provided. Other details of oil burning systems are described in the section on mechanical equipment. For the larger installations utilizing the heavier grades (Nos. 4, 5, 6) the requirements are similar. Additional provisions are required for heating the fuel to expedite handling and preheating for effective firing.

6) Gas, natural or manufactured. This fuel is a major energy source for multi-family housing. It is normally supplied on demand from off-site storage or pipe-line systems. With proper burners it can be burned directly in occupied spaces for cooking and small capacity space heating. Larger capacity space heaters, water heaters, and all furnaces must be stack-vented. Fuel specifications, usually required by public law, must be adhered to. As with other combustion systems, safety requirements of fire, explosion, etc., must be considered. Because the fuel is distributed through parts of the occupied space, connections must be leakproof under all reasonable conditions of use. In many locations, strict codes pertain to gas piping. Larger systems using engines driven by natural gas are used to provide power, cooling and heating.

7) Gas, liquified petroleum. Propane and butane are the principal gases of this type used for multi-family housing, usually in areas not serviced by utility gas lines. Cooking, water heating and space heating apparatus is available for use with this fuel, and small engines can be operated. The safety precautions pertaining to distribution and burning of natural gas also pertain to these fuels. In addition the storage containers and handling equipment must be selected in strict conformance to safety and other performance requirements. The storage vessels must be protected against physical damage and kept in a well-ventilated place (usually on the building exterior). Pressure regulators and tank connections must be kept in good working order.

8) Solar. Much experimental attention is being directed to systems using solar energy to heat water, provide space heating, and produce power. At the present state of the art, it is not likely that wide use will be made of such systems for multi-family housing. Careful attention will be given to such systems for possible future consideration.

9) Water, wind.

10) Nuclear. At the present time, these energy sources are used, in varying degrees, to provide power for producing electricity. Some wind-powered water pumping may be used. As far as multi-family housing is concerned, the electricity produced by such systems is the energy form to be considered, the same as if it were produced from coal, gas, or oil-powered systems.

11) Electricity. The distribution and utilization of electricity and the specific requirements therefor, have been discussed in considerable detail in another section of this report.

12) Fluids under pressure. In some locations, central power or heating facilities may be used to cool, heat or provide power in multi-family housing. Steam, hot or cold brines, compressed

air, water (under pressure for power) are used. The specialized requirements for utilization of such energy sources are related to the safety, dependability, adequacy of supply, rate of response to demand, and effective conversion.

13) Chemical or other. Not directly related to multi-family housing.

5.3.4 Existing Standards and Specifications

Many standards and specifications related to the use of energy are concerned with requirements for storing, transmitting, or utilization of a particular type, or installation of the system, rather than the characteristics of the fuel itself. Standards and test methods for various fuels have been developed by groups such as AGA, EEI, API, ASTM, SAE, the Federal government and others. For example, ASTM Materials Specifications for Fuel Oils, D-396-60T, provides test methods and a grading system for fuel oils with respect to many of the properties important to utilization. This Standard classifies fuel oils relative to viscosity (important to ease of flow and atomization), flash point (ease of ignition and safety), pour point (important to outdoor storage), water and sediment (related to fouling and corrosion), sulfur (related to atmospheric pollution and corrosion), ash (related to wear of pumps) and distillation temperatures (important to vaporization). Likewise, the proximate analysis of coals determines the percentage of moisture, volatile matter, fixed carbon, sulfur, and ash which are of interest to the user in relation to particular types of fuel-burning equipment. Other important properties of coals are screen sizes, ash softening temperatures, friability, caking properties, and the qualities of the volatile matter. Most of these properties are related either directly or indirectly to the general performance requirements for safety, convertibility, controllability, distribution, cleanliness, and disposal of waste products stated heretofore. Specifications and other purchase documents use these parameters to obtain fuel characteristics suited to the combustion or conversion equipment in which it is to be used. The properties of fuels, and characteristics of the various grades are readily obtainable from the industry groups concerned with the furtherance of use of their respective types. Typical of organizations are:

American Gas Association
Edison Electric Institute
American Petroleum Institute
National Oil Fuel Institute
National Coal Association
National L-P Gas Association
American Society for Testing and Materials

5.3.5 Future Research

Selection of a fuel for housing is made on the basis of several factors (safety, availability, etc.) with expected long-term cost as one of the most important. Effectiveness of utilization directly affects cost so that, in planning ahead for future housing, it is incumbent on those who will select fuels to encourage research and development of improved means for energy distribution and utilization. Some of the areas to be investigated further include:

1) Improved means for large-unit generation and transmission of electric power, such as nuclear power plants, mine-heat plants, low loss transmission, etc.

2) Improved means for central plant generation of steam, hot water, or other fluids combined with effective underground distribution to individual buildings.

3) Development of improved methods for treating fuel to reduce or eliminate air pollution as a consequence of its use.

4) Development of fuel-using systems which utilize higher percentages of available energy, such as those which provide water heating or absorption refrigeration operation using exhaust gases from power units for other purposes, such as on-site generation of electric power.

5) Improvement of heat-pump types of heating devices.

6) Improvement of buildings to minimize total power needs (insulation, thermal storage, etc.).

7) Integration of systems to conserve energy, such as heating with lighting, use of heat-conservation systems, air inlet-exhaust heat exchangers, air quality control devices to reduce ventilation needs, central station vs. independent heating/cooling, etc., and diversity of usage among appliances and among buildings.

8) Consideration of optimum utilization of various fuels in combinations such as gas-oil standby, and on-site generation to provide standby or peak-shaving power.

9) Development of improved means for utilizing low-grade fuels and for utilizing fuels derived from waste materials.

5.4 ELECTRICAL SYSTEMS

5.4.0 Executive Summary

The National Electrical Code (NFPA No. 70, USASI C1-1965) is generally considered to be the "state-of-the-art" for the installation of electrical wiring and equipment in buildings. Partly by performance requirements, but mainly by specification-type language, the National Electrical Code describes the methods for distribution of electricity with adequate capacity for permanent, semi-permanent, and portable appliances and devices without excessive voltage drop and with reasonable safety and assurance of durability. Reliability and continuity of service are not discussed in the National Electrical Code. The FHA Minimum Property Requirements follow the National Electrical Code with minor exceptions. Further study is needed of emergency lighting requirements. This subject is discussed somewhat in NFPA No. 101-1967, the Code for Safety to Life from Fire in Buildings and Structures.

Five areas of research on electrical systems are identified, including a study of the economics of electrical systems in low-income housing, greater use of permanent lighting fixtures, better integration of electrical distribution with other building systems, the economics of on-site power and heat generation in apartment structures, and a study of the diversity of electrical usage within buildings and among buildings.

5.4.1 Housing Problems in the Area of Electrical Systems

Electricity is the most widely-used source of energy for power and light in dwellings today. Its use as a primary source of space heating is growing. The characteristics of the electrical service to dwellings are highly standardized in the United States, but there are significant variations in other countries. The most inflexible characteristic is frequency; only somewhat less flexible are the voltage characteristics. The high level of national standardization in distribution technology through the National Electrical Code and in the characteristics of frequency and voltage provides both the benefits of mass production and also some inhibition to innovation and development. The development of on-site generation in large residential and commercial structures as a part of the so-called "total energy" systems provides an opportunity for new concepts in electrical characteristics and distribution technology. However, such innovations would tend to be inhibited by the unavailability of appliances with the required electrical characteristics, by the requirements of existing codes, and by possible use of existing electrical distribution systems for emergency or standby purposes.

5.4.2 Significant Performance Requirements

The performance requirements for an electric system in a building are:

1. Distribution of needed capacity without loss of quality characteristics beyond some stipulated limit.
2. Adequate capacity to a variety of devices at selected locations including diversity considerations.

3. Adequate placement of convenience outlets for portable devices.
4. Adequate switching and overload protection.
5. Reasonable safety with respect to fire, electric shock, and other safety considerations related to exposed equipment.
6. Adequate reliability with respect to continuity of service and deterioration of system components.

5.4.3 Existing Standards

Compliance with the essential characteristics of the National Electrical Code is a requirement in most jurisdictions. The Minimum Property Standards of FHA deviate in small detail from the National Electrical Code.

The National Electrical Code contains requirements, which are partly performance and partly solution, for the safety of electrical distribution systems within buildings. It appears to be also a solution to the quantity requirements of such a system. Its coverage of this aspect is quite complete; the basis for this is that insufficient electric power will result in hazardous conditions. For permanently installed electric equipment (such as permanently installed stoves and air conditioners), the NEC requires sufficient electrical capacity for their successful, reliable, and safe operation. That is, electrical requirements are going to be at least partially determined by whatever utilization equipment is to be used. For lighting and portable appliances, the NEC requires sufficient electrical capacity for their estimated use and overload protection in cases where their use exceeds the capacity of a circuit.

5.4.4 Research Recommendations

Promising research programs are as follows:

1. A study of electrical needs and the economics of electrical systems in low-income housing, including greater use of permanent lighting fixtures, the distribution of energy for portable devices, use of fluorescent lighting, the integration of electrical distribution with other building systems.

2. The effectiveness and economics of on-site power generation.

3. Effective integration of natural and artificial lighting.

4. The diversity of electrical usage within buildings and among buildings.

5. Emergency lighting requirements in residential properties.

5.5 MECHANICAL EQUIPMENT

5.5.0 Executive Summary

A large number of standards and test methods are in use for evaluating the performance of various types of heating, air conditioning, and ventilating equipment, especially in small and medium sizes. These have been prepared and issued by the American Society of Heating, Refrigerating, and Air Conditioning Engineers, the Air Conditioning and Refrigeration Institute, the National Warm Air Heating and Air Conditioning Association, the American Gas Association, the Institute of Boiler and Radiator Manufacturers, the Air Moving and Conditioning Association, and other organizations. For the most part these standards confine themselves to measurement of capacity, efficiency, safety, control, and other operating characteristics of the equipment itself. A few provide guidance or rules for installation that help to attain effective application of the heating or cooling effect in the building, but none assure any specific quality or uniformity of environment.

A similar situation exists for air cleaning equipment, odor control equipment, laundry equipment, waste disposal equipment, and acoustic control devices except that there are fewer standards and test methods in these categories of mechanical equipment.

In the United States there has been little effort expended in determining or describing user requirements in the areas of sensory environment in buildings or for the service systems that meet the daily living needs of the family. In general, specifications for the mechanical systems have been based on the characteristics of the available equipment. The development and evaluation of equipment has taken place in the engineering and market analysis departments of the manufacturers where a mixture of sales appeal, utility, and engineering ingenuity is brought to bear on the equipment design.

For low-income housing where a maximum of cost-effectiveness is sought in the application of mechanical systems, a direct evaluation of user requirements should be undertaken. A start could be made by assembling experienced people from organizations in direct contact with the user such as large department store or chain store managers, procurement personnel in government housing agencies, home economists from the U.S. Department of Agriculture, and personnel from market analysis departments of manufacturers to review existing knowledge and studies on user needs. This effort should be supplemented by new programs aimed at determining user needs directly by field surveys, laboratory studies, and the use of prototype installations in selected residences. There are some existing studies and analyses that have been completed that could be used as a basis for performance specifications for certain kinds or components of mechanical systems, such as criteria for air duct materials, and criteria for sanitary plumbing fixtures.

The newly created Comsumers Standards Board of USASI should be utilized in the development and promulgation of standards for user requirements.

A model national heating and air conditioning regulation based on performance should be developed. This regulation should cover health, safety and physiological requirements. Such a performance regulation would significantly improve the state-of-the-art in meeting user needs without inhibiting innovation or competition. Since no such regulation now exists the difficulties with established proprietary interests in existing regulations would be avoided in the development process.

5.5.1 Rationale for Performance Requirements - User Needs

Many people who work regularly with the design, selection or operation of mechanical equipment or systems for housing are familiar with performance requirements. It became apparant early in this limited-time investigation that, for the most part, the performance requirements with which most of these people were familiar related to the ability of the equipment in question to meet some designated requirement for capacity, load, durability, reliability or other criterion, rather than the ability of the equipment to perform some function directly described in terms of the user need. For example, a direct requirement for thermal environment (a user need) calls for a certain temperature to be maintained in a house. The performance requirement for a heating system to be installed in a house has to be expressed in heating capacity units, such as Btu per hour at specified conditions. In between the two levels of performance requirements is the process by which it is determined that the heating system installed in a certain house will be able to maintain the desired temperature at specified conditions. Similar examples can be shown for all groupings of mechanical systems. A typical pattern for these relationships is, for example, that the occupant does not need electricity--he needs the things that electricity can do for him, he does not need a certain type of sewer system--he needs the facility a sewer system can provide, etc. Once it is determined what the user needs in the way of light, heat, power, etc., performance or operational requirements can be described which an electrical system must meet to provide the needs. Similarly, waste removal needs of the user must be described before performance requirements can be developed for a sewer system. It appears certain that, where the present procedures are followed for combining various systems in a house in response to defined user needs, there will continue to be a need for performance requirements for systems to meet the selected values which have been determined as capable of meeting the separately-described user needs. Eventually performance requirements and test procedures directly related to user needs can be developed to determine if a given device or system meets these needs. It is this objective toward which this investigation is directed.

There are many mechanical systems in present day housing, and the problem areas in need of study for development of performance requirements can be grouped into several categories:

a. Large versus small buildings.

A two-family house will have different equipment requirements from a large building such as a high-rise apartment. Well-designed, high quality conservatively rated, understressed central equipment for a high-rise building may well prove to have the lowest long-term cost whereas lower quality, planned-replacement equipment may be the best for the separate small buildings.

b. Many separate systems.

Each dwelling has several definable systems for diverse purposes such as cooking, air conditioning, waste removal, etc., each having individual performance requirements.

c. Interrelationships of elements of systems.

One piece of equipment may be a part of several systems. For example, a motor-driven garbage-disposal unit installed in a kitchen sink is, at one time, an integral part of the food preparation system, the plumbing system, the waste removal system, and the electrical system.

d. Type of occupancy grouping.

It is probable that most low-income housing will be oriented around the family group, each having generally independent facilities. It must be recognized that, even where individual dwelling units are customary, there are many community-type facilities already considered normal, such as recreation areas, certain food facilities, laundry facilities, lobbies, elevators, etc., with particular regard to large buildings many more of facilities take on the community aspect, such as central air conditioning systems (for heating, cooling, air cleaning, ventilation) serving many separate dwelling units in one or more buildings, communication systems, trash-removal systems, laundry facilities, etc. It is also possible that community quarters for sleeping and living areas will be used more in the future for groups of children, elderly or dependent people.

5.5.1.1 <u>Types of Mechanical Systems</u>

The following partial list is included to indicate the variety of separate mechanical systems in multi-family housing. Items a, b, and c are identified here and discussed in detail in subsequent parts of this section. Items d through h are covered in other sections of the report, and Items i through n are listed for identification only and are not covered in detail in this report.

a. Environmental

Included in environmental systems are those which provide heating, cooling, humidity control, air quality and motion, and ventilation. Although it is not treated here as a mechanical system, the building itself plays a large part in respect to the thermal environment, and acoustical privacy and noise control.

b. Laundry

Laundry facilities for multi-family housing range from a laundry tub to automatic washers and dryers in each dwelling unit, and from laundry tubs to automatic washers, dryers, and dry cleaners located in central facilities for common use by occupants of several dwelling units.

c. Waste Removal

Effective waste removal systems are essential to satisfactory living conditions. Several systems coexist including water-borne wastes to sewers (toilet wastes, bath water, dish water, kitchen liquid wastes, garbage disposal discharge, laundry water, etc.), garbage (receptacles, incinerators, etc.), air-borne wastes (ventilation systems, combustion products, etc.), solid wastes (trash, ashes, packing material, large discarded items, etc.).

d. Transportation (in premises)

e. Food Services

f. Plumbing

g. Lighting

h. Energy

Although the various forms of energy are discussed in another section, it is significant to note here that utilization of energy requires equipment or devices to convert the energy to usable forms to accomplish a desired function. Frequently the energy forms are converted more than once, for example, in on-site generation of electric power, gas or oil usually is used to fuel an engine-driven generator, the exhaust gas used to heat water, which is in turn used to heat the building (or provide domestic hot water), and the generated electric power is used to operate a pump to deliver the heated water and for a multitude of other purposes. Distribution of energy through a building involves supporting systems such as the electrical distribution system, domestic hot water system, and gas distribution system, which are described in other sections.

i. Security

Protection from intrusion and provision for privacy require access (doors, windows, skylights, etc.) to the individual dwelling unit under control of the occupant. In groups of houses, or in high-rise apartments the security systems interrelate with community services such as guard forces, closed circuit TV, protective lighting, alarm devices, etc.

j. Communications

Doorbells, annunciator devices, alarm circuits, integral telephone circuits, central TV aerials, etc., are examples of communication systems requiring consideration in multi-family housing.

k. Cleaning of Premises

Design of buildings to facilitate cleaning is the first step in developing a cleaning system and cleanability is provided by proper selection of surfaces, shapes, materials, accessibility, etc. Central vacuum systems are being installed in both large and small buildings. Carpet, furniture and floor cleaning machinery is available and should be considered for use in maintenance of the larger buildings. Features such as reversible windows to facilitate cleaning should be developed.

l. Utilities

For any building there are usually several systems of utilities which connect to the building, such as water, sewer, electric power, fuel oil, telephone, coaxial cable, fire alarm circuits, and others. Some of these items are included in other discussions in this report.

m. Independent Appliances

Depending on the manner of providing certain operational facilities in low-income housing, it is possible that there could be arrangements for a system of providing packaged pieces of equipment, such as air conditioners, heating devices, television receivers, humidifiers, air filtering units (for pollen, etc.), cleaning machines, washing machines, clothes dryers, etc., on loan, rental, or programmed replacement basis, perhaps as a function of central housing management. If this is a possibility, these performance requirements can be developed and used for procurement of the individual pieces of equipment.

n. Materials Handling

Occupants of low-income housing are likely to be away at work during normal delivery hours. A system for providing safe storage of large mail, packages or other delivered articles until they can be claimed by the occupant should be considered, and will probably have to be automatic because personnel is not likely to be available for such purposes.

5.5.2 General Performance Requirements

5.5.2.1 Environmental Systems

Under any combination of climatic conditions and interior use likely to occur during its useful life, the heating, air conditioning and ventilating system shall be able to provide and maintain within the living zone of all occupied spaces in a building, the following conditions of thermal environment:

a. A combination of dry bulb temperature, relative humidity, mean radiant temperature, and air motion within the comfort range of the occupants;

b. Control of the rate of change of temperature, relative humidity, and mean radiant temperature within the physiological tolerance of the occupants.

c. Provision of a supply of air of sufficient purity for the biological needs of the occupants, the combustion needs of fuel-burning equipment, the control of gaseous and particulate contaminants in the occupied space, and to meet the health and housekeeping needs of the occupants.

All elements of the environmental system shall function in a safe, effective and reliable manner, free from hazard and nuisance to persons and property.

5.5.2.2 Laundry Systems

Laundry equipment shall provide safe, sanitary and effective means of adequate quality and capacity to thoroughly wash and dry clothing, bedding and other washable fabrics, of types and quantity normal for the class of occupancy without undue delay so as to meet the reasonable needs of the occupant(s). The location of such equipment shall provide a comfortable, well-lighted, adequately ventilated environment and reasonable security for the user. The equipment shall function without hazard or nuisance to persons and property.

5.5.2.3 Waste Removal Systems

Under any reasonable conditions likely to result from maximum occupancy, waste removal systems shall provide safe, sanitary, and effective means for removal of all types of waste normal to the living habits of the occupants. The systems shall be convenient to use and shall function in a manner free of hazard or nuisance to persons and property.

5.5.3 Currently Used or Known Solutions

5.5.3.1 Environmental Systems

A heating and air conditioning system is comprised of the heat generating apparatus,the refrigerating apparatus, a distribution system for delivery of the heating or cooling effect to the occupied spaces, a disposal system for waste products, and a control system to regulate the operation of the system. The function of the distribution system is to divide the heating or cooling effect among the several occupied spaces in proportion to the overall requirements of these spaces, and further to introduce the heating or cooling effect into the occupied spaces in a manner that will counteract undersirable asymmetry inthe radiation and convection conditions in these spaces. The function of the control system is to provide safe operation of the equipment, but principally to adjust the rate of production of the heating or cooling effect to exactly offset the requirement of the occupied spaces by either a modulated or intermittent operation of the generation equipment.

The thermal environment in a room is usually asymmetrical with respect to thermal radiation and air temperature. A typical room has one or two exterior walls containing windows through which solar heat enters on sunny days for some exposures, a variable amount of outdoor air leakage, and it may or may not transfer heat through the ceiling and floor surfaces. In such a room, 80 to 100% of the total heat transfer occurs through the exterior wall surfaces resulting in (1) large surface areas either colder or warmer than the air temperature and (2) a major movement of cold air downward toward the floor in the winter or warm air upward toward the ceiling in the summer along the full length of the exterior walls. The exterior wall surfaces, including the windows, create a non-uniform radiation exchange with the occupant, and the vertical movement of air near the exterior walls produces a vertical temperature from floor to ceiling and a horizontal air temperature gradient from the exterior wall to the interior wall. The major performance requirement for the distribution system is to compensate for and counteract this asymmetrical air and radiant temperature pattern in a room or building.

A wide variety of heating and cooling elements have been used for heating and cooling rooms ranging from all-convection systems, to radiant panels covering one or more entire room exposures, to elements which combine radiation and convection in different proportions. Many universities, manufacturers associations, and the National Bureau of Standards have studied the effectiveness of various heating and air conditioning systems in providing low air temperature gradients and satisfactory mean radiant temperatures in simulated or actual dwellings. None of these studies has rated the various systems with respect to their ability to compensate for the "cold-wall" effect or the vertical and horizontal air temperature gradients in occupied spaces, nor have performance requirements been standardized for these parameters. Nevertheless, the general principles involved in an effective system are known and tentative performance requirements could be drafted.

The ASHRAE Thermal Comfort Standard 55-66 and all the other documents identified in the Executive Summary of Section 4.3 on Thermal Environment oversimplify the description of the thermal environment in a building during either the summer or the winter season. The air temperature gradients and the non-uniform mean radiant temperatures are completely ignored in all but the ASHRAE Standard. It is probable that few, if any, existing systems can provide the environmental conditions described in the ASHRAE Standard. Additional parameters of environmental control that are not covered by performance requirements in the FHA Minimum Property Standards or other procurement standards are related to permissible air velocities in the occupied space and the permissible rate of change of temperature and humidity.

All available fuels are used, several types of heat exchanges are used, several means of heat distribution, various techniques for ventilation, filtering, odor removal, etc., are in use. There is no clear policy regarding cooling of housing. The degree of sophistication of environmental systems is largely determined by the owner's willingness to pay and the skill of his designer and installer. For larger buildings each installation is now an individual design and is influenced by cost. Procedures for determining the required size of air conditioning or heating systems are, for the most part, based on those outlined in the ASHRAE Guide and Data Book, or on procedures developed by leading equipment manufacturers. Computer programs are being developed to make system and equipment type selections as well as to determine the cooling and heating loads. ASHRAE has a task group currently working to develop a standard computer technique for heating and cooling load determinations which are based on real-weather transient conditions and for predicting energy usage. Much work needs to be done to establish real user needs for environment in housing. Some of the questions which must be answered are: (1) Is cooling to be provided? (2) Is air filtering to be provided and if so what level of performance? (3) Is odor control equipment justified? (4) What is the basis for cost estimating of various systems, particularly for large buildings? (5) How well do the various distribution systems really work? (6) How can long-term reliability be obtained? (7) How many zones are needed? (8) What control system is the best suited to a particular installation? There are, of course, many more--not new questions but still without recognized or standard answers. In general, then, the current solutions are, for the most part, the use of guide specifications like the FHA Minimum Property Standards, or a requirement for inside temperature, with the equipment selection determined by cost.

5.5.3.2 Laundry Systems

The trend for household laundry machines is definitely moving toward installation of automatic washing machines and dryers, if not in each dwelling unit then available as a central facility within reasonable distance of each dwelling unit. Many central facilities have coin-operated machines. Dry cleaning machines are being provided in some housing facilities. In some areas convenient commercial self-service laundry facilities are satisfactory. Because of typical plumbing codes, laundry tubs are customarily provided for each dwelling unit or group of units.

5.5.3.3 Waste Removal Systems

Four types of waste must be accommodated by the waste removal systems in the typical house:

a. Liquid-borne wastes from toilets, shower stalls, bath tubs, kitchen sinks, lavatories, laundry tubs. Discharge into the house sewer system is almost universal.

b. Garbage. Use of electric motor driven disposal units discharging into the house sewer is a principal current solution. Use of central incinerators or refuse-collection points on each floor of larger buildings and use of covered receptacles for scheduled community pick-up are alternative systems. Individual household fuel-fired incinerators are being introduced.

c. Solid waste materials, including trash, paper, discarded household items, etc. Community pickup from individual receptacles or from refuse-collection rooms on each floor is the principal means for removal from the site. This study does not consider the ultimate disposal problem.

d. Air-borne wastes. These include exhaust from combustion devices, incinerators, clothes dryers, house-venting systems, range hoods, central vacuum cleaning exhausts. Direct discharge to the outdoors is the current solution. Air pollution requirements may affect this solution, particularly in regard to incinerators and combustion devices.

5.5.4 Existing Standards

5.5.4.1 Environmental Systems

There are few, if any, existing standards which describe in performance language the required performance of a complete environmental system. There are many standards in use which treat of a part or component of such a system. The ASHRAE Guide and Data Book is the principal reference for broad coverage of design, equipment selection, testing and rating of elements, and, in conjunction with the ASHRAE Comfort Standard, provides a basis for developing performance requirements for environmental systems from user need to installation of the system. This is not to say that it is the "best" reference for any one part of the overall selection process. Leading manufacturers such as Carrier and Trane have developed different techniques and methods for load determination and system selection which are widely used. Trade associations such as Air Conditioning and Refrigeration Institute, National Warm Air Heating and Air Conditioning Association, American Gas Association, and National Electrical Manufacturers Association have issued design procedures for selected types of systems. ASHRAE is the sponsor of USA Standard B9, Safety Code for Mechanical Refrigeration, which is used as a basis for many building code requirements. Several trade associations such as ARI, Air Moving and Conditioning Association, Institute of Boiler and Radiator Manufacturers, AGA, and many others have developed certification procedures where performance and ratings in varying degrees are certified within the industry. The General Services Administration issues many federal specifications and standards for individual types of equipment and related materials. Many Product Standards pertinent to the field are issued by the U. S. Department of Commerce. Safety aspects of equipment of many types are covered in standards of the Underwriters Laboratories, Inc., A.G.A., National Fire Protection Association, and others, many of which are issued as USA Standards. Boiler inspection services exert strong influence on safety aspects of heat and pressure elements of environmental systems through insurance connections. American Society of Mechanical Engineers codes for fired and unfired pressure vessels and piping are widely cited in developed codes and standards. Many groups such as the American Society for Testing and Materials, ARI, Steel Boiler Institute, ASHRAE, Society of Automotive Engineers, and others, have developed testing and/or rating methods for many specialized classes of equipment. These various sources of codes, standards, and test methods are cited here only as examples of the very large number of individual references available and in use. It would be redundant to list all here by name and title, because lists are readily available from the various organizations or could be compiled by NBS. Chapter 70 of the 1967 ASHRAE Guide and Data Book, Systems and Equipment Volume, lists many applicable codes and standards and organizations producing them. Guide Specifications such as issued by DOD and FHA and many state and local codes make use of numbers of these available standards to describe acceptable equipment. It is important to note that improved methods for calculating heating and cooling loads based on real-weather data, and uniform computer procedures for selecting equipment and predicting energy usage, are being developed at present. Much work remains to be done to develop requirements based on user needs for ventilation, odor control, humidity control and air cleanliness of environmental systems to augment the start made toward comfort requirements as described in the ASHRAE Comfort Standard.

5.5.4.2 Laundry Systems

Selection of types, capacities and sizes of automatic laundry equipment to meet the needs of various housing occupancies is largely a matter of the experience or general practice of individual builders or occupants. No recognized standard for making this selection was identified by any of the organizations contacted in this limited-time investigation. Many building codes permit installation of automatic washers and dryers but usually require only a specified number of laundry tubs for each dwelling unit or group of dwelling units.

The Association of Home Appliance Manufacturers (a merger group including the former Home Laundry Manufacturers Association) has developed rating and testing standards for domestic washers and dryers.

Several USASI Standards cover performance and/or safety aspects of both domestic and larger laundry devices, including C33.13-1965 (UL 560), Z8.1-1961, Z21.5.1-1962, and Z21.5.2-1962. Federal specifications for various items of laundry equipment include 00-D-735a, 00-D-738a, 00-D-750a, 00-D-755a, 00-D-1297, 00-E-990a, 00-L-131i, 00-L-138b, 00-T-760a(1), 00-W-0020a, 00-W-25a, 00-W-50b, and 00-W-00860b. All but the last pertain to equipment larger than household size.

5.5.4.3 Waste Removal Systems

a. Liquid-borne wastes.

Standards for this group are discussed in the Plumbing Section of this report.

b. Garbage

When garbage disposal units are installed, garbage removal becomes a part of the liquid-borne wastes systems. The alternate methods of garbage removal are use of individual fuel-fired incinerators in each dwelling unit, use of a central building incinerator, or use of covered receptacles for pickup by a community service. USA Standard Z21.6-1966, Approval Requirements for Domestic Gas-Fired Incinerators, and Incinerator Institute of America Incinerator Standards set safety and performance standards for certain domestic and central incinerators, respectively. Because the garbage collection by pickup is a management service, standards relative to this method are limited to acceptable containers and design of collection rooms or stations. Those details are typically described in buildings codes and in guide specifications such as FHA Minimum Property Standards. Federal specification RR-C-82c(1) gives requirements for zinc-coated ash and garbage cans.

c. Solid Wastes

Household trash such as paper wrapping materials, packaging, and other combustible materials can be disposed of in incinerators as described above, and the same standards apply. Where incinerators are not used, trash pick-up is a community service and standards relate to the containers and collection points as described above. Disposal of large items, such as furniture is generally a management responsibility.

d. Air-borne Wastes

The principal area requiring standards in this method of waste removal relates to air pollution, values for which are typically established in building codes and guide specifications. Provisions of the Federal Clean Air Act include recommended limits for combustion system discharge.

5.5.5 Standards Needed

5.5.5.1 Environmental Systems

Further development of user requirements is needed for most aspects of environmental systems, along the lines of the new ASHRAE Thermal Comfort Standard, and including odor control, air cleanliness, light, acoustical, and humidity needs for occupied spaces in housing.

Well-developed test methods are needed to evaluate in-place or as-installed performance of environmental systems. A method is needed for evaluating the ability of a heating or air conditioning system to distribute heating or cooling effect adequately in time and space to compensate for the non-uniformity of air temperature and radiation exchange in residences, measured against the physiological needs of the user. Methods for evaluating long-time reliability potential, maintainability, and operational efficiency of environmental system equipment are needed.

5.5.5.2 Laundry Systems

Better determination is needed of the user requirements for laundry equipment which is to be furnished as a part of multi-faimly housing, with regard to type, size, capacity and operation characteristics.

5.5.6 Future Research

5.5.6.1 Environmental Systems

Laboratory and field studies to evaluate new heating and cooling load determination methods under development should be undertaken.

Programs should be strengthened to develop computer techniques for heating and cooling load determination, equipment selection, and prediction of energy usage.

Necessary laboratory and field work should be undertaken to develop methods for field-testing of installed environmental systems.

5.5.6.2 Waste Removal Systems

Evaluation of new trash collection systems such as the Swedish central vacuum system should be made.

5.6 TRANSPORTATION SYSTEMS

5.6.0 Executive Summary

Stairs, ramps, hallways, doors, and elevators are likely to continue to be the methods used in houses for horizontal and vertical movement of people and materials. The dimensions, design, speed, etc. of these components are generally dictated by the rate and distance of movement needed under fire conditions, by the rate of movement considered reasonable under normal use conditions, and by the size of the longest object to be moved by the particular transportation component.

The important specifications and requirements for elevators and other transportation systems are contained in five model building codes, a code of the National Fire Protection Association, several USASI Standards, the Minimum Property Standards of FHA and a book on vertical transportation by Strakosch. These sources are listed in Part 5.6.10 of this section on Transportation. Most of the requirements in the NFPA code, the model codes and USASI Standards are written in specification language although some performance language is used. These provisions deal principally with the fire emergency situation and with the size of object that must be movable through the system. One USASI Standard deals specifically with the requirements for handicapped people. The FHA Minimum Property Standards contain the best set of specifications relative to the capacity, speed, and number of elevators required in apartment buildings.

It is believed that a research study of transportation needs in apartment buildings might lead to a saving of 20 percent in cost of transportation components. Such a study should include investigations of entrances and doorways, halls and corridors, stairways, and elevators and involve the disciplines of fire protection, architecture, sociology, and the scheduling parameters of elevators. Simplification and standardization of elevators for low-income family apartment dwellings should provide significant savings.

5.6.1 Rationale for Performance Requirements

Transportation has since the beginning of time been a recognized need of people. Satisfactory means for people to get themselves and their personal belongings to and from and within their living units appears to be obvious and needing no further explanation.

5.6.2 Generalized Performance Requirement Statements

With reasonable time limits, with reasonable safety, with reasonable comfort, and with reasonable reliability, people need to be able to:

1) Move between their living units and public areas outside of the building their living unit is located in.

2) Transport furniture, groceries, and other personal belongings between their living units and outside public areas.

3) Move themselves and transport their personal belongings within their living units.

5.6.3 Additional Performance Requirements for Currently Used or Known Solutions

Transportation within buildings is being classified into two basic categories as follows:

1) Facilities which permit people to walk or move portable vehicles vertically or horizontally. (Examples of portable vehicles: wheel chair or shopping cart).

2) Permanent building facilities which move people horizontally or vertically. (Examples: elevator, moving walk).

5.6.4 Facilities which Permit People to Walk or Move Portable Vehicles

Stairs, ramps, doors, hallways, and other unobstructed horizontal surfaces are the facilities which are being referred to. These facilities are necessary for fire emergency purposes. An evaluation of this category of building facilities indicates that fire emergency conditions would impose the most severe performance requirement, with the possible exception of the requirement on "size of objects" discussed below.

Fire emergency conditions, as well as those associated with tornados, earthquakes and floods, will dictate all "people capacity" requirements for these facilities concerning the rate of movement of people. Requirements concerning rate of movement of materials will be considerably less severe than requirements concerning rate of movement of people and therefore need not be considered. Architectural safety requirements of these facilities, such as rise and tread of stairs should also be considered under the condition of their severest use, which is the fire emergency condition.

The one non-fire condition performance requirement, which may or may not govern the size of doors, width, and other architectural considerations of hallways, ramps, stairs, and other unobstructed horizontal surfaces is the requirement concerning the moving of some size of an object (such as a sofa) into and out of and within living units.

5.6.5 Suggested Performance Requirements

An object with cubic dimensions of A x B x C shall be capable of being transported from outside of a building to rooms within living units classified as X, those with cubic dimensions D x E x F shall be capable of being transported to rooms classified as Y, etc. X would be living room, Y would be bedroom, etc.

5.6.6 Permanent Building Facilities Which Move People or Materials Horizontally or Vertically

Transportation equipment which moves people or material is too complex to be considered strictly in performance terms.

The functional requirements of a building transportation system could possibly be expressed in measurable performance terms. An attempt to identify functional performance requirements for building transportation systems will be made after detailed discussion of the types of transportation systems now in use and discussion of the need for vertical and horizontal transportation.

However, it is inconceivable that safety requirements for a radically different type of building transportation system could be written before at least the basic principles of such a system have been developed or identified. The basic safety performance requirement, of course, is to provide reasonable protection against any type of applicable hazard. A listing of presently known hazards, of course, could be made. However, with few exceptions, these are not measurable at this time, and will not be for many years.

5.6.7 Types of Building Transportation Systems Now in Use

The following types of building transportation systems are now in use: (1) elevators, (2) dumbwaiters, (3) escalators, (4) moving walks, (5) private residence inclined lifts ("Stairclimbers"), (6) manlifts, (7) conveyors. All seven of these transportation systems are used for vertical transportation (between floors). Moving walks and conveyors are also used for horizontal transportation.

5.6.7.1 Horizontal Transportation

No horizontal building transportation system (which carries people or materials) is now in general use in any type of high, medium, or low-cost housing. At the present time there appears to be no compelling reason to consider horizontal transportation in housing, particularly low-cost housing.

5.6.7.2 Vertical Transportation

Vertical transportation is necessary for housing units more than X floors or Y feet above ground level. 40 or 50 years ago X and Y were generally on the order of "5 floors" or "50 feet". Today they are generally on the order of "2-1/2 floors" or "25 feet" where "freedom is the market place", is in effect. For people whose income might be considered "upper, middle or above", "X and Y" would probably be less than "2-1/2" and "25".

What "X" and/or "Y" is for low cost housing is, of course, a matter of judgment. It may vary in different localities or for various reasons. It is, however, a basic decision which radically affects the type of housing built in a given location. Vertical transportation (which for all practical purposes means "elevators") is a costly part of any building. Generally, in apartment building, elevators cannot be economically justified on the basis of "X+1" or "X+2" floors. Generally it means that fairly high-rise buildings must be built.

5.6.8 Feasibility of Transportation Equipment Now in Use

Before the feasibility of any transportation system can be determined, it must be evaluated in terms of needed functional performance. It is firmly believed that all of the above-mentioned transportation systems, except elevators, would not be feasible under any conceivable performance requirements which might be developed. However, evaluation of these transportation systems to determine this seems unnecessary because all of these transportation systems cannot be used in a low-cost housing area for safety reasons. One assumption has been made which is "transportation systems will be readily accessible to unsupervised children".

Manlifts can now be safely used only by trained, fairly agile people, such as car parking attendants. It is universally accepted that these devices cannot be used by the general public.

Dumbwaiters must be limited to certain dimensions (4 ft. high, 9 sq. ft. floor area). They do not have many safety features which are required on elevators and it is understood that people are not to ride on them. They could not be used where accessible to children because children could, and would, ride on them.

Private residence inclined lifts ("Stairclimbers") are permitted only in private residences (not in hallways leading to a number of apartments). Such devices could not be safely used in areas accessible to the general public, and particularly in areas accessible to unsupervised children.

This means that elevators form the only known safe means of vertical transportation in low-cost housing. The use of elevators in public housing have posed special functional and safety problems because of the crime, vandalism, and mischievous habits of children and adults who live in this type of housing. A systematic study of such problems in public housing units might provide information which would be valuable in the design of elevators for future low-cost housing.

5.6.9 Generalized Performance Requirements for Vertical Transportation Systems

Under specified conditions:

1) Vertical transportation systems, when buildings are above certain heights, should be capable of transporting people and materials between the various floors of the building:

a) with some limit on waiting time and some limit on travel time or with some limit on the combination of waiting and travel time,

b) at some minimum capacity rate (such as people per minute),

c) with reasonable comforts,

d) with reasonable safety including:

   (1) fire prevention qualities,
   (2) electric shock prevention qualities,
   (3) without falling or accelerating or decelerating beyond some amount,
   (4) physical hazard prevention qualities.

e) with reasonable reliability,

f) carrying materials of X-Y-Z dimensions and W lbs.

In addition, this system must interface with other building functions and components and not create hazards or other undesirable conditions such as:

1) Falling hazards into unprotected hoistways.

2) Means for the passage of smoke or fire.

3) Excessive noises.

5.6.10 Publications Concerning Building Transportation

1) Code for safety to life from fire in buildings and structures (NFPA No. 101-1967) National Fire Protection Association, 60 Batterymarch St., Boston, Mass. 02110.

2) BOCA Basic Building Code, Building Official Conference of America, 1313 E. 60th St., Chicago, Ill. 60637.

3) Southern Standard Building Code, 1116 Brown-Marx Building, Birmingham, Ala.

4) Uniform Building Code, International Conference of Building Officials, 50 South Los Robles, Pasadena, Calif. 91101.

5) National Building Code, American Insurance Association, 85 John Street, New York, New York 10038.

6) New York State Building Construction Code Applicable to Multiple Dwellings. Building Codes Bureau, 393 Seventh Ave., New York, New York 10001.

7) American Standard Specifications for Making Buildings and Facilities Accwssible to and Usable by the Physically Handicapped, UASAI A117.1-1961.

8) American Standard Safety Code for Elevators, Dumbwaiters, Escalators, and Moving Walks, USASI A17.1-1965. American Society of Mechanical Engineers, 345 E. 47th St., New York, New York 10017.

9) Minimum Property Standards for Multifamily Housing, Federal Housing Administration, Washington, D. C. (FHA No. 2600).

10) Vertical Transportation: Elevators and Escalators by George R. Strakosch, Otis Elevator Co. Published by John Wiley & Sons, Inc. 1967.

Publications 2 through 6 are five of the best known model building codes. Partly in performance language but mostly in solution language, all of these publications quite thoroughly describe requirements of transportation facilities described in 1a. Publication 1 contains similar type requirements for this type of transportation facility. These publications are all mainly concerned with the "fire emergency" situation but obviously consider other aspects such as the "size of object" that should be movable within buildings. The requirements of these six model codes differ but, in actuality, the differences are not great.

Publication 7 is the best available source concerning requirements of handicapped people.

Publication 8 governs nearly the entire production and installation of elevators in the United States. Its emphasis, of course, is on safety. One recent code change, which was made primarily because of experiences in public housing projects, requires that top emergency exits in elevator cars be openable only from the top of the car. This requirement has helped greatly in solving performance requirements related to vandalism.

Publication 9 is listed because it contains one of the best known sections concerning specifications relative to the capacity, speed and number of elevators required in apartment buildings. These specifications are not of a performance type according to the definitions adopted in this report.

Publication 10 is not a code, standard, or set of minimum requirements. It contains explanations concerning the various factors now used in elevatoring buildings, including residential buildings. Its recommendations are, in general, consistent with the FHA minimum property requirements and this book is highly regarded in the elevator industry.

5.6.11 Recommended Research

A study of building transportation needs in apartment buildings for low-income families is recommended for early implementation. Such a study could possibly save up to 20 percent of the costs of building transportation costs, which would mean savings of up to 4 percent in building construction costs. Such a study should involve investigations of entrances and doorways, halls and corridors, stairways and elevators, and deal with the disciplines of fire protection, architecture, sociology, and the scheduling parameters of elevators.

5.6.12 Elevator Costs

Because of the large market for apartment house elevators and because pressures on costs (to the exclusion of service, decoration, etc.) in residential construction is extreme, "standard elevators" at lower costs have been developed for this market. (Examples are 2000 and 2500 lb. elevators at 500 fpm.). These elevators are of specific capacities, sizes, speeds, and incorporate specific features and constructions which are sold in "standard packages". Lower cost equipment such as single slide doors (which are considered too inefficient for most commercial buildings) are used where possible. A building must be designed to incorporate one of these standard packages if they are to be used without expensive modifications.

There could no doubt be economies in elevatoring large numbers of subsidized apartment buildings if facilities for elevators were standardized by HUD. The elevator industry should be consulted in establishing these standards. The elevator industry would extensively cooperate on such a project.

B.4 RESEARCH RECOMMENDATIONS

B.4.1 THE CONCEPT OF A PHASED PROGRAM

Where so much needs to be done, and when the funds to undertake the work are limited, there are two approaches possible to the design of a research program. The first would be to list all of the research projects that need to be done in some order of priority and begin working through them. The second would be to begin with a series of phased programs which began with limited funds in as many areas as possible and built out from the initial work into broader and more complex problems. We are suggesting a phased program in areas which we believe to be of highest priority (based on our professional judgement) either because they can show early results (Tom Rogers concept of "grabbing the nickels") or because they are needed as a basis for an intelligent longer range program. In Section B-5 we present our arguments on why we believe a more elaborate rank-ordering technique or a priority scheme based on costs and benefits is not feasible at this time.

We outline in the balance of the chapter several different programs within the concept of a phased program. In those areas where available knowledge is limited, like the pschophysical criteria or the determination of user needs, we recommend a first phase of exploration and elaboration on just what should be attempted and what can be accomplished. These programs will serve as the spring-boards for future research efforts of major proportions to be supported by HUD in many different institutions. In other areas where our base of knowledge is better established, our phased program will produce some immediate results within the first year which can be extended and broadened in succeeding years. In areas like structural requirements and plumbing systems the directions that we need to go are relatively clear, while in areas like safety we will need a better data base in order to be more certain of the range of needs. One final proposal for a technical information network proposes a first phase of designing the network. This design phase, which includes an evaluation of alternatives, would be followed by the implementation and operation of such a network.

A phased program, therefore, offers the opportunity for a rational approach in the absence of sufficient time or sufficient funds to make a more detailed analysis. In a field like housing performance standards, it offers the further important possibility of adding to our knowledge base more intelligence about the major research opportunities before committing large blocks of money to programs that in future years may prove to be of limited utility. Contrary to some popularly held beliefs it is not entirely clear at this point in history just what kinds of research will produce the best results. We hope we have demonstrated that focusing exclusively on attempts to cut-costs for existing housing products is not clearly the most strategic direction. A phased program will buy time and wisdom about future directions.

B.4.2 A PROGRAM OF DEVELOPING PSYCHO-PHYSICAL CRITERIA

BACKGROUND:

A person responds to his surroundings inside a building almost entirely through his senses of vision, hearing, smell, and touch; the physical effects of vibration; and the physiological effects of temperature, humidity, and air motion. Most of these stimuli are transmitted to his body by physical phenomena that can be measured by existing instrumentation. However, the interpretation of these stimuli by the individual has not been explored sufficiently in most disciplines to permit description of the range of response, the sensitivity of response to various parameters, the integration of various stimuli, or the response norms in terms of their measurable physical parameters. Perhaps more experimentation has been carried out on the relation of temperature, humidity and air motion to comfort than on any of the other sensory parameters. Yet, even in this area, the thermal comfort scale is a five-to-seven-step descriptive scale ranging from hot to cold, based on somewhat over-simplified laboratory data, and no specific health interpretations have been assigned to various combinations of the three parameters of temperature, humidity, and air motion. Thus, the physical measurements that can be made of the various environmental parameters have not been converted, for the most part, into any kind of grading system using even qualitative words such as satisfactory, acceptable, objectionable, stimulating, etc.

Some of the parameters of a building environment that are evaluated by the human sensory system are: light, color, contrast, pattern, shape, distance, area, volume, sound, pressure, movement, vibration, texture, friction, odor, temperature, radiant energy, humidity, velocity, impact, mass, thermal conductivity, density, and frequency. Thus it can be appreciated that the human body is a very complex sensory system.

In terms of housing, some of the more important environmental parameters that need further research are noise and vibration control and acoustical privacy, thermal comfort, and visual comfort and privacy. These disciplines are psycho-physical in nature, i.e., they involve the relation of mental and physical phenomena. Therefore, an assessment of the degree to which the environment in a dwelling will be satisfactory to most people will depend on the physical stimuli transmitted by the environment to the occupant, the interpretation that his senses make of these stimuli, and a means for measuring both the stimuli and the response, preferably in quantitative terms by instruments, but perhaps necessarily by statistical analysis of qualitative reactions by the occupants. Research must go forward simultaneously on all three of these aspects of sensory environment to have the maximum usefulness, because they are so inextricably related to each other. The following research proposals seek to advance the knowledge of sensory environment in some of the more urgent areas for low-income housing. Some are related to the characteristics of the structure alone, and others to the interaction between the occupant and the structure.

OBJECTIVE:

The objective of the research studies in the disciplines related to sensory environment is to provide better understanding of the response of human beings to their housing as interpreted by their senses, and to develop quantitative measures of this response through instrumentation or statistical means as a basis for performance requirements. It is postulated that cost reductions can accrue from some of these investigations in addition to improvement of the effectiveness of housing, e.g., increased use of permanent artificial lighting in lieu of movable lighting, the practicability of building on low-cost real estate if external noise penetration is controlled, and the use of smaller heating and air conditioning systems if zoning and the heat capacity effects of houses can be adequately analyzed.

PROPOSED STUDIES:

A. Standards for Daylighting and Artificial Lighting

Investigate the parameters of lighting which are related to a sense of safety and satisfaction to the house occupant, such as gloom, contrast, orientation;-- and develop standard measuring procedures for these parameters.

Carry out field studies in illumination in housing coupled with survey questionnaires of users.

Study effectiveness and economics of fixed versus movable lighting sources in low-income housing.

Develop a technique, using scale models, for evaluating effectiveness of artificial and daylighting systems.

Cost:	FY 1969	$50,000
	FY 70, 71, 72	$100,000/yr.

B. Study of Subjective Response to Acoustical Environment

Need and Background:

The user requirements for acoustical privacy and noise control are generally recognized, but the question asked immediately relates to the levels of performance of structures required to satisfy the occupants. For the lack of comprehensive answers to this question, structures are sometimes "overdesigned" acoustically, often at great expense, but most commonly, provisions for acoustical privacy are either ignored or dismissed as too expensive.

Studies of subjective reactions to acoustic stimuli such as aircraft noise, industrial noise, and others, have been and are being conducted. Studies of the subjective response to the acoustical environments of business offices have been conducted also. In the U. S., very little information, however, has been obtained relating the subjective response to the acoustical environments in residential housing to levels of performance that can be measured objectively.

Objectives: The objectives are to study subjective responses to acoustical environments in residential construction, and to the degree possible, relate these to the results of objective measurements.

Approach and Scope:

1) Conduct a literature search to obtain results of similar studies conducted in Europe, and the U.S.A.

2) Examine the feasibility of obtaining subjective response to acoustic stimuli and degrees of acoustical privacy in psycho-acoustic laboratories. The approach would be to subject a panel of observers to controlled degrees of simulated accustical intrusions and attempt to determine their response of reactions to the intrusions.

3) Conduct "in-depth" interviews with occupants of dwellings wherein the degrees of acoustical privacy and details of the environment have been documented objectively.

Cost: FY 69 $75,000
FY 70 $100,000

C. Prediction and Measurement of the Dynamic Thermal Performance of Buildings

A digital computer program would be developed for calculating the thermal response of a building or rooms or zones of buildings on a dynamic basis taking into account the heat capacity of the building interior and contents, for purposes of design, prediction of interior thermal conditions with or without various degrees of heating or cooling, and comparisons of alternative designs.

Approach: Several concomitant steps are required to accomplish the objective:

1) Development of the mathematical procedures for the calculation, and its incorporation in a computer program.

2) Preparing a means for introducing data describing a particular building into the computer program with minimal human effort and cost, as for example, by use of FOSDIC.

3) Preparing, with the aid of the U.S. Weather Bureau, standard or representative weather data tapes for computer input on weather conditions throughout the year, or in periods of extremes, for selected areas of the country.

4) Ultimately, a trial should be made of the predictive value of the program either in a selected building, or by laboratory tests of a prototype building.

In applying a complex computer program to the prediction of the dynamic thermal behavior of a building, some uncertainty as to input data is bound to exist; for example, as to actual details of construction and workmanship, or as to the extent and location of air exchanges between the building interior and exterior.

It appears possible from preliminary studies to determine the dynamic thermal performance of an existing building by relatively simple means, which would include the effects of workmanship, air leakage and other factors. Development of a method of measurement applicable to existing buildings would enable determining by how much buildings of various types and constructions differ in their thermal response characteristics. In addition, existence of a feasible method of measurement of this characteristic of a building would make it possible to write and use a thermal performance specification for a building. This project would develop a method, and instrumentation and procedure, for measuring the dynamic thermal response characteristic of existing buildings.

Approach: The dynamic thermal performance of a building can be expressed in terms of a thermal attenuation factor, defined as the ratio of the standard deviation of the interior air temperatures to the standard deviation of the outdoor temperatures for the same period of cyclical weather. To determine the attenuation factor, hourly temperatures indoors and outdoors would be observed for a period of one or more days, with the building "floating" on the weather, (i.e., with no heating, cooling, or energy input, or, with a constant rate of input). The attenuation factor would include the combined effects of exterior wall and window heat transfer and air infiltration, and take into account the heat capacity of the building interior and its contents.

ESTIMATED TIME AND COST: FY 69 $165,000
FY 70 $100,000

D. Studies of Comfort in Non-Uniform (Non-Adiabatic) Environments

The ASHRAE Thermal Comfort Standard 55-66 and all other so-called "performance specifications" set forth the requirements for thermal environment in over-simplified terms. Only the ASHRAE Standard takes any cognizance of the disparity between air temperature and mean radiant temperature in a dwelling and recognizes that horizontal and vertical air temperature gradients may exist. Even this standard deals with this asymmetry indirectly. No known heating or air-conditioning system fully compensates for the inherent non-uniformity in thermal environment created by the heat loss or heat gain of a typical dwelling. The various mechanical systems differ significantly in this respect.

For low-income housing where a maximum of cost-effectiveness is sought in the application of heating and air conditioning systems, a direct evaluation of user tolerance for non-uniformity is needed. A research study should be initiated promptly to evaluate user needs in non-uniform thermal environment. This should be comprised of field surveys, field measurements in selected dwellings, laboratory studies in a test building with controlled outdoor environment and typical thermal asymmetry, and physiological studies in idealized facilities such as the Kansas State University climatic facility. It is already known that some of the existing simplified systems do not provide adequate user comfort, but these are no standards against which to make determinations of acceptances. The environmental chamber at NBS is ideally suited to studies of this type, and the professional staff for properly guiding such a study will be available at an early date.

The estimated cost for carrying out these studies is $60,000 in FY69 and $100,000 per year in succeeding years.

B.4:3 A PROGRAM FOR PROVIDING A FRAMEWORK FOR USER NEEDS

NEED:

There are two methods presently used for developing performance requirements for housing. The first is to develop statements of USERS NEEDS-those "satisfactions" the user needs from housing. The second method is to use existing hardware configurations (or systems) as models, and to abstract from these their important and desired performance characteristics. Both methods can be developed into performance specifications used to procure housing. The second method however, is very limited in solving those parts of the housing "problem" which have to do with better housing or cheaper housing. Since it does not go back to the user to determine his needs and thereby assure his satisfaction, it is doubtful that it can be instrumental in producing significantly better housing for this user. Since it uses existing hardware systems as a model, and abstracts its characteristics and then casts these in performance language, THE HARDWARE THAT CAN BE PROCURED FROM THIS SPECIFICATION MUST BE VERY LIKE THAT WHICH WAS THE ORIGINAL MODEL, and if the range of innovation is so limited, the cost reduction opportunities are also limited.

It is for these reasons we should go to the USER to determine his needs. He cannot articulate certain needs, and therefore professionals must construct a way of determining those needs. If these can be clearly stated WITHOUT REGARD TO THE HARDWARE SYSTEMS WHICH PROVIDE THEM the way would open to assuring his satisfaction from his residential environment. By involving industry in a creative manner through permitting alternate routes to needs satisfaction we open the way to significant cost reduction. Further, by clearly stating needs without regard to solutions, we permit a range of trade-offs which might also yield cost reductions.

OBJECTIVE:

To develop a full statement of USER NEEDS, we must first develop a rigorous framework to point out what information is germane, how it may be manipulated, where it falls in relationship to other information, when it is applicable, and to whom it pertains. If an absolutely rigorous framework can be developed such information will be much easier to develop. IT IS THIS FRAMEWORK WE PROPOSE TO DEVELOP AS A SHORT TERM EFFORT.

APPROACH:

We propose to develop the framework as already described in Section B.2:3 & 4 of this report, and to continue work on the user needs which has been the first attempt at such a definition. We acknowledge that a more rigorous framework may be found to develop such information than we have proposed, and sense that a continued development will point to those areas which are not sufficiently rigorous.

The framework has not been tested for information dealing with user psychology and sociology. We propose to do these in conjunction with the already partially developed physiology framework. The "TEAM" will be expanded to include the behavioral scientists and the systems analysts of the Technical Analysis Division of the Institute for Applied Technology. The first output will be a framework for developing user needs. As statements defining physiology become "crisper" we expect to be able to develop criteria from all available sources so these user needs statements may be utilized in the design of buildings before ALL the research is done. In psychology and sociology, quantified criteria may never be available-- in its stead will be substituted evaluative techniques and/or judgement. The framework for developing USER NEEDS for Physiology, Psychology and Sociology is a short term, high priority research element which leads to "a longer term" performance requirements for low-cost housing. The longer term project will be structured to yield usable "spin-off" in six month increments for its duration.

LEVEL 1 RESEARCH PROGRAM: A FRAMEWORK FOR USER NEEDS

FUNDING: $60,000 FY-69
DURATION: 6-12 months

LEVEL 2 RESEARCH PROGRAM: USER NEEDS STATEMENTS FOR PHYSIOLOGY, PSYCHOLOGY AND SOCIOLOGY

to follow Level 1 research program
FUNDING: $150,000 FY-70
DURATION: 1 year

LEVEL 3 RESEARCH PROGRAM: CRITERIA AND EVALUATIVE TECHNIQUES FOR PHYSIOLOGY, PSYCHOLOGY, AND SOCIOLOGY

to run concurrently with Level 2 research program and utilize development of psycho-physical criteria (B.4:2)
FUNDING: $360,000 FY-70, 71, 72
DURATION: 3 years

B.4.4 STRUCTURAL DESIGN REQUIREMENTS

BACKGROUND:

The load-bearing capacity of structures and structural elements has been determined in the past by either the "working stress" method or the "ultimate strength" method. Either method can be applied to structural systems of different degrees of complexity, depending on the state-of-the-art in structural analysis. In the former method, the safe working stress is related by a safety factor to the stress that would cause failure or permanent deformation, whereas for the latter method the design load is related by a safety factor to the combination of loads that would cause collapse. In both procedures, there is need for better information on the values of live loads and the combinations of loads likely to occur from wind, snow, seismic effects, and live loads; and in both procedures a house or building system needs to be considered as one structural entity rather than as an assembly of sub-components. It is considered likely, that savings in materials and costs can be realized for low-income housing by a more thorough determination of loads and their probability of occurrence, and by investigating the composite or system performance of buildings.

OBJECTIVES:

The objectives of this proposal are:

a) a short-range effort to develop a first set of structural performance specifications based on the latest accepted design information for wind load, snow load, seismic load, live loads, etc.

b) a longer-range effort to develop better information on loads based on "statistical probability of recurrence" and to develop performance tests and performance requirements for complete residential building systems related to strength, static and dynamic deflections, and inelastic deformations.

APPROACH:

It appears feasible to develop a first set or interim set of structural performance specifications based on the latest information in USASI Standard A58-1955, Minimum Design in Loads for Buildings and Other Structures, and on the FHA Minimum Property Standards for live loads and dead loads; on the latest information on wind loads, snow loads, and seismic loads developed by a subcommittee of USASI A58, but not yet published; and on the design information on combined loads contained in the AISC Code and ACI Code. There would be significant gaps in this interim specification with respect to dynamic deflections, creep under sustained load, performance of full-scale structures, human tolerance for vibration, sonic boom, fire loads, and other performance characteristics. These underdeveloped areas of technical knowledge would be the subjects of research with special emphasis on low-income housing and potential cost saving. The more important of these research investigations related to low-income housing are believed to be:

1) Survey and evaluation of live loads in multi-family housing, including statistical analysis of frequency of occurrence of loads.

2) Study of the probability of combined loading in order to determine criteria for load reduction.

3) Study of wind effects on buildings in terms of dynamic deflections, resonant frequencies, vibration of cladding, window panels, etc., and the development of vibration testing procedures and equipment.

ESTIMATED TIME AND COST:

It is estimated that the short-term development of an interim set of structural performance specifications could be accomplished in 6-8 months and is included in the funding proposed in B.4.8.

The studies of live loads, combined loads, dynamic deflections, and vibration testing procedures, are multi-year programs. These research programs should be financed at a rate of $250,000 during the first year and $400,000 per year thereafter. Some of the programs would be completed in as little as 2 years, and others would require 3-5 years.

B.4.5 PERFORMANCE SPECIFICATIONS FOR PLUMBING

BACKGROUND:

The FHA Minimum Property Standards, as well as plumbing codes and standards in general, tend to inhibit the introduction of new plumbing materials, equipment, and systems because of the prevailing reliance on specification-type or prescription-type language, and on requirements limiting, excluding, or requiring specific materials, equipment or systems.

Recent studies have indicated that it is possible to introduce the performance concept into plumbing specifications, codes, and standards to some degree, and that this can facilitate the orderly introduction of innovations. There is considerable evidence that cost-savings can be realized in plumbing systems both by a better analysis of actual hydraulic loads on waste and vent systems and by research on the performance of simplified and innovative systems for drain-waste-vent functions and water distribution.

A suitable proving ground is necessary for trials of innovations found tentatively acceptable from a consideration of potential performance. It is believed that HUD can provide such a proving ground, provided that HUD has access to a competent body of experts and adequate laboratory facilities to aid in making sound preliminary evaluations of promising proposals in advance of field trials.

OBJECTIVES:

1. Introduce performance language into specifications such as the FHA MPS's for plumbing, insofar as possible, based on existing technical information.

2. Provide needed new technical data and recommendations on test methods for plumbing, oriented to the performance concept.

3. Provide criteria for use in evaluation of innovations that might be proposed under a performance specification for plumbing.

4. Provide recommendations as to the need for evaluation for promising novel plumbing materials and hardware through laboratory and field testing, and conduct appropriate technical investigations relating thereto.

APPROACH:

1. Utilize applicable findings and recommendations in the literature, to improve existing specifications for plumbing through a greater use of the performance approach.

2. Develop instrumentation and investigative procedures as required, and carry out essential studies to obtain missing technical data required to support or complete performance specifications for plumbing.

3. Work with HUD, its advisory body or bodies, and national standards organizations in the application of data and recommendations developed in 1. and 2.

OUTPUT:

1. Field evaluations of the performance of promising simplified or new plumbing systems, to be performed concurrently with essential supporting laboratory tests.

2. Improvement of the accuracy and usefulness of methods for predicting peak hydraulic loads on plumbing systems, through theoretical work and collection and analysis of field data.

3. Selection or development of suitable test methods to aid in the evaluation of hydraulic, acoustical, thermal, structural, and durability performance of plumbing materials, components, and systems to the extent that is feasible in view of the limitations on the state of the art.

4. Cooperation with HUD, its advisory groups, and national standards bodies in the improvement of the evaluative art in relation to performance specifications for plumbing.

5. Maintenance of a technical information center for plumbing and plumbing standardization.

6. Maintenance of a principal laboratory facility for servicing an "agrement" - type body that HUD might turn to for recommendations as to performance of specific innovations, etc., in the plumbing field.

7. Recommended revision of the FHA MPS's on plumbing based on application of existing technical information, to be carried out as a part of Research Proposal B.4.8 on Writing Performance Standards from Existing Technical Information.

SPECIFIC TASKS--SHORT-RANGE PROGRAM:

1. An investigation of hydraulic and pneumatic performance of selected single-stack and small-vent drainage systems in a field situation, together with essential supporting tests in the laboratory.

2. Selection and/or development of theory, instrumentation, and procedures for collection and utilization of data on peak hydraulic loads on plumbing systems; also recommendations for a comprehensive program adequate to meet the need.

3. Outfitting of a plumbing laboratory facility of the type essential to the servicing of an Agrement-type program indicated under Item 6 of "Type of output" above.

4. As a part of Research Proposal B.4.9, to provide prompt servicing of requests for information on the current state of the art in plumbing standardization in the USA and Western Europe. Maintenance of this activity could be expected to extend indefinitely, depending on the continuation of a need.

5. An investigation to establish performance requirements and identify or develop test methods essential to evaluate water-conserving and incinerator type plumbing fixtures and sanitary waste-disposal systems.

6. A study to develop performance requirements and tests relating to plumbing systems for the kitchen and laundry areas.

TIME AND COST ESTIMATE:

It is estimated that proposals 1, 2 and 3 could be completed in one year at a total cost of $200,000. These three projects should all be implemented during the first year of the program. Items 4, 5 and 6 should be implemented in the second year at an estimated cost of $200,000 per year and might require 2 years to complete.

B.4.6 GENERAL SAFETY REQUIREMENTS FOR HOUSING

BACKGROUND:

The large annual incidence of fatalities, 20 to 30 thousand, and the millions of incapacitating injuries that result from accidents in the home, indicate the necessity for measures designed to eliminate the hazards or mitigate their effects. Congress has, for example, seen fit to require the development of safety measures for automobiles because of an annual rate of 50,000 fatalities and recently passed legislation for fire safety. We are separately implementing a program of fire research based on this recently enacted legislation, but in the other areas of safety we believe much needs to be done. For low-income families safety hazards might well be increased by attempts to reduce costs in inappropriate ways. In order to recognize and deal with this important area of performance a national program is needed since no single manufacturing sector can be given the responsibility.

We recognize that an accident in the home is often the result of some action of the victim, but we believe much can be done to help avoid such accidents or mitigate their results by attention to the design requirements of houses. We propose to work with the Department of Health, Education and Welfare in developing better home accident statistics as an input to this program. We know enough now, however, to recognize the need to concentrate on the avoidance of falls.

OBJECTIVE

One objective of the project should be to provide the highest possible level of safety in residential occupancies concordant with the overall objective of providing housing at low cost. Some performance requirements for the provision of safety can be met through proper design with little or no added cost to the construction. Features falling in this category are the avoidance of small changes in level in walkways, and the elimination of sharp or pointed projections and transparent surfaces on structual elements or installed equipment in or adjoining hazardous substances or objects falling into irresponsible hands, and making storage areas openable from the inside will prevent some of the cases of suffocation of children now occurring.

APPROACH AND PROJECT OUTLINES:

Falls, both on a single level and from one level to another constitute the greatest single cause of accidental casualties, accounting for about 40 percent of home accident fatalities and perhaps as many as 7 million incapacitating injuries.

This area is one where research appears to offer possibilities for reducing the incidence and effect of the hazard. A principal cause of falls is the slipperiness of walking surfaces. An examination of the standards and data available to implement a requirement that floors and walkways (interior and exterior) shall not present a hazard of falling caused by their slipperiness, indicates that a research project should be instituted along the following lines.

1. Development of a standard, and generally acceptable method of determining the slipperiness of floors, including the development of any necessary test equipment or devices.

2. Determination of the quantitative criteria for slipperiness that will provide the requisite level of safety.

3. Examination of flooring and walkway materials for their performance under the above requirements, including the effects of surface abrasion on the slipperiness characteristic, and the durability of the material in resisting abrasion, the effects of moisture on the surface, and for materials for exterior use, the effect of weathering of the surface.

Another large cause of casualties is falls on stairs, a particularly fatal accident to the older segment of the population. The necessary research here is as follows:

1. Determination of requisite slipperiness factor (as outlined for flooring in general).

2. Examination of dimensional requirements for stairs relative to the user needs, and especially to the needs of the user group suffering the most accidents.

3. Investigation of light (artificial and natural), shadow, and color as they affect visibility and recognition on stairs, landings, and spaces leading to stairs.

4. Study of the possibility of providing a light source that would provide adequate visibility for stairwells filled with smoke.

TIME AND COST ESTIMATES:

Tentatively, the times necessary for the above investigations, and the costs that would be accrued, are as follows:

A two year program designed to produce recommended criteria and test methods, in the following phases:

.First six months: data gathering and in depth analysis of existing safety requirements related to falls:	NBS	$30,000
	HEW	60,000
.Development of criteria and test methods for slipperiness of walking surfaces: 1-1/2 yr;		90,000
.Development of criteria and test methods to avoid hazards on stairways: 1-1/2 yr;		90,000

B.4.7 A CONTINUING SERVICE FOR EVALUATING HOUSING INNOVATIONS

NEED:

The Department of Housing and Urban Development has a continuing need for technical information to provide solutions to a broad range of technical problems, particularly those dealing with housing innovations. Solutions may require information ranging from that readily available from the expert to analytical results derived from special laboratory tests.

OBJECTIVE:

This program will establish an open communication line connecting the decision-makers at HUD to the applied scientists in IAT, enabling HUD to get quick response to technical problems for which answers are known or can be developed by laboratory testing of housing innovations.

APPROACH:

A model of the approach envisaged in this report is "Phoenix" wherein technical experts from IAT assisted HUD in planning a testing program, proceeded to carry out the necessary tests in the laboratory, reported these results to HUD, and planned to conduct field tests at HUD's request.

It is recommended that the "Phoenix" solution be extended to further evaluation under this project to include acoustical properties, environmental (interior) examination, durability, and fire tests.

Under this project other innovative solutions to low-cost housing would be tested in a manner similar to the "Phoenix" solution or by other more appropriate tests. Non-routine testing would be carried out in NBS laboratories. However, significant amounts of routine testing if developed would be placed with qualified testing laboratories. IAT staff could (1) advise HUD as to where such testing could be done, or (2) provide the service of subcontracting routine testing to commercial laboratories.

In addition to evaluating housing innovations, a consultative and advisory service would be provided to HUD. Services provided could be the immediate-answer type by applied scientists in IAT, to ad hoc committee activities, to loans of personnel for specific tasks. Experience during FY 1968 shows that HUD has need of IAT staff in all of these capacities.

This project is one that would be responsive to HUD's request throughout the Fiscal Year, and specific tasks under it could be implemented only with HUD's authorization. However, the existence of such a project simplifies greatly the rapidity of the response that IAT can make and, in effect, eliminates paper work after initial authorization.

FUNDING:

For quick response consultation and testing: $200,000 for FY 1969 deposited by HUD with IAT as a "checking account." Unused funds would be returned or carried to next fiscal year.

DURATION OF PROGRAM:

Year-to-year basis as required by HUD.

B.4.8 WRITING PERFORMANCE SPECIFICATIONS FROM EXISTING TECHNICAL INFORMATION

NEED:

The number of existing performance specifications for low-income housing is extremely limited, but a severe need for these exists if the performance concept is to be implemented in seeking solutions to the housing problem. In addition, time is limited for the development of performance standards. HUD, therefore, has a need for an early conversion of specifications or knowledge that could readily be stated in performance language and, thus, implemented in its other "hardware" oriented programs.

OBJECTIVE:

Under this project, existing technical knowledge and specifications that are nearly in performance terms would be converted to performance language for immediate implementation by HUD.

APPROACH:

The NBS-HUD Study of Performance Standards for Low-Income Housing has disclosed many specifications and supporting technical information that could be converted to performance standards by experts in given fields. Subject areas included are:

1. Structural Systems: Stability and Strength of Components and Materials Used in Housing
2. Safety
    a. Fire Protection
    b. Falls
    c. General Safety
3. Durability
    a. Durability as the Time Dimension of Performance
    b. Air, Moisture, and Water Penetration
4. Characteristics of the Interior Environment
    a. Acoustics Environment
    b. Air Cleaning and Odor Control

c. Thermal Environment

d. Visual Environment

5. Service Systems Within Housing

a. Plumbing

b. Food Services

c. Energy Sources

d. Electrical Systems

e. Mechanical Systems

f. Transportation

Under this project, to be directed by the Chief, Codes and Standards Section, Building Research Division, teams of technical experts would draft recommended performance specifications based upon existing knowledge. The order of approach would coincide with those areas of most interest to HUD. Two areas for early output (six months) are: (1) Translation and/or conversion of "performance" type specifications now being obtained from other countries (particularly the French Agrement specifications) and (2) Conversion of the recent NBS Report (9817) to FHA on Performance Criteria for Exterior Wall Systems into a performance specification document. Much of the remaining state of the art specifications could be converted during the remainder of FY 1969. These would be transmitted to HUD on a continuing basis, as completed, throughout the year.

A valuable by-product of this program would be to sharpen our focus of future research needed to produce the knowledge and evaluative techniques needed for improved performance specifications in the above subject areas. No laboratory testing or research is envisioned under this program.

FUNDING:

$200,000 for FY 1969

DURATION OF PROGRAM:

18 months

B.4.9 DEVELOPMENT OF A TECHNICAL INFORMATION NETWORK

BACKGROUND:

Professional communication in the building industry is very inadequate. Contacts with builders, architects, engineers and research personnel in universities indicate that professionals have great difficulty in finding out what research is going on related to their interests. This situation has been recognized for some time, but has lacked a cohesive force for two reasons:

- .Within narrow disciplines individual communication has been relatively good, but interdisciplinary interests have lacked leadership.

- .The bulk of research in building has been done by private companies with a proprietary interest in the results.

Now that there is developing a broader base of research support (primarily through the government) and because the research is often interdisciplinary in character, the need exists to provide a mechanism of relating the professionals doing research in the field to one another in order that they can know what's new, who's doing what, and where the trends are. Professional journals have not served this purpose.

OBJECTIVES:

Our investigations on this project showed that much work is presently underway that is not generally known, but which should be applicable to the development of the performance concept. These areas of work are increasingly moving away from the single discipline approach such as physics, chemistry, civil engineering, mechanical engineering, etc. Many of these projects now involve the liaison of physics, chemistry, engineering, sociology, economics and management. It is this departure from traditional disciplines which makes effective communications so difficult. We propose to design and implement a mechanism which will link the research activities of the Building Research Division, the universities, and other organizations in a communications network that will work to the mutual benefit of all organizations involved in developing the performance concept as applied to buildings. We would not intend this network to operate at the urban level, nor to deal with research in specific product development not related to advancing the state-of-the-art of the performance concept.

APPROACH:

The concept of a technical information network of this type is not new. Its application in the field of building, however, is not a simple problem because of the diversity of interests. We would plan in the first six months to design a network for this purpose after consultation with universities, other government agencies, the Building Research Advisory Board of the National Research Council, the Building Research Institute and the Science Information Exchange of the Smithsonian Institution. The Institute for Applied Technology of which we are a unit, includes a Clearinghouse for Federal Scientific and Technical Information. This activity is largely a research report and document distribution service, not a current research information network. We see, however, the possibility of combining a network of professionals such as we envision with a distribution service provided by the CFSTI. Because we are both within the same organizational unit we see this concept as one of definite utility to the professional researcher.

FUNDING:

Because the utility of such a network would be for research related to the performance concept as applied to all building types, not just housing, we propose a joint funding effort between HUD, NBS, and other government agencies who sponsor building research. The first six months effort (the design of the network) would require funds of $45,000 of which we are asking HUD to provide $15,000. The cost of the continuing network operation we can only estimate at this stage to be on the order $250,000 per year. We would anticipate HUD's share of this cost to be between $50,000 and $100,000 per year.

B.4.10 SUMMARY OF RESEARCH PROPOSALS

The research proposals for continuing activity by NBS in developing performance standards for low-income housing are summarized below:

No.	Program Title	Proposed Funding FY1969
B.4.2.	PSYCHO-PHYSICAL CRITERIA	$350,000
B.4.3.	FRAMEWORK FOR USER NEEDS	60,000
B.4.4.	STRUCTURAL DESIGN REQUIREMENTS	250,000
B.4.5.	PERFORMANCE SPECIFICATIONS FOR PLUMBING SYSTEMS	200,000
B.4.6.	SAFETY REQUIREMENTS FOR HOUSING	150,000
B.4.7.	CONTINUING SERVICE FOR EVALUATING HOUSING INNOVATIONS	200,000
B.4.8.	PERFORMANCE SPECIFICATIONS FROM EXISTING INFORMATION	200,000
B.4.9.	TECHNICAL INFORMATION NETWORK	15,000
	TOTAL	$1,425,000

B.5 RANK ORDERING OF PERFORMANCE STANDARD NEEDS

In order to establish priorities for research we wish "to rank-order those performance standards to be developed in terms of their impact upon construction."

This "impact upon construction" might come about in five ways, and we have described five techniques for rank-ordering. It is understood that the goals of all the participants in any research program affect the relative importance placed on projects within the program. The system chosen for rank-ordering priorities must be selected with these goals in mind. There are a number of alternative goal structures which strongly affect rank-ordering. We discuss these in the following section B.5:1, Techniques for Rank Ordering.

In section B.5:2, the Measurements of Costs and Benefits, we elaborate on the problems and opportunities in establishing a system to measure these.

1. TECHNIQUES FOR RANK-ORDERING

"Impact upon Construction" may be taken to mean any or all of the following considerations when we conceive of "construction" as that entire process which delivers residential environment to the point of consumption, the user. From such a conception of "construction" we can derive five techniques for rank-ordering research, each based on a different goal structure. They are:

1. IMPORTANCE TO SOCIETY:
in terms of satisfying the goals of all the people and institutions who affect housing or are affected by it.

2. MAXIMUM COST REDUCTION OPPORTUNITY:
in terms of reduction of first costs of construction and/or total life-cycle costs of construction.

3. MAXIMUM INCREASED BENEFITS TO USERS:
who are low-income urban consumers. It is understood that some goals of such consumers may at any one time, not be consonant with the general goals of society--A case of sub-optimization.

4. SOCIO-POLITICAL VISIBILITY:
in terms of the lectorate perceiving that such efforts are taking place and producing beneficial results in critical problem areas of "construction."

5. SMOOTHNESS OF TRANSITION:
assumes that one of the major impacts on construction might be a transition from the method of procuring residential environment to another, and desires to structure such a transition with the least disfunction in the present system.

These are the primary techniques for rank-ordering. To each of these must be applied a set of secondary considerations for each program and projects within programs. These are:

1. Costs

   a. of research and development

   b. of applying R & D in "real-world" situations

2. Feasibility

   a. of obtaining qualified research personnel

   b. of performing research and development

   c. of applying R & D in "real-world" situations

3. Time

   a. to do research and development

   b. to apply R & D in "real-world" situations

Any rank-ordering should be based on all five primary techniques and the secondary considerations of Costs, Feasibility and Time. To do this, we have further developed each of the five primary techniques into the factors necessary for their use, and described the problems in achieving such use.

In each of them, there are limitations so fundamental as to preclude their use at this point in time, and on this problem. Therefore, our rank ordering of research program priorities is based upon our professional judgement and the available capabilities of research institutions.

The five primary techniques, with their factors and problems are displayed in a series of charts which follow.

1. IMPORTANCE TO SOCIETY

desirable factors in rank-ordering	problems
1. Clearly established goals of the Society or a system for establishing and articulating such goals.	1.a. Any goals which can be stated are at a very high level of abstraction and not easily decomposed into operational statements. b. Problem of stating goals satisfactory to all elements in a heterogeneous democratic society--there are widely varied and competing sub-goals. c. Political structure is not generally motivated to make clear goals statements to electorate. d. Value systems of electorate and elected officials not always consonant. e. Question of Church/State relationship in goals' hierarchies. f. Competing "establishments."
. . . .	
2. Evaluative techniques to know when goals have been reached	2.a. Lack of criteria (other than specially developed Ad Hoc criteria) to make evaluations. b. Lack of evidence of causative relationship between system change and goal achievement. c. Evaluative techniques tend to be developed for sub-optimization of system goals (such as costs) rather than full evaluations... equations involving disparate information such as cultural values, benefits, costs are not developed.

desirable factors in rank-ordering	problems
. . . .	
3. Feedback system for continuous goal establishment	3.a. When systems goals are met, there is always unwanted output or side-effects which often form new "crises" - these in turn demand new goal establishment.
	b. Getting relevant information from all parties. Many groups in the Society do not have easy access to decision-makers, and further, have difficulty in ascertaining and articulating their goals.

2. MAXIMUM COST-REDUCTION OPPORTUNITY

desirable factors in rank ordering	problems
1. Cohesive data-base for housing costs. (Necessary input to cost accounting system)	1. Present data-collection varies widely in format since present accounting systems vary. Contractor-Builder, Owner-Client, Designer-Engineer have different operating pattern needs, therefore data differs. In-use costs difficult to assemble and pro-rate.
2. Comprehensive system for cost analysis/ cost synthesis (a dynamic accounting system) which can deal with first costs and/or life cycle costs.	2. Work currently being done to develop such a system. However it is essentially based on a common method of data-gathering throughout the housing process. System not yet operational or tested.
3. Described alternative hardware solutions to compare cost.	3. Performance requirements generally examines the needs of the user, and only peripherally the hardware which meets these needs. Therefore, a large range of Performance-based alternative hardware solutions to user needs is not available. To make them available (or to simulate them) for cost comparison implies INVENTION and is outside the scope of this project.

desirable factors in rank ordering	problems
4. Positive relationship between development of Performance requirements and reduced costs.	4.a. To correct our present residential environment disfunctions through a more clearly articulated statement of user needs may not reduce physical hardware costs at all. This raise in building hardware costs may well be more than offset by reduced costs elsewhere. Our present decision-making and cost-accounting systems do <u>not</u> permit these comparisons to be made. e.g.: Reduced Welfare and Police costs as a function of increased quality (and therefore costs) of the residential environment. A fuller discussion of the use of costs as a measure occurs in the next section B.5:2, the Measurement of Costs and Benefits. b. There <u>are</u> areas of cost-reduction opportunity dependent on use of Performance Design. These are: (1) By more thorough analysis of loads, overdesign may be revealed which will permit saving of materials. (Ex.-Live Load Data, Plumbing Loads, Weather Data) (2) Integration of function may result in more economical design and saving of cost. (Floor-ceiling sandwich, Integrated structural and electrical systems)

desirable factors in rank ordering	problems
	(3) A better balance in expected useful life of various components may permit savings. (Rehabilitation project in New York.) (Performance promotes concept of balanced systems.)
	(4) More adequate measurement of rates of deterioration may result in saving in materials. (Durability relative to exterior environment and to interior exposure.)
	(5) Trade-offs between less important characteristics and more important characteristics may allow savings. (Exterior balconies, stairs, elevators.)
	(6) Broadening the base of competition among different classes of materials by performance-based requirements may reduce costs of adequate systems. (Sanitary Plumbing Fixtures.)
	(7) Permission of integrated systems, spaces, or functions, through performance would generate economies through: lowering safety factors, promoting novel, fuller utilization of space and time, overlap of functions.

3. INCREASED BENEFITS TO USERS

desirable factors in rank ordering		problems
1. Defining the user	1.	User groups are not simply defined, and change over time. These groups are mobile and, in a sense, distrustful of being "studied."
2. Clearly stated User needs which Benefits are to satisfy, or a system for establishing such needs	2.	No fully developed statement of user needs (for housing) exists, nor a system for their development. Needs statements must be based on the users physiology, psychology, sociology and the resources available to satisfy the needs.
3. Clear measures of benefits	3.a.	Difficulty of measuring whether benefits have or have not been received. (We use Ad Hoc measures.)
	b.	Difficulty of refining existing measurement techniques due to "sluggish" State-of-the-Art in psychology and sociology.
	c.	Problem of establishing causative relationship between systems "adjustment" and benefits received. Are other factors responsible?
4. Feedback system	4.	Getting relevant information from Users who are generally distant from decision-makers, and who have difficulty in ascertaining and articulating their needs.

4. SOCIO-POLITICAL VISIBILITY

desirable factors in rank-ordering	problems
1. Rapidity in response/"speed"	1.a. The corrective efforts for large-scale physical systems are of longer duration than political (or decision-makers) tenure in office. Therefore long-term efforts must have continuous or short-term visible "payoff."
	b. Only short-term results can occur, while some testing may be long-term for best results.
2. Visible links between change "initiators" and change results/ "visible responsibility"	2. Schemes become associated with particular people. Problems of competitive housing schemes (all trying to solve same problem) promoted by people in competition for positions, power, profits, etc. This type of competition does not necessarily lend itself to cost reduction or user benefits.
3. Large-scale pervasiveness of probable change/"size"	3. Large-scale tends to "lump" all users into a norm and does not provide for variety of response needed.
4. Desirability of response to electorate or affected groups/ "quality"	4. Maximum user desirability and maximum socio-political visibility are not necessarily co-equal. Users' analyses of their own needs are not adequate in many areas (safety, health) and that which is desired is not always necessary.

desirable factors in rank-ordering	problems
	c. New housing presents new physical solutions to problems (i.e., Waste removal, transportation) which may be more complex at the user level.
	d. User's unfamiliarity with new materials and new "housekeeping."
5. User's social transition simplified	5. New housing (large volume) destroys stable community social patterns. May be unavoidable at scale being contemplated, unless great effort is made.
6. Community functioning unimpaired	6. Probable cataclysmic effects on community services and values if housing (quantity) problem <u>is</u> solved...i.e., Services, Schools, Transportation, Physical Attenuation from Centers, etc.

B.5.2. THE MEASUREMENT OF COSTS AND BENEFITS

The "performance requirements hierarchy" of Section B.2 is a compilation of a user's needs that housing should satisfy. However, in order that it be useful in directing a housing program, each of the need statements, and each combination of them, must be evaluated against various costs and benefits. It is the task of this section to discuss the "measurement systems" we have available for this purpose and those that must be developed to accompany the range of statements of what needs housing must satisfy. Many of these techniques at present have had very little development. Hence what follows is a list of the range of techniques that must be developed and an outline of the variables they must encompass.

1. Benefits from specifying performance

When we move from specifying objects to specifying the performance desired of them, our requests allow a larger range of objects to be considered as alternative ways to supply what we want. For example, if instead of requesting a beam of certain dimensions and materials, we specify how it must perform (what loads it must bear and how it shall behave while supporting them), we allow the supplier to consider many more alternative routes by which to meet the request. Specifying how the beam should perform will not itself cause a cost reduction; rather, it will permit a larger range of alternatives to be considered. IF AMONG THESE ALTERNATIVES THERE IS A MORE EFFICIENT SOLUTION, THEN, A COST REDUCTION WILL RESULT FROM SPECIFYING PERFORMANCE.

A second way cost reductions can result from specifying performance stems from the way in which the specifying is done. Any object in the environment, especially a house, fulfills many functions, is capable of many performances. Confronted with a description of the object, a supplier finds it difficult to know what combinations with differing performances are permissible; but confronted with a description of performance, he knows what issues to consider. A characteristic of questions that relate to performance is that answering them forms the basis for judging whole alternative configurations. In other words, because performance specifications demand to be answered on the basis of whole solutions, the specification devices serve as a context for defining systematic relationships between parts of the environment. Once such a tool is developed it becomes possible to judge what is overall a more efficient solution.

Any system which delineates the consequences of following alternative routes also clearly displays alternative paths, can act both as an instrument to evaluate alternatives or to suggest them. A method used to judge the relative importance of providing a place for recreation inside the home or for providing compensatory recreation space elsewhere, suggests to the provider that such alternatives be looked at. In short, not only does specifying performance allows for broader ranges of cost saving solutions, but also stimulates the development of innovative alternatives.

2. Specifying and measuring objects

The method for specifying environments that develops the narrowest range of alternative solutions is specifying the physical object itself. In the extreme, one specifies only a single solution such as a particular housing product. One step removed is a system of specifying the class of objects (e.g., a 4 bedroom house) in a great deal of physical detail (such as do the present Minimum Property Standards). Generally such specifications are in terms of spaces to be procured (bedrooms, kitchens, instead of the activity to be accommodated, their physical dimensions, their materials, or sometimes a particular construction process. There is an accepted nomenclature for describing these. Trade standards exist which form the basis for materials selection in the construction process. The physical sciences have developed the measurement of the physical properties of building elements to a reasonably sophisticated level.

3. Specifying and measuring performance

A quantum jump in the number of alternatives that can be provided is made when we specify the performance an object must have. There are two kinds of such specifications--either (1) specifying the performance the object can give, or (2) specifying the performance the user desires. Hence, by specifying through more general need statements, we permit more numerous combinations of particular solutions, more alternatives, to be considered.

4. Measuring costs and benefits from performance

If a specifying technique not only spells out a range of variables, but also permits various rank orderings of the variables, a second improvement in the number of alternatives to be allowed is made. Not only can we inspect alternatives that are called for by a set of specifications, but, we can begin to examine alternative sets of specifications as well. A further expansion of our specification tool is necessary if it is to be used to make such evaluations of alternative sets of variables; some way must be devised to measure the costs and benefits of alternative specifications as well as proposed solutions.

The matrix of "the environment in use" (mentioned in Section B.' compares needs to the ability of various environmental artifacts to support them. Neither costs nor benefits result from such a yes or no evaluation. Costs are incurred in the process of putting the environment into place and operating it; benefits occur by carrying out functions whereby needs are met. As the chart "cost-benefit relationships" shows we measure costs by putting a time dimension against environmental elements which describes the steps of manufacturing and operating the environment; analogously, we put a time dimension against the description of needs to illustrate that the process of functioning to meet these needs produces benefits. In this instance, we have illustrated the functions that housing traditionally performs, the processes that one reasonably intends housing to support to satisfy needs (e.g., sleeping, dining, leisure activity, etc.).

These matrices form only a very rough approximation of what a cost-benefit tool might be. They are included here to illustrate the urgent need for, and complications involved in, developing such a device. Such a tool is needed not only to expand the range of alternatives; but more importantly, to develop ways to relate such evaluative variables, and to make decisions about environmental programs as using performance specifications makes possible to do. What follows is an attempt to suggest the kinds of considerations to be added to the performance concepts developed above.

a. Costs

Of the two measures, costs and benefits, costs measurements have been developed to a much greater degree. In the chart "Cost Benefit Relationships" costs appeared as a matrix, one axis of which lists the environmental elements, and the other the cost of constructing and operating them. This section of the "cost-benefit relationships" illustration is expanded in detail in the "cost matrix" chart. Here, the environmental elements are broken down into a relatively traditional list of the elements that we call furnishings, services, fabric, link, and site. Buildings comprise services, fabric and link. Link refers to the foundations and elements that connect the rest of the building to the site. The fabric includes all the elements of a building that relate to support and enclosure elements. The services comprise the life supporting elements such as air conditioning, heat, power and light. The site comprises all the elements of housing which are outside the buildings but within the site of the housing project. The infrastructure is the provision of the flow of goods and services outside the housing project but which are essential for housing and living.

cost matrix

PROCESSES incurring costs

FUNCTIONING	MAINTENANCE
	OPERATING
CONSTRUCTION PROCESS	MATERIALS
	RESOURCES
PRE-REQUISITES	PLANNING
	LAND
	FINANCE
	ENTREPRENEURS'P

COSTS

ENVIRONMENT to be used

COMMUNITY INTERFACE	SUPPLY
	REMOVAL
	SOCIAL SERVICES
	COMMUNICATIONS
	CENTRAL SERVICES
SITE	SERVICES
	ROADS
	LANDSCAPE
LINK	EXCAV. FOUNDATIONS
	FABRIC
	SERVICES
FABRIC	STRUCTURAL
	WALLS-EXTERNAL
	WALLS-INTERNAL
	OPENINGS-VISUAL, ACCESS
	SHAFTS
	FLOORS
	CEILINGS
	ROOFS
	FINISHES, DECORATIONS
SERVICES	ACCESS SYSTEMS
	AIR CONDITIONING
	POWER & LIGHT
	HEAT
	COMMUNICATIONS
	WATER
	SANITARY FIXTURES
	WASTE REMOVAL
	INSTALLED EQUIPMENT
FURNISHINGS	FURNITURE & FITTINGS

Against this axis is displayed the processes by which these elements are put into place and maintained. There are three major divisions: prerequisites, construction, and functioning. These three types of cost can be converted onto scales commensurate with other costs by converting initial, capital costs to a cash flow basis or vice-versa.

Traditionally, the only cost that research in the housing industry has attacked is that of the process "initial cost-construction process" for materials and construction resources combined. The following is a further breakdown of this category, i.e., construction process only by the following components of the environment in the cost matrix.

site		.1%
link -	excav. foundations	1.4%
	fabric	2%
fabric -	structural	15.9%
	walls, external	6.3%
	walls, internal	10.1%
	openings - visual, access	7.1%
	floors	7.9%
	ceilings	5.5%
	roofs	1.5%
	finishes, decorations	5.4%
services -	access systems	3.6%
	air conditioning, heat	12.5%
	power and light	5.7%
	communications	0.1%
	water	0.4%
	sanitary fixtures	7.3%
	waste removal	0.7%
	installed equipment	8.0%
		100.0%

NOTE:
These figures are adapted from a survey done by FHA of hypothetical bids of high-rise, multiple family dwellings in a number of urban areas.

At present each of these elements is often researched independently from the others. Though it may be possible that dramatic reductions can occur in any of these categories, given that this whole list is only a small part of the cost of housing, only a small percentage of the cost may be influenced by traditional research which concentrates on improving only one category of construction at a time.

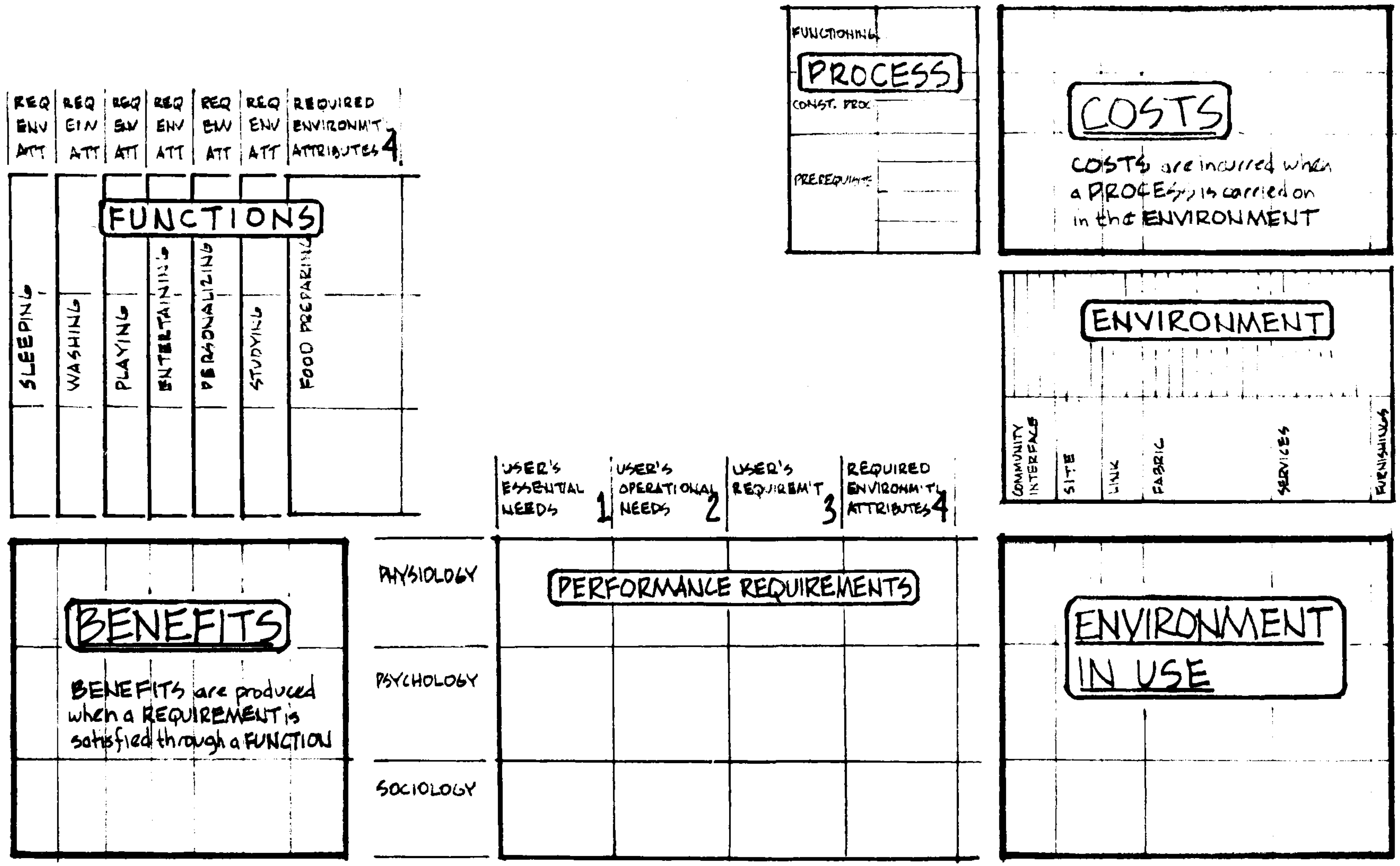
Reference can be made to Volume II, Appendix C, Document B and Document C for further amplification of the Cost Allocation System.

b. Benefits

There is a very great danger in using this performance matrix for describing alternatives and then charting only their costs. If this were all one was able to do with it, alternatives could only be ranked in terms of reduced costs. While reducing costs may be a valid goal, it may not necessarily improve the housing situation. Yet if the only yardstick available for evaluating alternatives is costs, new programs may miss the important possibility of rising benefits.

In the terminology of this cost-benefit tool, benefits are described as resulting from needs being met as the house functions. In this case, we have listed only the functions that traditionally are considered to be carried out in the context of houses. Though this definition seems simple, and simply related to the cost-benefit mechanism being developed in this report, there are many very serious limitations implied in this description. For example no recognition is given to benefits such as the security and the quality of life which do not directly come from the physical house or the obvious functions a house performs; rather they come through secondary routes, through the economic, political and social structures which form the context for housing--and whose institutional structures are entertwined with that of housing. The description of benefits implied in this chart does not show the real relationship between these institutions, the elements that produce benefits from housing. It cannot be used to evaluate alternatives that involve them.

Perhaps the most difficult problem to solve in finding a way of using measures of benefits is to find an evaluative standard to give relative values to a number of them. Many measures do exist, but not on commensurable scales--and cannot be compared, judged, weighed against each other. Since the act of evaluation involves judging, comparing, such "measures of benefits" cannot be used to make evaluations. We have yet to learn how to "model" in appropriately complex and real terms the relationship between man and environment.



cost - benefit relationships

The question now arises, if the administrators of a housing program who use this cost/benefit tool do not rank or delimit the goals, on whom will such decisions rest?

The need for a process for setting standards in a changeable, expandable way becomes clear when we observe that the goals of a particular evaluator or user change in reaction to new experiences, new possibilities. Because of changeable character of human goals, any system which is set up to continually satisfy human goals must permit the goal structure to change. What we are proposing here is a method of administering a housing program whereby the goals can be changed in accordance with the users changed desires. In other words, carrying the performance concept to its logical end, the user must be the one who decides on the relative importance of goals and also what new ones must be considered; and this must be carried on continuously.

Methods for permitting user responses have been incorporated into some existing projects, and promise to allow for getting expressions of satisfactions from users over broad areas of performance, and reacting to their evaluations. Planning projects are being developed not to make specific environmental changes, but to first organize a small group in a neighborhood to start spending effort on some environmental problem. This effort is to stimulate dweller's interest in such problems, to show that community action can alleviate them, and hence to stimulate further reactions which in turn lead to more problem statements and solution efforts. These "incremental planning" efforts will not only aim at alleviating environmental problems; it is expected that the increment of improvement may occur in the work sphere (job creation, skill training) and others (economic, political) as well.

These desired complications in the measurement of benefits will not be easy to obtain. Because they are possible of conception, a major effort should be made to develop them. We hope that this will become one of the major concerns of the Urban Institute.

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