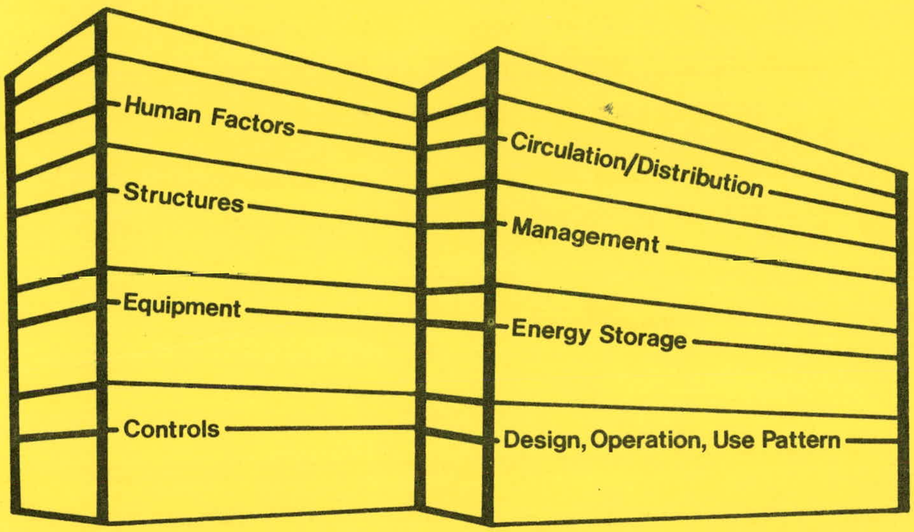
RECEIVED BY TIC OCT - 9 1979

PROCEEDINGS
OF THE WORKSHOP ON

MASTER

THE DYNAMIC RESPONSE OF ENVIRONMENTAL CONTROL PROCESSES IN BUILDINGS

March 13-15, 1979
Purdue University



Sponsored by:

RAY W. HERRICK LABORATORIES
School of Mechanical Engineering
Purdue University

AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR CONDITIONING ENGINEERS INC. (ASHRAE)

and

UNITED STATES DEPARTMENT OF ENERGY (DOE)
Under Contract No. EM-78-C-01-4221

Editor

DAVID R. TREE
Purdue University

Assistant Editor

MERLE F. McBRIDE
Owens Corning Fiberglas

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Any opinions, findings, conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the Department of Energy nor the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Prepared under Department of Energy Contract No. EM-78-C-01-4221.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

TABLE OF CONTENTS

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

TABLE OF CONTENTS (cont.)

FOREWORD

For many years it has been apparent that the world in general and the United States in particular can not continue to use energy at ever increasing rates and, in many cases, wasting large amounts of energy. The known supply of hydrocarbon fuels is limited. It was not until the oil embargo of 1973, that this fact was clearly pointed out to almost all people. Something must be done to reduce or at least slow down the rate of increased energy usage and to minimize the wasting of energy.

It has been estimated that about 14% of all energy consumed nationally is used to heat or cool buildings of the commercial and industrial type buildings. An additional 20% is used in residential buildings.

There are many ways to reduce energy in buildings. One way is to completely neglect the comfort of people. This is not an acceptable solution and thus other options must be considered . There are some people in ASHRAE who believe that comfort and energy may be simultaneously optimized through the use of operating strategies which consider the dynamic characteristics of comfort, the built structure and the environmental control system. William Chapman is such a person. Under his direction an ASHRAE task group (TG) was organized to pursue this idea. At the ASHRAE meeting in Seattle in June 1976 a seminar was held to tell ASHRAE members what several people thought should be done. This workshop is an outgrowth of that seminar.

The goals of the Task Group on Dynamic Response are to determine those activities necessary to develop operational strategies for the optimization of energy use in buildings and, through the other technical organizations in ASHRAE, to work toward the accomplishment of these activities. The workshop reported in these proceedings represent a major step toward achieving these goals by bringing together experts representing the many aspects of environmental control systems to determine 1) the present state of our knowledge, 2) the additional information needed and 3) the research necessary to obtain the needed information.

William P. Chapman, chairman of the ASHRAE Task Group on Dynamic Response and a Vice President of Johnson Controls, Incorporated opened the workshop by telling the participants the purpose of the workshop and what was expected of each participant. He then introduced the keynote speaker, Paul R. Achenbach, from the National Bureau of Standards. Mr. Achenbach outlined past and future problems related to the achievement of the goals of the task group for the workshop.

The workshop was then divided into eight (8) working sessions. 1. Equipment, 2. Controls, 3. Structures, 4. Human Factors, 5. Circulation/Distribution, 6. Design, Operation and Use Pattern, 7. Management and Codes, and 8. Energy Storage. These proceedings report the findings of these eight working sessions.

In addition at the conclusion of the workshop, a summary session was held. The results of this summary session are also included as part of these proceedings.

The organizers and participants of this workshop realize that the recommendations in this proceeding are not all inclusive. There may be oversights and some of the recommended research efforts may already be in progress or have been done. The ASHRAE Task Group on Dynamic Response welcomes your comments. Comments should be sent to: Dennis E. Miller, Johnson Controls, Inc., P.O. Box 423 MS 47-680, Milwaukee, WI 53201.

The Ray W. Herrick Laboratories, School of Mechanical Engineering of Purdue University is proud to be a part of this important workshop. We hope that this workshop and these proceedings are a useful part of the program to understand and optimize energy usage in building and at the same time maintain the comfort of its occupants.

We wish to thank all those who participated in the workshop, ASHRAE for its forsight in seeing the need for such a workshop, and DOE for their financial help.

David R. Tree
Workshop Chairman

NOMENCLATURE

A	amplitude of temperature change
ACES	annual cycle energy storage
ADPI	air diffusion performance index
AMCA	air movement and control association
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
ASHVE	American Society of Heating and Ventilating Engineers
BTU	British thermal units
°C	degrees Celsius
Cal	calorie
Cfm	cubic feet per minute
Clo	measurement of the insulating value of clothing
DOE	Department of Energy
DX	direct expansion
E_{max}	the maximum evaporative cooling allowed by the environment
E_{reg}	required evaporative cooling
E_r	sweat regulatory losses
ET	Effective temperature scale
EUI	energy utilization
°F	degrees Fahrenheit
ft	feet
gpm	gallons per minute
hr	hour
HSI	heat stress index
HVAC	heating, ventilating and air-conditioning
HUD	Housing and Urban Development
i_m	permeability index for clothing
KSU	Kansas State University
kW	kilowatt
L	heat losses
LiBr	lithium bromide
M	metabolic heat production
m	meter
Met	unit of measurement for the metabolic heat production, 1 met = 50 kcal per square meter per hour
min	minute
MRT	mean radiant temperature
NBS	National Bureau of Standards
NBSLD	National Bureau of Standards computer program for heating and cooling loads in buildings
P_A	vapor pressure
PIHI	predicted indoor habitability index
PMV	predicted mean comfort vote
PPD	percentage of persons dissatisfied
Q_C	convective heat loss
Q_{diff}	diffusional losses through the skin
Q_R	radiant heat exchange
Q_{res}	respiratory heat losses
R or r	rate of temperature change
RH	relative humidity
sq	sqare
SW	sweat secretion
T_A	dry bulb temperature
T_B	basal temperature
TC	ASHRAE technical committee

T_{CORE}	body core temperature
TG	ASHRAE Task Group
T_M	mean ambient temperature
T_N	neutral temperature or temperature at which there is thermal comfort
T_S	body skin temperature
TS	thermal sensation
TS/a+	thermal sensation; mode: ascending; temperature: maximum
TS/a-	thermal sensation; mode: ascending; temperature: minimum
TS/d-	thermal sensation; mode: descending; temperature: minimum
TS/d+	thermal sensation; mode: descending; temperature: maximum
VAV	variable air volume systems
W	watt
ZnBr	zinc bromide

ORGANIZING COMMITTEE

General Chairman and Proceedings Editor
David R. Tree, Purdue

Assistant Proceedings Editor
Merle F. McBride, Owens Corning Fiberglas

Workshop Organizer
Gary F. Lee, Purdue

ASHRAE Workshop Subcommittee
Merle F. McBride, Owens Corning Fiberglas
Dennis E. Miller, Johnson Controls
Alfred Greenberg, GEO - Energy Limited

Advisory Committee
Raymond Cohen, Director, Herrick Laboratories, Purdue
Arthur H. Lefebvre, Head, School of Mechanical Engineering, Purdue
Joseph F. Cuba, Director of Research, ASHRAE
William P. Chapman, Chairman ASHRAE Task Group on Dynamic Responses, Johnson Controls

WORKSHOP CHAIRMAN

1. Equipment - David A. Didion, National Bureau of Standards
2. Controls - George R. Schade and James R. Tobias, Honeywell
3. Structures - Ross F. Meriwether, Ross F. Meriwether & Associates
4. Human Factors - Ralph F. Goldman, U. S. Army Research, Institute of Environmental Medicine
5. Circulation/Distribution - Herman F. Behls, Sargent and Lundy
6. Design, Operation, Use Pattern - Alfred Greenberg, GEO - Energy Limited
7. Management and Codes - Alfred Greenberg, GEO - Energy Limited
8. Energy Storage - Calvin D. MacCracken, Calmac Manufacturing, Inc.
9. General Sessions - William P. Chapman, Johnson Controls, Inc.

The Chairman would like to recognize three graduate research assistants of the Ray W. Herrick Laboratories who helped with many details while the conference was in session, they are: Gregory Johnson, William Murphy and Steven Thomas.

CHAPTER I

OPENING SESSION

1.0 Welcoming, by Raymond Cohen, Director of Ray W. Herrick Laboratories, School of Mechanical Engineering, Purdue University

We have many conferences at Purdue servicing many thousands of visitors to the campus who enjoy these fine conference facilities. I hope you do also. But beyond that, because of the Herrick Laboratories' long association with ASHRAE, we are especially glad that you chose to hold such an important workshop as this here.

The energy problems of our times have become all pervasive for ASHRAE, as they are fast becoming for our society. This workshop is one manifestation of ASHRAE's response to these problems - a response that started when I was chairman of ASHRAE's Standards Committee in 1971-73. The National Bureau of Standards had been working on standards to minimize energy use in buildings and it was suggested to me by Walt Spiegel, then president of ASHRAE, that we should appoint a project committee to consider the work of NBS with the idea of developing an ASHRAE Standard with that same objective. The Standards Committee had been accustomed to developing consensus standards based on common practice. ASHRAE shied away from standards that went much beyond measurement techniques leaving rating standards or the like to trade associations. So it was not an easy matter to respond to Walt Spiegel's request, especially when viewed, in addition, in light of the expected arguments and controversy from different segments of ASHRAE. We knew there was no visible consensus, if indeed there was one at all. But we did appoint Standard Project Committee 90 and ASHRAE Standard 90-75 was produced three years later. ASHRAE responded to the need then and has continued to respond since. Now there are very few programs in ASHRAE that are not energy conservation related.

ASHRAE is doing a fine job in the conservation field. I am glad to have been a part of it. I presume all of you are too, otherwise you wouldn't be here. This particular topic of "dynamic response of buildings" is terribly important to energy conservation.

2.0 Conference Theme and Introduction of Keynote Speaker, by William P. Chapman, Chairman of ASHRAE Task Group on Dynamic Response and Vice President for Research, Johnson Controls

We have a workshop here today, gentlemen, and I want to welcome you to it. We emphasize the WORK in WORKSHOP.

This workshop has been a long time in coming. We had our first planning session for this workshop without realizing that we were planning for the workshop; it was in Seattle in June of 1976. We held a seminar to tell the membership what several of us thought had to be done. At that time we asked the membership if they agreed with us. On the panel with me were Ross Meriwether, Chuck Sepsy and Larry Spielvogel.

That seminar didn't produce much, I will have to confess. For one year we struggled. We didn't really get off the ground until the next year when the Task Group on Dynamic Response was formed. It was placed in Section I of the R&T Committee under Bob Tamblyn, who is here this morning to participate. In that first year, July, 1977 to June, 1978, the Task Group developed a hypothesis; namely,

> The design and operation of buildings, if changed from our present worse case design - the static, thermal equilibrium assumptions - to the consideration of dynamic response characteristics of all elements, we could have more energy effective buildings.

The problem, though, is that we lack a great deal of data, so much in fact, that the research that is required goes beyond the capabilities of any corporation; goes beyond the capabilities of a group such as ASHRAE if they had to rely on their own general funds. So it was essential that we turn to the Department of Energy and ask them for their participation and their help. We were encouraged by DOE last year to do some work for them, but we had to get our thinking straightened out; we had to get organized; we had to put something of substance together. This, in fact, was the first challenge that the R&T Committee gave us. Well, we did that and we have formulated our plans. In this packet (see Appendix A) you will find some of this background. You will find the objectives. You will find the thinking of the Task Group. At this moment the objective of this Task Group is to verify its hypothesis. We intend to do that by actually operating a number of systems. But before we can do that we need research data so we come back to our primary objective, which I hope will be the product of this workshop. A product which we plan to put forth to the membership at Los Angeles. A product which we will work on for many, many man hours in a period from today until Los Angeles. A tentative plan will be open for discussion at Detroit and will be the subject of several meetings. Our product should be the long range research plan to develop the dynamic response characteristics of the building system.

We may have described that system as consisting of three subsystems, or three elements, (1) the passive element, which would be the building envelope, the pipes, conduit, the non-energy consuming elements that affect the operation of the system; (2) the active elements, those elements that are actually using energy, primarily the motors that drive the pumps, fans, compressors, the lighting, the auxiliaries - those devices that discharge energy and create the internal load - and that is the cross-over into the third element; namely, (3) the occupant.

The occupant is a dynamic machine. I will say that our technical committee, 2.1 Physiology, is about five years ahead of the other technical committees of our society in appreciating dynamic response. I hope you were in attendance at our seminar in Albuquerque. Ralph Goldman gave a very fine presentation on work that T.C. 2.1 has done. But they, too, know there is more to be done, so they are participating in this Task Force.

The Task Group this morning in this workshop are saying that because of the dynamic characteristics of the occupant it is possible to operate our system in such a way that we need not have a fixed room temperature, but rather it can be flexible. Our comfort conditions, our temperature, our humidity, our air velocity, can vary, and during this variation the occupant can adjust for a limited period of time for a limited amplitude. We can, therefore, allow the system to provide varying conditions. This indicates that we should be able to set priorities of operation to take advantage of changing conditions. The highest could be energy effectiveness within limits of comfort conditions. It would be an amateurish, foolish operation, of course, to completely optimize energy without regard to comfort and consume no energy whatsoever. One could work in the dark. One could work in the cold or the heat. One could open the windows and go back 50 years to the conditions that were prevalent then before we understood the physiological aspects of the environment. We feel that we need not be that unprofessional. We feel that by maintaining a professional attitude we can make our structures more energy effective and maintain the quality and performance that we have developed after these many years of research. We feel we can meet the goals, the objectives that have been set for us; namely, to reduce operating loads 25%. We can do this without sacrificing quality. This is our hypotesis.

Personally, I am convinced of it, and I think most of us on the Task Group are convinced of it, but our problem is to prove it. If, indeed, we prove it we then have another task. We have to convince our membership to change today's design criteria. We will have to publish new design procedures in our Handbooks. The design professionals will not accept our hypothesis if it is not endorsed by ASHRAE and published in the Handbook. It has to be described there as the operating strategies of energy effectiveness, and that leads us to the point of our keynote speaker this morning.

He is going to speak on the problems and the opportunities that we have and the difficulties of taking our technology from the laboratory, from the research stage, and bringing it into the marketplace, the designer's office. It is not too early to think about this next step at the outset. I remember in 1958 we had a conference in the old ASHRAE laboratories in Cleveland when we first started to speak about dynamic characteristics. We were speaking about dynamic characteristics of coils - water to air coils - not even a change of state; it was too complex to think of steam coils. One of the points brought up at that conference was that if we get this information, if, indeed, we can describe the elements in terms of their dynamic characteristics, how in the world will we ever use the information? How in the world will we ever be able to bring such a complex design procedure into the consultant's office? Well, some of us said, we don't know, but let's not worry about it at the moment - let's at least get on with the work, somehow there will be a way. What happened, of course, was that we didn't get started aggressively enough; we did establish RP5 (we are in the 200 series now) to study the dynamic characteristics of a simple coil, the water to air coil. We worked hard, we came up with extremely complex equations to describe dynamic response, and we have worked along and plodded along through several other projects. In the meantime the computer industry took over, and today the application of our data is not a concern. We will not have difficulty getting a design procedure put to practice because all of our consulting offices have access to computers. So the problem of using complex procedures is over. It does illustrate, however, the resistance at that time, 20 years ago, to take work from the laboratory and get it into being and make it useful. It is today an important aspect, and it is proper to consider it at the outset of our workshop. Utilization of research has to be considered before research is initiated.

With that as background, let me introduce our keynote speaker, Paul Reese Achenbach. Paul has been in the research arena of our industry, our profession, for many years. So far back that air was pure. We didn't have Air Conditioning in our name. Paul has been with the Bureau of Standards most of that time; he had a small excursion from the Bureau many years ago, but even then his work was related to the HVAC industry. Paul is a Fellow of ASHRAE, holds the F. Paul Anderson Award, and I am sure has been known to many of you for many years for his work in all aspects of our profession.

3.0 Keynote Speech, by Paul R. Achenbach, Senior Research Engineer, National Bureau of Standards

OPPORTUNITIES AND PROBLEMS IN THE DYNAMIC APPROACH TO ENVIRONMENTAL CONTROL IN BUILDINGS

by

P. R. Achenbach

3.1 ABSTRACT

Most of the energy-using processes in buildings as well as the energy requirements for environmental control in buildings vary with time. The dynamic nature of energy use in buildings is caused almost wholly by the cyclic nature of the solar system as it affects climate and the pattern of energy use by the occupants.

The application of computer technology during the last 15 years has provided the means for analysis and prediction of the energy used in many of these dynamic processes and has opened up a broad new vista for experimental and analytical research. The integration of the various dynamic releases of energy and the various dynamic requirements for energy in an occupied building provides a major opportunity for greater overall efficiency in energy utilization.

This discussion identifies the many institutional barriers that impede the prompt flow of a new complex technology from concept to application in the particular context of building design and construction. It also emphasizes the need for planning ways to facilitate technology flow at the same time that the research plan is developed.

Key Words: Analytical modeling; building design; building research; computer analysis; dynamic energy use; energy conservation; institutional barriers; technology flow.

3.2 OPPORTUNITIES AND PROBLEMS IN THE DYNAMIC APPROACH TO ENVIRONMENTAL CONTROL IN BUILDINGS

P. R. Achenbach

It is unnecessary to justify characterizing the analysis of the energy requirements of buildings as a dynamic process to this audience. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has had this Task Group on Dynamic

Response in existence for about a year and a half and many of you have been involved in this type of analysis for a decade or more. However, a brief review of past practice may provide a sense of direction for the future. For example, in the 1950's the ASHRAE Guide published winter design temperatures for calculation of design heating loads that were chosen to be approximately 15 degrees F (8 degrees C) above the lowest temperature ever recorded in each locality. This steady-state approach was reasonably satisfactory in that the increment of about 15 degrees took advantage of the short duration of the lowest temperatures and the heat capacity of the building in selecting equipment capacity.

By 1959, the Guide published several winter design temperatures; namely, those minimum daily average temperatures which occurred once in 5 years, 10 years, 13 years, 20 years, and 40 years, respectively. This approach allowed the designer to choose a level of risk as well as to vary the choice with the heat capacity of the particular building and other factors. These temperatures were used for calculations of a steady-state heating load.

The writer was Chairman of the ASHRAE Heating Load Technical Committee at the time. When it was proposed in the Committee that the Guide include a paragraph suggesting what factors of building design, materials, climate, and occupancy should guide the designer in choosing one or the other of these design temperatures, one of the consulting engineers objected because he said it would make every new college graduate an expert in calculating heating loads and selecting heat equipment. However, the multiple listing of winter design temperatures and the paragraph of guidance was placed in the Guide. There was no indication that the information decreased reliance on experienced engineers for design purposes.

Annual energy requirements continue to be calculated using heating degree-days and cooling degree-days or cooling degree-hours for some purposes. However, there has always been substantial dissatisfaction with the use of cooling degree-days and there is growing dissatisfaction with use of heating degree-days based on an outdoor temperature of 65°F (18°C) for well-insulated buildings.

Since the advent of computer technology in the calculation of the energy requirements for buildings an abundance of programs, many of which are proprietary, have been developed for calculating loads, energy requirements, and costs. These have ranged in complexity from the "bin method" based on hourly temperature frequency data to the use of hour-by-hour sequential coincident values of temperature, humidity, solar radiation and wind data for a typical year.

An examination of the basis for the dynamic nature of the energy requirements in buildings reveals that it is almost wholly caused by the cyclic nature of our solar system. The relative motions of the earth and sun are the basis for the annual weather cycle and the diurnal climatic cycle and are probably responsible for our preferring to sleep in the dark and carry out work and recreational activities primarily in the daytime.

Most of the energy conversion and distribution apparatuses, control systems, energy price schedules, and load management techniques used for buildings are designed to accommodate the dynamic nature of the energy requirements. Even our clothing is designed to be compatible with two or more seasonal weather patterns. A short list of such adaptations is shown in Table 1. The table is illustrative only, but it does reveal the broad nature of the measures used to cope with varying energy needs.

Many of the participants in this workshop, like me, have been making lists of energy conservation opportunities in buildings for a decade, more or less. The list shown in Table 2 is neither unique nor comprehensive, but it has been tailored somewhat to

TABLE 1

Adaptations to Dynamic Environmental Requirements

- Heating and cooling systems, (seasonal integration)
- Intermittent operation
- Automatic control
- Modulated distribution systems: V.A.V. - double duct
- Summer and winter clothing
- Night setback

- Pickup factors
- Energy storage: solar, A.C.E.S.
- Shading techniques
- Demand charges
- Off-peak electric rates
- Peaking generators

TABLE 2

Energy Conservation Methodologies Benefitting from Dynamic Analysis

- Modeling of building systems
- Evaluation of seasonal efficiency of equipment
- Use of floating balance point
- Evaluation of boiler/furnace auxiliaries
- Economizer cycle for ventilation
- Analysis of infiltration
- Zoning of buildings - exposure and occupancy
- Integration of energy-using systems
- Solar energy utilization
- Energy storage
- Cogeneration
- Life-cycle cost analysis
- Dynamics of human physiology
- Building use schedules

indicate the many energy use processes in buildings that can benefit from dynamic analysis. The uses of analytical and computer programs to evaluate the energy conservation potential in these various dynamic processes have expanded so rapidly that few individuals have been able to assimilate them. It is my understanding that evaluation of the status and adequacy of these computational aids is one of the objectives of this Workshop.

The following figures will illustrate the dynamic nature of the daily and seasonal energy use pattern in different situations. The Manchester Office Building, Figure 1, was designed in 1973 for the General Services Administration and measurement of its performance has been sponsored by the Department of Energy (DOE) as a field research project of the National Bureau of Standards (NBS), to illustrate methods for saving energy in the design, construction, and operation of government buildings. It also provided a field laboratory for the installation of conventional and innovative energy conservation technologies. Figure 2 shows the predicted monthly and total annual energy consumptions for various energy-using systems at the design stage 1/. Figure 3 shows energy usage for the building during the first year of operation. The predicted annual energy use for the building was about 55,000Btu/ft^2 (173 Kwh/m^2) of floor area whereas the observed results were about 43% higher, or 78,600Btu/ft^2 (248 Kwh/m^2) for the first year of operation. This disparity was caused by departures of the actual building construction and operating schedules from those on which the design energy analysis was based. For example, it was discovered after construction was completed, that the exterior wall insulation was partially by-passed by cold air leakage, and the outdoor air dampers for the heating and air conditioning systems were not operating properly. As these construction and operational features are corrected, it is anticipated that the observed energy requirements will approach that determined by dynamic analysis.

Figure 1. The Manchester demonstration office building showing the windowless north wall.

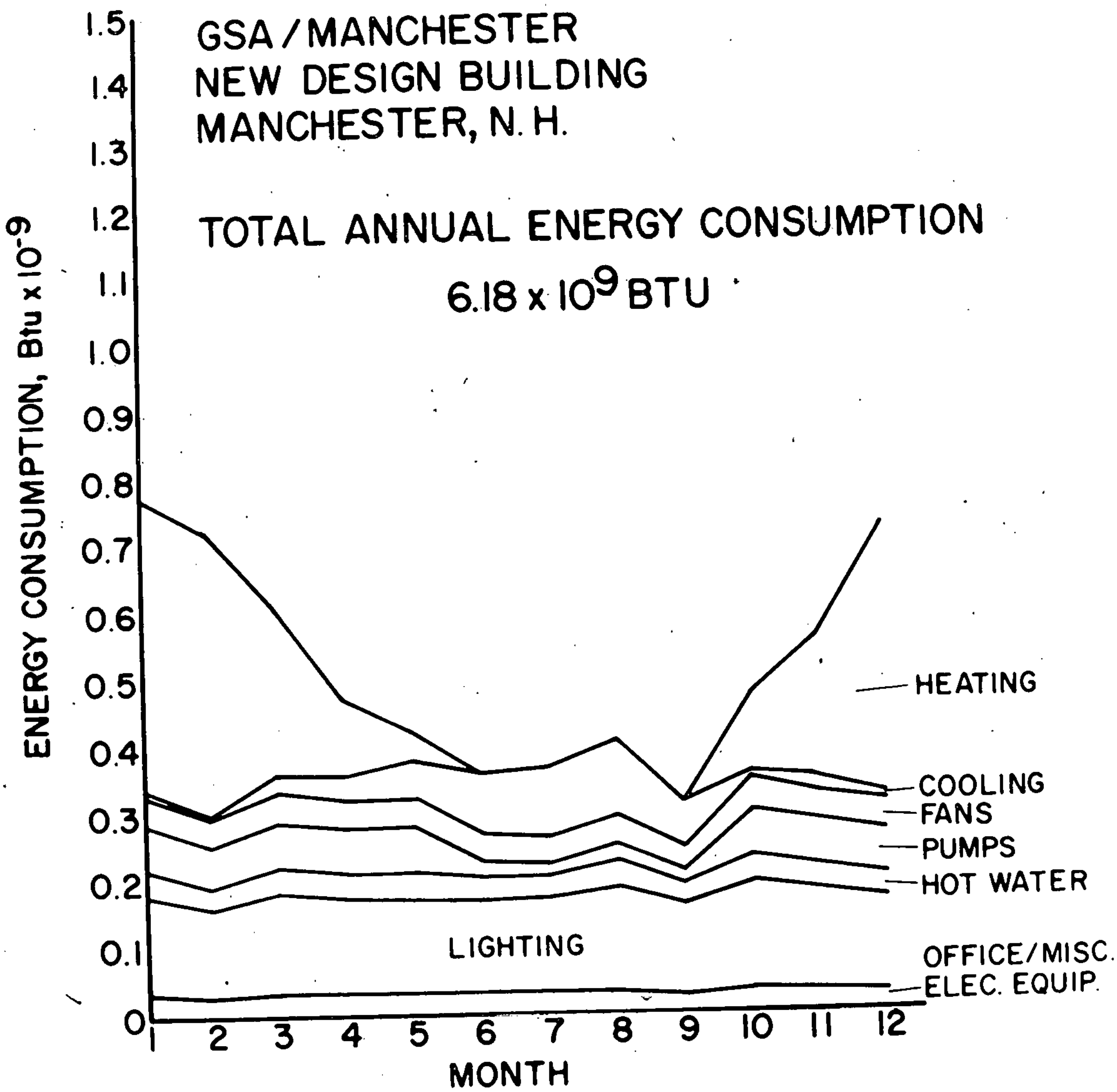


Figure 2. Predicted annual profile of component energy use in Manchester office building (10^9 Btu = 293000Kwh)

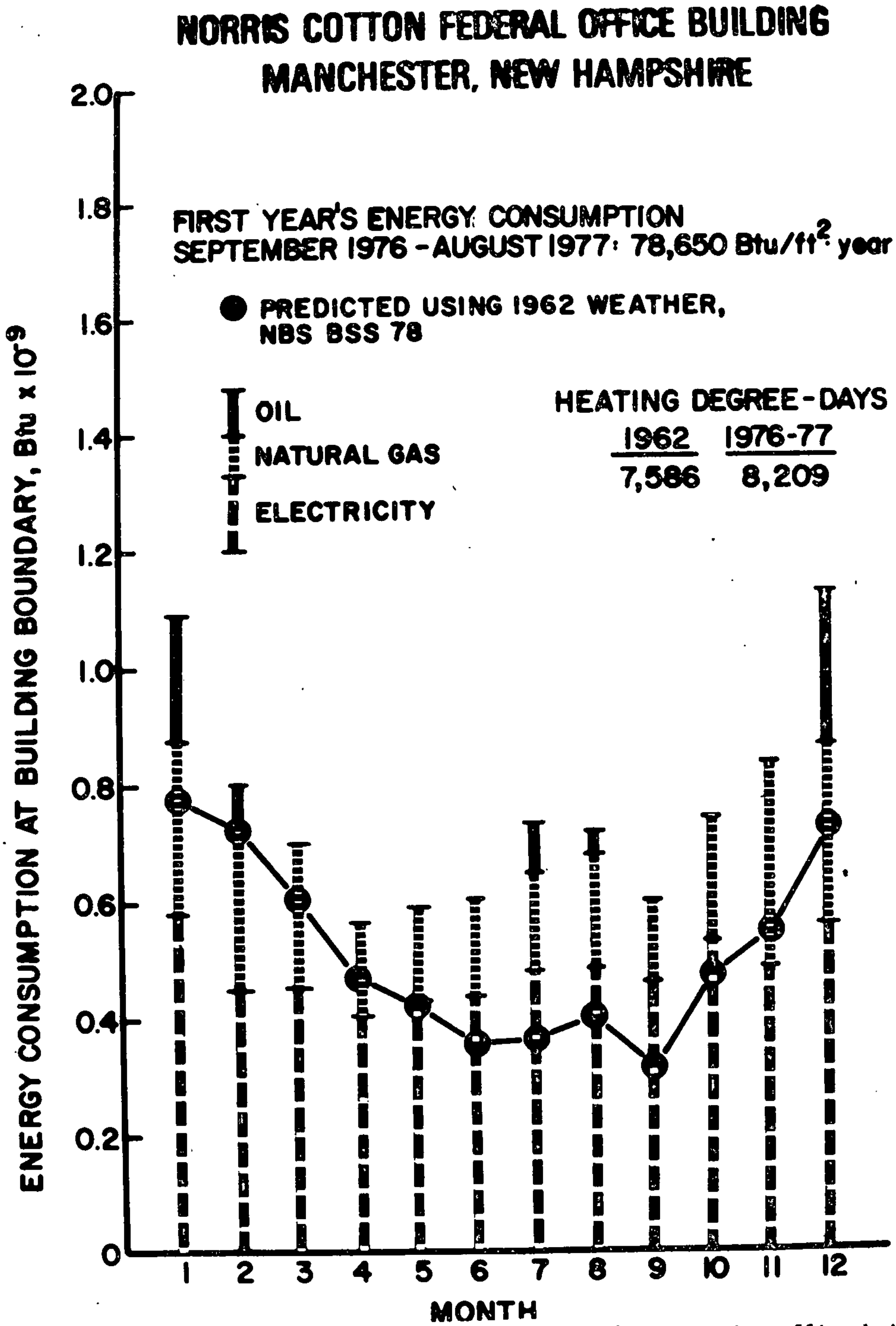


Figure 3. Observed profile of energy use in Manchester demonstration office building. (10^9 Btu = 293,000 Kwh)

Figure 4 is an aerial view of the Jersey City Breakthrough site developed by the Department of Housing and Urban Development (HUD), and utilized as an NBS field research site 2/for HUD and DoE to evaluate the energy conservation potential of a diesel-powered total energy plant in comparison with an alternative conventional central plant using purchased electric power. The total energy plant supplies all of the electric power, hot water and chilled water to the 485-unit apartment/commercial complex on the site. Figure 5 is a machine plot of the thermal energy demands on the primary hot water system for heating and cooling and the heat provided by the water jackets and exhaust heat exchangers of the diesel engines. It shows four-day plots of the daily energy profiles in the months of February, May, August and October. For the twelve months from November 1975 to October 1976, the energy savings realized with the total energy plant was equivalent to 160,000 gallons (606 m^3) of fuel oil, or 17.3% of the observed annual energy requirements for the total energy plant.

Figure 5 illustrates both the diurnal and seasonal variations in energy use by the apartment complex. Several design improvements were identified during the study which could raise this annual savings potential to about 25%. The data from the Jersey City development should be useful for validating dynamic energy analysis procedures as well as to predict the potential energy savings obtainable by using on-site integrated power packages for a large community.

Figures 6 and 7 show the minimum, maximum and average 15-minute power demands for each hour of the day in the months of January and August, respectively, in all-electric 3-bedroom ranch type houses equipped with heat pumps in Little Rock Air Force Base. 3/ The upper and lower plots show the respective maximum and minimum 15-minute power demand occurring on any day of the month and the middle plot shows the average for all the days of the month. These figures show that daytime demands were substantially higher than night demands that the maximum demand at any hour of the day or night is more than double the monthly average for these all-electric houses. Good dynamic analysis procedures should be able to duplicate this type of data.

One of the purposes of this workshop is to assess how dynamic analysis of the performance of buildings and their energy-using systems can be utilized in the design and operation of buildings to optimize energy utilization. In my opinion, reaching this objective requires, not only research, but a well-planned process for introducing research results into design and construction practice. One of the Institute Directors at NBS expressed this concept very succinctly as follows:

> "Applied research, to be useful, must be done well, but in addition those who do applied research must also identify or help create, if necessary, the institutional mechanisms which will use the results of their research."

Figure 8 is a chart showing the principal paths by which technology moves from concept to construction practice. The row of boxes across the top of the chart illustrates the flow of technology from the concept stage to incorporation of test methods and performance requirements into specifications, codes and regulations.

The bottom row of boxes illustrates the use of research results in modeling, product and system development, construction practice and design practice. Other lines of communication could have been shown on this figure together with several feedback loops, but it would have made the chart too complex for this presentation.

ASHRAE, as a Society, performs all of the functions illustrated in the top row of boxes and engages in the development of computer algorithms and improved analytical models. The Society approaches the area of codes and regulations with some diffidence, although this function is identified in their Articles of Consolidation. The Department of Energy engages in all of the activities shown in the top row of boxes plus the development of computer programs and analytical models, and in product and system development in a very limited way. A university engages principally in conceptualization of user needs, research, dissemination of information through education and in conferences and seminars, and in computer programs and analytical modeling. University staff members participate in most of the other areas of activity illustrated in Figure 8 in a limited way, often as extracurricular activities.

Letters A to G, in Figure 8, illustrate the location of institutional constraints or barriers that can impede the free and prompt flow of technology. These barriers will be described briefly and illustrated through current or past research programs. I am convinced that some or all of them will be applicable to the comprehensive research program that his Workshop seeks to develop and promote. Furthermore, the ultimate success and usefulness of the research may be determined by the amount and quality of advance planning brought to bear on maintaining the flow of technology through the steps illustrated in Figure 8.

Barrier A

It is difficult to maintain interest in and support for research projects that require five years or more to complete, partly because the support to undertake such projects is often not forthcoming until the need for the results is already urgent. Under such conditions, it is sometimes impossible to produce the needed results at the time of apparent greatest need. Furthermore, it is not unusual for the administrator who is responsible for approval of funding to change in a 5-year period. In addition, researchers and research organizations sometimes do not have a strong desire or adequate means for converting research results into application guidelines for handbook and standards purposes. The introduction of new technology into standards and codes is often time-consuming and may be regarded by some researchers as compromising the purity of research results.

Barrier B

A large number of computer programs and analytical models and much computer software have been developed in recent years for calculating the energy requirements for buildings. Several of the programs are proprietary, and others have been developed in government-supported research programs or by academic institutions. Some programs evaluate building heating/cooling requirements only and others include some or all of the HVAC systems and equipment in buildings. The building design professions need to know how reliable various programs are for use in contractural transactions. No generally-accepted criteria for the adequacy of a computer program for energy analysis has yet been developed for this application. A current ASHRAE research project will provide comparisons of the calculated annual energy requirement of an identical office building using several proprietary hourly-simulation computer programs, such as the DoE-2 program, the BLAST program with the results obtained by manual calculation using short-form modified REAP program. A project of this type can reveal the variation in results obtained with various energy analysis procedures and begin to indicate how much computer programs can be simplified while retaining suitable accuracy. However, a single project of this type is ad hoc in nature and does not solve the fundamental reliability and simplification problems in energy analysis technology nor develop criteria for evaluating computer programs.

Barrier C

There is often great difficulty in attaining consensus on proposed standards that integrate more than one discipline, trade practice, or major class of materials; or for which several different more limited standards are already in existence. I refer to this barrier as the "debating society syndrome." Efforts to issue an updated National Plumbing Code and a revision of ASHRAE Standard 90 have revealed some of these difficulties.

Barrier D

Manufacturers, designers, and builders have been reluctant to commit good environmental and energy conservation practices into building regulations when historically only performance related to health and safety has been regulated. Also, the inherent autonomy of state and municipal regulatory bodies has made it difficult to attain any large measure of uniformity in energy-use practices.

Barrier E

There is much inertia to be overcome in getting good energy conservation guidelines, standards, and model codes into everyday design and construction practice, because of the diffuse nature of the design, inspection and regulatory functions in building practice. It would require a major training and demonstration program to introduce new technology into design and construction practice in less than five years.

Barrier F

There are a number of obstacles to getting good design practices converted into good construction practices. Some of these obstacles are the effects of climatic factors during construction, upgrading workmanship, availability of materials and hardware, labor practices, costs, inadequate training programs, etc.

Barrier G

Published results frequently stimulate the design of new products, equipment and systems. However, commercial products sometimes do not perform comparably to the research predictions or to analytical models because of the constraints imposed on equipment design by factors such as safety, reliability, durability, cost, and performance of controls, that are not taken into account in the modeling process. These constraints were partly responsible for lower than expected energy savings in the Jersey City total energy plant.

How then does a workshop like this one, comprised of leaders from professional societies, academic institutions, government, and industry, develop plans, procedures, and objectives that will cause new research results to flow smoothly and expeditiously into construction practice and the commerce of building? I would like to suggest a broad objective that could be supported by all participants and all of the sponsoring organizations of the workshop.

Section 1.3 of the By-Laws of ASHRAE states the objective of the Society, as follows (underlining by the author):

> The Society is organized and operated for the exclusive purpose of advancing the arts and sciences of heating, refrigeration, air-conditioning and ventilation, and the allied arts and sciences, and related human factors for the benefit of the general public, as defined in the Certificate of Consolidation. To fulfill its role, the Society shall recognize the effect of its technology on the environment and natural resources to protect the welfare of posterity.

The officers of ASHRAE have pledged themselves to support this objective.

The Preamble of the U.S. Constitution reads as follows (underlining by the author):

> We, the people of the United States, in order to form a more perfect Union, establish justice, insure domestic tranquility, provide for the common defense, promote the general welfare, and secure the blessings of liberty to ourselves and our posterity, do ordain and establish this Constitution of the United States of America.

There is a strong parallelism between the underlined portions of these two documents which could serve as an overall objective of the research program which you are about to develop. Promoting the welfare of the general public is an objective which all participants in the workshop could support and the success in reaching this objective could well be the measure by which the results of the program are evaluated by the nation.

It could be argued that, in addition to superior technical talent, which this workshop provides, the leadership of this program needs the wisdom of Solomon, the patience of Job, the diplomacy of a Secretary of State, and the determination of a corporation president in order to successfully move dynamic response technology into practice in a reasonable time frame. You obviously have a very attractive research area to develop and it has major potential for promoting the general welfare through energy conservation. May I suggest that this week is not too early to charge a Task Group with formulating the procedures to get the forthcoming research results beyond the handbooks, library shelves, and the filing cabinets of the researchers who create the new technology.

REFERENCES

1/ Kusuda, T., Hill, J.E., Liu, S. T.; Barnett, J. P., and Bean, J. W., "Pre-Design Analysis of Energy Conservation Options for a Multi-Story Demonstration Office Building." NBS Building Science Series 78.. Nov. 1975

2/ Hebrank, J., Hurley, C. W., Ryan, J.D., Obright, W., and Rippey, W., "Performance Analysis of the Jersey City Total Energy Site: Interim Report." NBSIR 77-1243, 1977

3/ Achenbach, P.R., Davis, J. C., and Smith, W. T., "Analysis of Electric Energy Usage in Air Force Houses Equipped with Air-to-Air Heat Pumps." NBS Monograph 51, 1962

Figure 4. An aerial view of the Jersey City Breakthrough site. The buildings of the project are identified by a star (*).

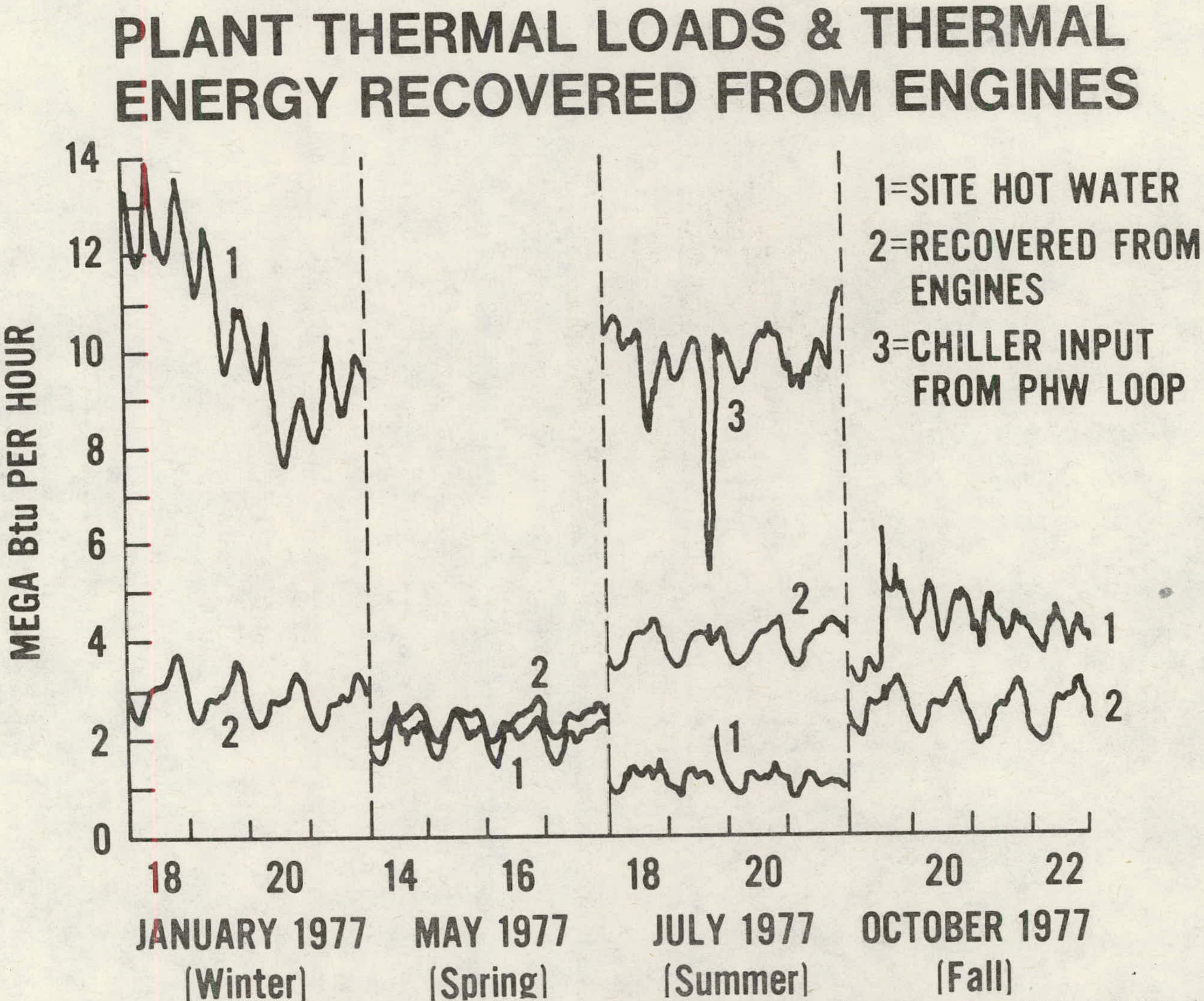


Figure 5. Typical seasonal plots of the thermal energy demands for heating and cooling and the thermal energy recovered from the diesel engines of a total energy plant.
(10^6 Btu/hr = 293 Kw)

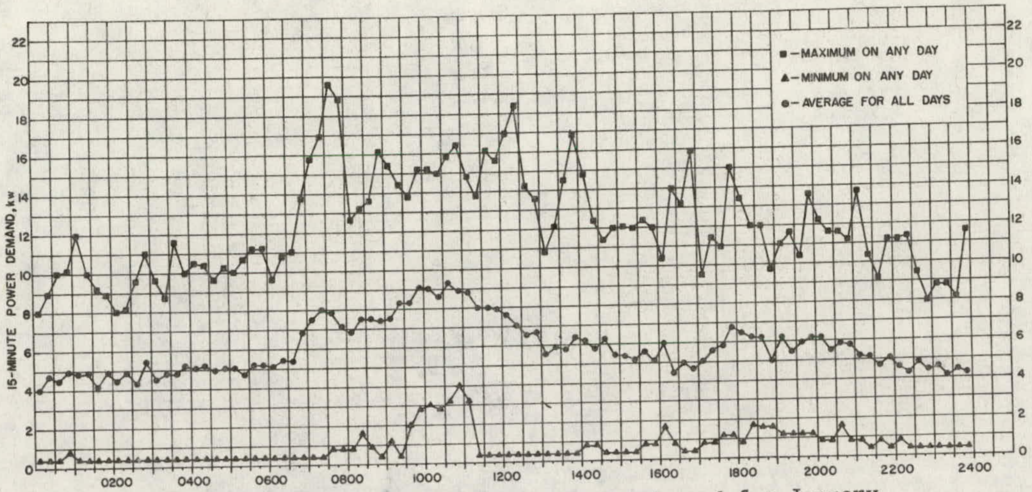


Figure 6. Minimum, maximum and average 15-minute power demand for January in a 3-bedroom all-electric house in Little Rock Air Force Base

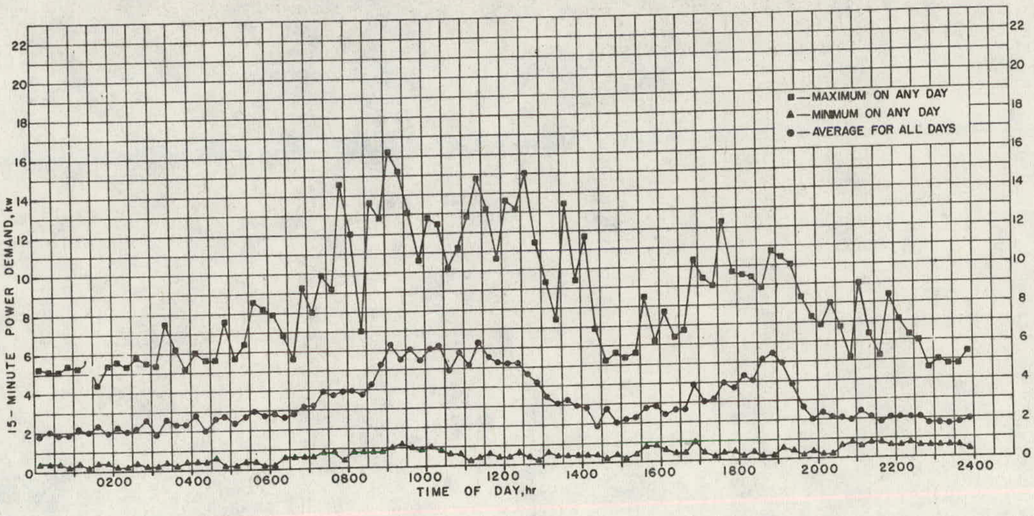


Figure 7. Minimum, maximum, and average 15-minute power demand for August in a 3-bedroom all-electric house in Little Rock Air Force Base

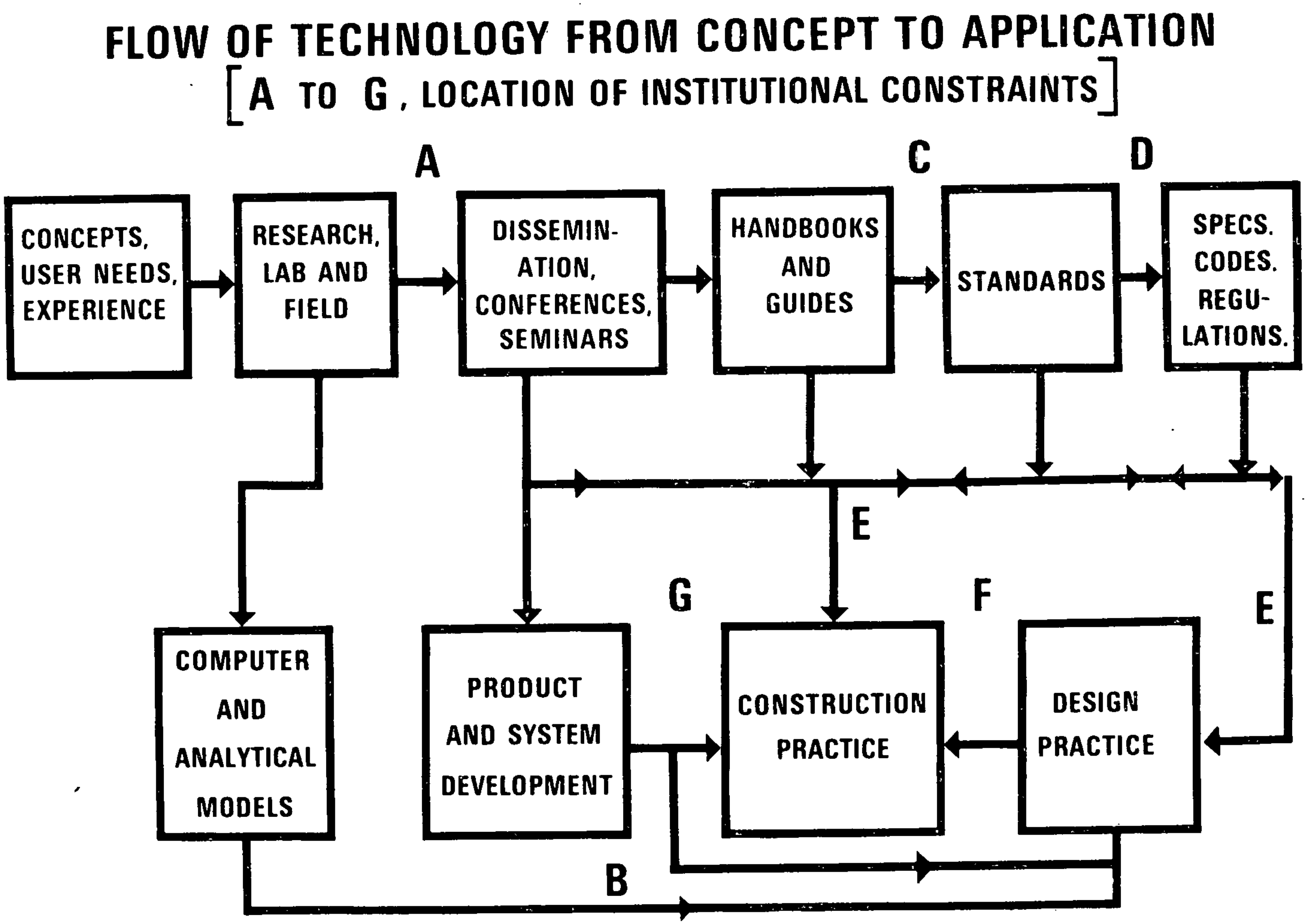


Figure 8. Chart showing the flow of technology from concept to building construction. Letters A to G show locations of institutional barriers to the free flow of technology.

CHAPTER II

EQUIPMENT

Committee:

David A. Didion, National Bureau of Standards (Chairman)
Alwin B. Newton, Consultant
Floyd C. Hayes, Trane Company
William E. Clark, Carrier Corporation
Richard A. Erth, York Company
James F. Hamilton, Purdue University

A REPORT ON RECOMMENDED RESEARCH IN BUILDING HVAC EQUIPMENT DYNAMICS

1.0 SCOPE

The intent of this report is to identify research activities which will provide a better understanding of building equipment's dynamic performance. When possible, there is also an indication of the research product or document format that would be most satisfactory. This, of course, requires the identification of the appropriate product user; such as, equipment designer, system designer, building owner, equipment operator, etc. The portion of the total building system considered to be this committee's responsibility is illustrated graphically in Fig. II-1. The building system is lumped into four basic categories; (1) the shell with its thermal communication links with the diurnal and seasonal weather patterns, (2) the HVAC hydronic or air conveyance system which provides the environmental conditions desired in the habitable spaces of the building, (3) the energy conversion equipment which creates the steam, hot water and chilled water necessary for the HVAC system at the expenditure of the primary energy of fossil fuel and electricity which crosses the building line, (4) the controls systems which provide the communications links among the first three. As indicated by the dotted line in Fig. II-1, this report deals only with category (3), the energy conversion equipment. It does not deal with the fans and pumps of the air handling rooms, nor the heat exchangers in the air boxes unless they are an integral part of the equipment itself, such as a DX coil. It is concerned with traditional chillers, and boilers of all types, unitary and field assembled equipment, residential and commercial applications.

2.0 APPROACH

The first thing that became apparent in discussions was the need for a clarification of what is meant by equipment dynamics. In light of the parent committee's desire for knowing how a building performs under dynamic conditions, it was felt that equipment performance under both part load steady state (off design) and true dynamic conditions should be considered. Fig. II-2 illustrates an example of each. A refrigerating system operating under part load steady state (off design) condition would have a different temperature difference between the refrigerant and the heat exchange media across each coil than it would under full load steady state conditions. This increase in ΔT will result in a significantly lower performance than would be predicted by considering a similar system operating at full load under the same condensor/evaporator temperature conditions. A "true dynamic" behavior of a building machine might typically be one where the temperature of some of its components varied for a significant part of its total operational period and as a result of this temperature variation, the performance of the overall machine differs from that of the steady state condition. For example, this behavior is noted in unitary furnaces and air conditioners which are operated with on/off controls.

With the distinction between the two types of equipment conditions clarified, the discussions began by considering categories of specific equipment individually (i.e., boilers, compressors, etc.). It was noted, however, that several categories had similar needs and thus the final project recommendations are listed under two major sub-headings, general and specific.

3.0 RECOMMENDED RESEARCH PROJECTS IN EQUIPMENT DYNAMICS

3.1 General

1. Establish representative use cycle (load cycle) that the equipment sees for heating/cooling of various buildings, climates, building HVAC systems or an annual and diurnal basis.

(Equipment Designers)[1]

2. Determine energy benefits of off design system optimization; that is, energy savings if equipment is sized to "average load" rather than maximum load.

(Equipment Designers)

3. Evaluate typical equipment dynamics (control caused ripples) for magnitude of potential energy savings for small equipment and large equipment categories, and cyclic equipment and modulating equipment patterns.

(Government Research Program Managers)

3.2 Specific Equipment

1. Boilers

* Develop performance simulation model of modulating boilers to aid product designers in understanding boiler dynamics.

(Equipment Designers)

* Do a study to identify the barriers to high seasonal efficiency low pressure boilers/furnaces (include economics and environmental effect).

(Government Research Program Managers)

2. Positive Displacement Compressor (and Compressor Systems) - reciprocating, rotary, screw.

* Develop dynamic model of unitary equipment looking at variations in load and ambient conditions (development of higher seasonal efficiency systems is happening in private sector without government stimulation).

(Equipment Research and Development People)

3. Electric Motors

* Conduct a feasibility study which will evaluate the energy impact, design options, and economics of new motor designs which have an improved performance over the entire load range.

(Government Program Managers
and Equipment Manufacturers)

4. Centrifugal Compressor and Compressor Systems

* Develop generic documentation that enables system designer to select chiller systems on an off-peak design criteria basis to obtain improved seasonal energy performance. (Manufacturers' cooperation in supplying data is imperative.)

(HVAC System Designer)

---

[1](. . .) indicates the primary intended audience the project's report should be aimed for.

5. Absorption Chillers

* Develop generic documentation that enables the system and controls' designers to optimize the part load performance through generator and cooling tower temperature monitoring. Where primary energy is being used as the driving force (gas-fired, etc.) this documentation should be carried out to include a testing and rating evaluation procedure.

(HVAC System Designer)

The following two projects are not dynamic problems per se, but since there is considerable renewed activity in this area it was felt that they should be included because of the danger of wasteful duplicative efforts.

* Document the history and present state-of-the-art of absorption systems; particularly point out the barriers to higher COP's and the inherent advantages/disadvantages of the different working fluids combinations.

* Determine capability of known working fluids for air-cooled small commercial units to about 40 tons, particularly methanol-LiBr (ZnBr) already proven to be feasible.

6. Engine Driven Heat Pumps

* Develop generic documentation that enables a product manufacturer to evaluate the potential of this concept particularly under part load conditions and establish a criteria for sizing his product with different building loads.

(Equipment Manufacturers)

7. Cooling Towers

* Explore the need for and availability of analytical models which will simulate part load performance as a function of both water-side and air-side temperature and mass flow variations. (Manufacturers cooperation in supplying data strongly recommended).

(Equipment Manufacturers)

* Conduct a state-of-the-art study of the degradation of performance of cooling towers as a function of water treatments. (i.e., biological growths, corrosion, etc.)

(Building Owners/Operators)

4.0 SUMMARY

All the projects under the General sub-heading should be given particular attention by the Federal Government as candidates for sponsorship. They involve studying the building system at the interface of its subsystems and thus are unlikely to be sponsored by private industry. They literally fall between the cracks of the various building industries' responsibilities. Yet, the information to be obtained from these studies is essential for better equipment design. Although the projects are not ranked in any particular priority order it should be noted that perhaps the most important project to get started on is number 1 under the General sub-heading. This project is a determination of how significant true dynamic behavior is in building equipment. That is, how much dynamic behavior is actually being demanded. For this determination to be made it is necessary to look at the entire building system. Referring again to Fig. II-1, a study of the relative time constants of the different lumped sub-systems would reveal whether the equipment is actually even receiving a significantly variable load or not. For example, it would seem reasonable that the large mass of chilled water in the piping system of an office building would dampen load variations to the point that part load steady state analysis of the chiller is all that is needed. Whereas, a residential unitary air conditioner might receive a widely varying demand. In any case, different equipment in different building systems should be studied in a generic manner to determine the actual magnitude of the demand at the equipment interface.

The research topics suggested in this report are in no way meant to be exhaustive. They are the thoughts of the committee during the period the workshop was conducted and the committee members recognize that there have been oversights and that some of the work may have already been completed without our knowledge.

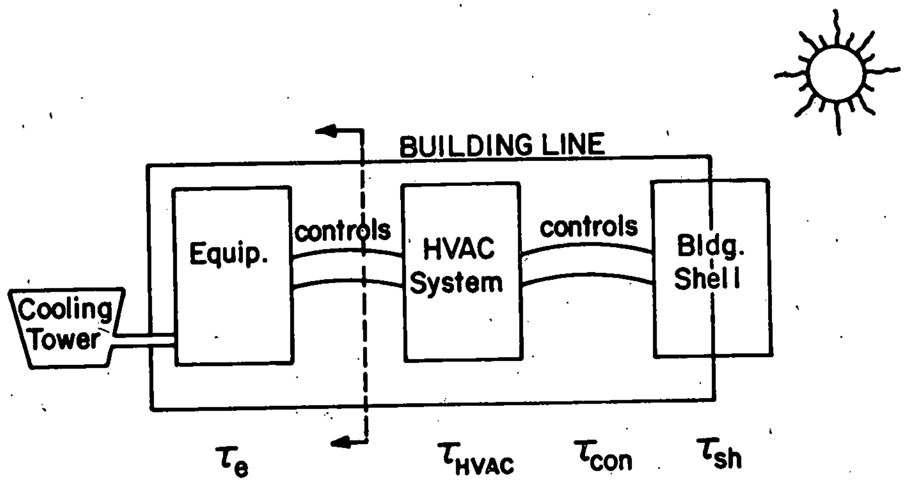


Fig. II-1 Commercial or Residential Building System.

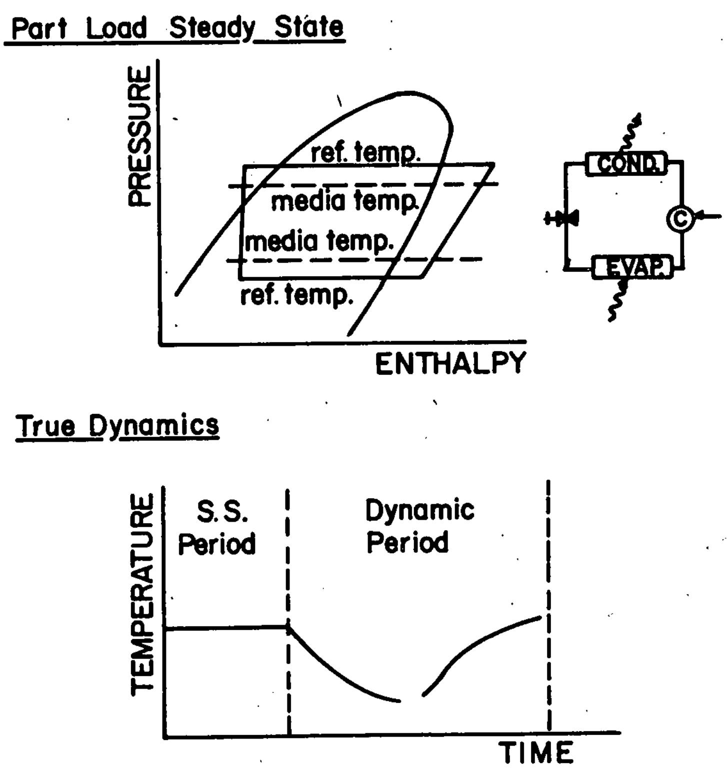


Fig. II-2 Equipment Performance Simulation

CHAPTER III

CONTROLS

Committee:

George R. Schade, Honeywell, Inc. (Chairman)
James R. Tobias, Honeywell, Inc.
James W. Ford, Public Works, Canada
James Y. Shih, National Bureau of Standards
Clayton A. Mote, Consumer's Power Company
Theodore J. Williams, Purdue University
J. Garth Thompson, Kansas State University

RECOMMENDATION OF THE CONTROLS COMMITTEE OF THE DYNAMICS RESPONSE WORKSHOP

1.0 INTRODUCTION

The research recommendations of the controls committee can be classified into two broad categories. The first category is the development of a research capability - specifically a computer simulation program which would be usable for evaluating building controls and control strategies with respect to energy consumption. The second category of recommendations includes the development of new control strategies and the resolution of some problems which are known to exist in HVAC system control. The computer simulation program would, no doubt, be a useful tool in carrying out the recommendations of the second category. However, several research projects have been identified which could be carried out concurrently with the development of the simulation program by utilizing existing methods.

2.0 COMPUTER PROGRAM

The development of the computer program is given the highest priority. Engineers working in HVAC feel the need for a means of objectively comparing the merits of various control strategies in specific applications. On site testing of competitive systems is often unsatisfactory since it is generally impossible to exactly duplicate conditions for a fair basis of comparison. The instrumentation required to evaluate controls with respect to energy consumption may be expensive and costly to install. On site testing proceeds very slowly, consequently years of effort would be required to fully evaluate a control method. Testing new concepts on site requires the implementation of hardware to carry out the control function being investigated. Finally, it may be difficult to properly utilize the result of tests in one application to estimate the effects in different applications. These problems would not exist in the simulation. The simulated test would be repeatable, and would proceed several orders of magnitude faster than a test of actual hardware.

The desired simulation program would be sufficiently detailed that it would be a useful research tool for evaluating the energy consumption effects of various building control strategies and controller characteristics. In order to achieve this level of validity, it would be necessary to simulate the dynamic operation of the building subsystems, including structure, control systems, HVAC equipment, physiology of occupants, and weather, and it would be necessary to simulate the dynamic interactions between these subsystems. Program validation is considered necessary.

3.0 NEW CONTROLS STRATEGIES

While the development of the computer program is proceeding there are several topics which should be investigated concurrently.

Systems operating at light load sometimes exhibit unstable "hunting" behavior due to nonlinearities of elements in the system. One example of this type of behavior occurs in systems utilizing control valves in which the modulated flow through the valve is a non-linear function of vlave opening, especially for small valve openings. When such a system is operating at light load, unstable "hunting" behavior can occur. It is recommended to study this phenomenon to establish the effect of this type of system behavior on building energy consumption.

There is much to be learned concerning other aspects of part load system operation. There is little information available to the engineer concerning the effects of dynamic response of HVAC equipment on system energy consumption under part load (off design) operation. The dynamic effects of cycling equipment is one area which deserves further investigation. Another area of concern is the part load operation of parallel equipment, such as the use of parallel fans in VAV systems. It is recommended to identify the dynamic characteristics and part load characteristics of the elements of environmental control systems.

There is a need to investigate the efficacy of imposing standards on the operation of controls. In order to determine the impact which such standards would have on system energy consumption, it is necessary to determine the effects of the controller characteristics which would be standardized (for example, linearity, hysteresis, offset, repeatability, etc.). This research on standards should also include the evaluation of formal testing and rating procedures for control components.

4.0 SUMMARY

The recommendations of the control committee follow in summary form.

I. Development of Research Capability

The highest priority is the development and "verification of a computer" program which simulates the dynamic operation of a building, including the structure, control systems, HVAC systems, occupants, and weather. This program must be sufficiently detailed to be used as a research tool for evaluating the energy consumption effects of various control strategies (for example: enthalpy optimization, or adaptive control), and for determining the effect which control characteristics (for example: proportional band, offset, hysteresis, etc.) have on energy consumption.

II. Specific Research Projects

The controls committee makes the following specific recommendations for research projects.

1. A study be developed to apply optimal control theory to a building in order to minimize its energy consumption. This investigation must consider the physiology of the occupants in the development of the optimal strategy. It is further recommended to study the sensitivity of this optimal strategy to determine the degradation in human comfort and energy consumption as a result of sub-optimal control.

2. A study to establish the effect on building energy consumption of unstable control due to non-linearities of control system elements. A specific type of instability to investigate is the control system hunting caused by control valve non-linearities at small openings.

3. A study to explore the dynamic characteristics and part load (off design) characteristics of elements used in environmental control systems (for example, the use of parallel fans in VAV systems).

4. A study to determine the effect on energy consumption of the controller characteristics, such as linearity, hysteresis, offset, repeatability, etc.

5. A study to evaluate control system performance standards.

6. A study to evaluate formal testing and rating procedures for control components.

CHAPTER IV

STRUCTURES

Committee:

Ross F. Meriwether, Meriwether & Associates (Chairman)
Tamami Kusuda, National Bureau of Standards
Michael G. Bitterice, PPG Industries
Wayne P. Ellis, H. B. Fuller Company
Gintas P. Mitalas, National Research Council of Canada
Richard O. Walker, Purdue University

Other participants:

Dan Nobbe, University of Michigan
Ted S. Lundy, Oak Ridge National Laboratory
Paul R. Achenbach, National Bureau of Standards

1.0 INTRODUCTION

The general topic of this group (the "structure", or the building itself) was subdivided into a series of specific subjects for discussion:

1. The relative contribution (and, hence, importance) of each component of the building to the total thermal load and annual energy consumption.
2. Heat transmission (including solar effects) of opaque walls, floors, and roofs.
3. Heat transmission and solar radiation of windows and skylights.
4. Infiltration (sensible effects).
5. Moisture gain (through infiltration or permeable walls).
6. Sensible heat storage in the structure (during shutoff or setback).
7. Latent heat storage in the structure.
8. Internal gains.
9. Overall heat balance of the building.

A series of questions were developed to guide the discussion of each specific subject:

1. Do we have adequate techniques and data for steady-state evaluation of the loads caused by the subject?
2. In what way does the dynamic behavior of the subject differ from the steady-state analysis approach?
3. Do we have adequate techniques and data for dynamic analysis of the load behavior due to the subject?
4. What additional data or research is needed to adequately describe the dynamic response?
5. In what ways might the dynamic behavior of the subject be affected by variations in other elements of the building/system complex?

6. Can we reasonably expect to be able to quantify (calculate) the change in the subject behavior with other changes in the system?

7. What data or research is needed to define the interaction of the subject and other elements in the system?

8. What research is presently underway or planned that will lead to a description or better understanding of dynamic response of the subject and the reaction to other elements?

2.0 INDIVIDUAL SUBJECTS

Each of the nine subjects listed above are discussed below.

2.1 Building Components

The discussion of the relative importance of the various subjects (and sub-elements within a specific subject) led to the conclusion that the importance varied with the type of building (residential/commercial/institutional), the type of design (high-rise/low-rise, large/small fenestration area), and the location (climatic conditions). For example, the heat transmission of floors and sub-grade walls is important in residential and a few types of commercial/institutional buildings in Canada and the northern U.S., but would not be very important in other areas of the U.S. or in other types of buildings. The probable order of importance of the subjects (as related to energy usage) were listed as:

COMMERCIAL

1. Internal gains
2. Windows
3. Infiltration
4. Opaque walls, roof, floors
5. Sensible storage
6. Overall heat balance
7. Moisture gain
8. Moisture storage

RESIDENTIAL

1. Infiltration
2. Windows
3. Opaque walls, roof, floors
4. Internal gains
5. Sensible storage
6. Overall heat balance
7. Moisture gain
8. Moisture storage

Some discussion was devoted to the use of floors and sub-grade walls as a transfer medium to the ground as a heat source/sink to help maintain a constant (or less variable) room temperature. It was also concluded that the variability in construction practice and in material properties could be as much of a contributing factor to heat gain or loss as some of the eight items listed above.

2.2 Heat Transmission

The discussion of heat transmission revealed the weakness of the available data on floor losses. However, a current research program at the National Research Council of Canada may provide the needed information. It was also felt that the heat transfer characteristics of slab-on-grade was inadequately treated in the ASHRAE literature, particularly as it affects cooling requirements. It was concluded that research on this subject was a definite need.

The discussion of insulation indicated that the data on loose-fill or ventilated insulation was inadequate. Similarly, the long-term heat gain/loss effects from shrinking, settling, or cracking of various types of insulation were not adequately covered in literature. However, a current research program by DOE through the Oak Ridge National Laboratories is addressing these questions and may fill in the missing information. It was also pointed out that the phenomenon of "bridging" across insulation in walls was not covered in the ASHRAE handbooks, and needs to be addressed to provide adequate information on heat transmission across complete walls. A call was also made to expand the wall heat transmission data to include two-dimensional and three-dimensional flow. The recommended approach was to use response factor procedures verified by a limited number of field tests to provide this data, but even this approach may require a large research program.

2.3 Windows and Skylights

One weak area in the available data for calculating glass solar loads is in glass which has had one of the many types of films added to it. TC 4.5 is exploring this subject and should be able to define what's needed in the way of a research project or a standard test procedure. It was also felt that the variation in U values of heat absorbing glass was not adequately known.

Mention was made of an industry organization recently formed (or in the process of forming) under the name of National Fenestration Council. This group will likely sponsor a number of research projects of interest to ASHRAE.

Discussion also revealed the lack of adequate data on the thermal performance of window frames. The manufacturers might have the needed data, but it is not available in a readily usable form.

A discussion of shading, shuttering, and draping indicated a general need for new and up-dated data and test procedures to handle the many new materials and interior shading techniques now in use or proposed.

The group felt that the published cooling load factors for converting solar heat gain into cooling load needs to be expanded to cover a wide variety of buildings. It was felt that there was also a need to try to experimentally verify some of these values under field conditions.

Skylights were mentioned in the discussion of fenestration, but the group did not feel competent to evaluate the adequacy of the presently available data. However, the group agreed that the subject should not be overlooked because of the possible increasing use of skylights for natural daylighting. It was suggested that the subject of the adequacy of the Handbook data be explored with a knowledgeable technical person at one of the leading plastics manufacturers. Mr. Bill Berkhart was recommended as one possibility.

The renewed interest in the use of windows for natural ventilation accents the need for data to adequately evaluate its impact on annual energy consumption. In the light of extensive work on this subject by the British and others, it was felt that the cognizant TC should survey the available literature and look into extracting key information for possible inclusion in the next Handbook.

2.4 Infiltration

It was agreed that even the steady-state data on infiltration was totally inadequate for commercial and institutional buildings and was only marginally adequate for simple residential structures. The delta-P approach most widely recommended now appears to have the potential to handle most cases, but measurements are needed in each type of application to establish flow coefficients and identify sources of leakage. The lack of information on the impact of variable outside air on infiltration rates is just one illustration of the lack of data on the interaction of infiltration with other elements of the building/system.

The need to improve the measurement technology for infiltration was identified, with specific emphasis on the need to correlate the negative pressure and the tracer gas techniques.

It was agreed that some type of simple tests need to be devised to measure the infiltration of existing commercial buildings under a variety of operating and climatic conditions. It was also agreed that there is a need to be able to identify the exit paths for infiltration air, particularly for use in evaluating the moisture problem.

2.5 Moisture Gains

As background for the discussion of this subject, Wayne Ellis submitted a bibliography of over 300 pertinent references. The bibliography is included in these proceedings.

It was agreed at the outset that most of the literature and previous research on this subject addresses the question of condensation and its attendant deterioration of various materials in or on the walls. Very little has been done on the energy impact (increased humidification or dehumidification) of moisture gain or loss.

It was felt that the general needs for information and research on this subject are outlined in the National Program Plan for Building Thermal Envelope Systems and Insulating Materials (see section 3.2). However, the emphasis in the Plan is still on the deterioration of materials due to condensation, with any emphasis on energy impact likely to be only the indirect effect of the change in heat transmission resulting from moisture changes within the wall cavity.

NBS has recently proposed a research program to DOE which will deal with techniques for moisture control, but again the emphasis is on the condensation problem.

The discussion also concluded that infiltration is such a dominant factor in the moisture gain (loss) within the space that the energy impact of moisture migration through permeable walls is of little concern in all but a few special cases (such as basements).

2.6 Sensible Heat Storage in the Structure

The group concluded that the methodology for handling sensible heat storage in the structure and its furnishings is adequate, but the coefficients need to be reexamined and expanded to cover a broader variety of cases. There needs to be a general improvement in the "weighting factors" (cooling load conversion factors).

2.7 Latent Heat Storage in the Structure

It was quickly concluded that there is virtually no meaningful data on the storage of moisture within the conditioned space. The value of natural ventilation to reduce the need for sensible cooling cannot be adequately evaluated until we can also evaluate the possible later increase in cooling load resulting from the moisture absorbed within the conditioned space while in the ventilating mode. A research project is needed to establish the absorption/release rates for interior materials (building and furnishings) under a variety of dynamic operating conditions (air flow rates, etc.).

2.8 Internal Gains

There was some question about the adequacy of the handling of the heat gain from lights, but the group was informed that Kansas State University was currently studying the subject and may be able to provide improved data.

There appears to be little information available on the transient (that is, time lagged) heat gain from appliances or office equipment (such as copying machines).

Of particular interest to some of the group was the effect of the use of natural daylighting on the internal gain from lights. Mike Bitterice distributed some material on natural daylighting practices for the group to use as a reference (see References, Section C). It was also pointed out that PPG is planning a project to develop analytical techniques, and that Stephen Selkowitz at Lawrence Berkley Laboratories is developing plans to identify research needs on this subject.

2.9 Overall Heat Balance of the Building

Tamami Kusuda gave a brief presentation on the need to develop an analytical procedure for evaluating the relative frequency response characteristics of all the elements of the building, the occupants, the HVAC systems, and the environment to help guide the selection of frequency of analysis or level of detail needed to properly analyze the interactions of these elements.

3.0 SPECTRUM ANALYSIS FOR DYNAMIC RESPONSE

A brief outline of Tom's presentation follows.

In order to describe dynamic response of building with respect to its energy consumption, spectrum analysis technique should be considered. The spectrum analysis technique would permit the characterization of building dynamic response in the frequency domain rather than in the conventional time domain representation. If the building energy consumption data is recorded continuously throughout the year, a well-known technique, so-called the Fourier Transform Method, can be applied to generate its power spectrum for various frequency levels. Likewise, frequency domain analysis, spectrum representation can be made for the weather data, building occupancy data, and building operational data, all of which are excitation signals to the building problems. A power spectrum of the building energy consumption could be related to these excitation spectrums by the so-called frequency response function or filters. Mathematical representation of the building energy consumption spectrum, excitation spectrum function, and the frequency response function is expressed as follows:

$$E(n) = W(n) \cdot X(n)$$

$$n = 0, 1, 2, \ldots \infty$$

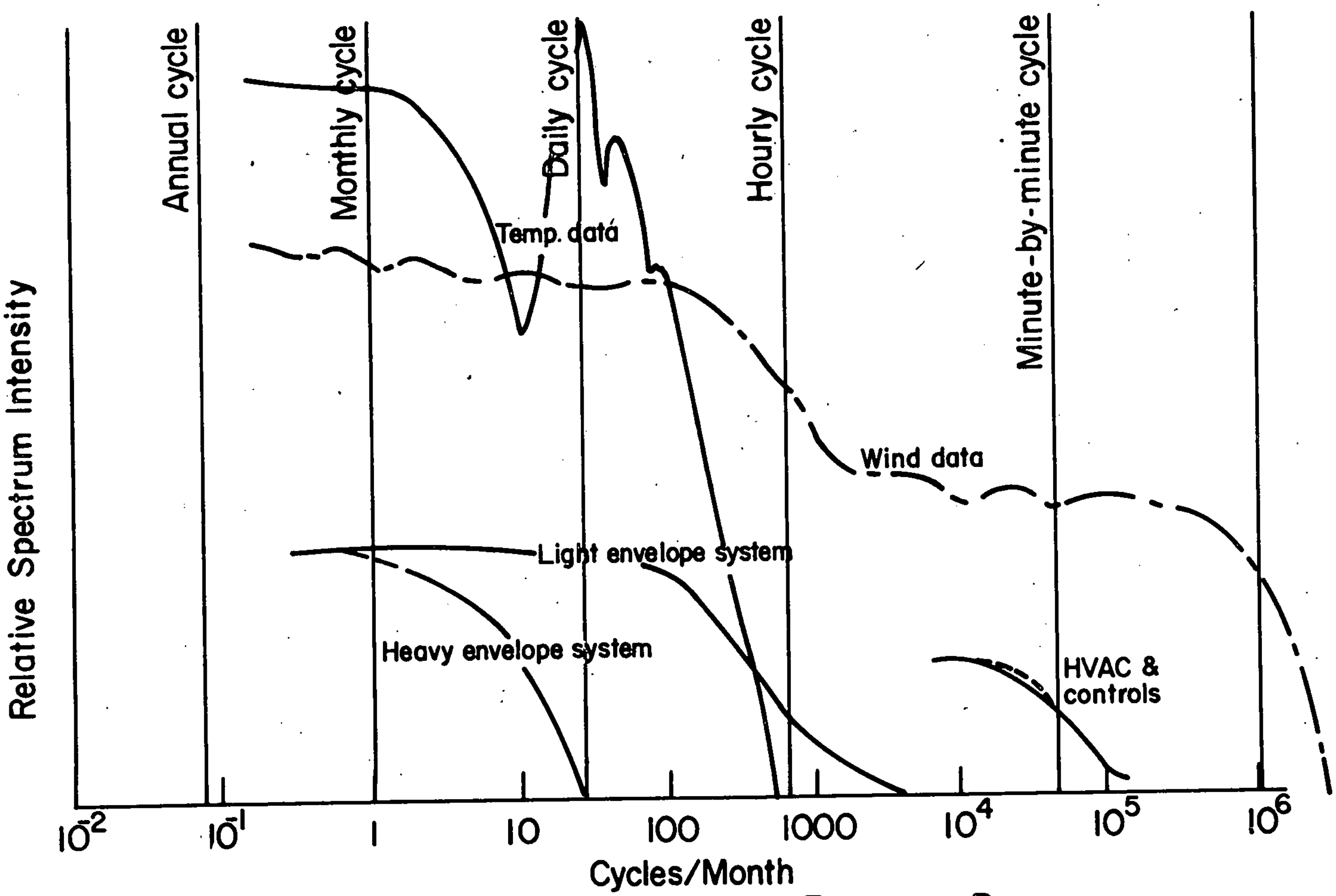
where

E (n) = Fourier Transform of Energy Consumption at frequency n

W (n) = Frequency response function evaluated at frequency n

X (n) = Excitation function at frequency n

The building frequency response function consists of numerous response functions, all of which are coupled to each other by complex heat transfer relationships. Well-known response functions are building envelope impedance, transfer functions of heating/cooling systems and controls. Although exact formulation of response functions is dependent upon the specific envelope systems, HVAC system and controls, their predominant frequency are fairly well-known; for example, the predominant frequency for the envelope system varies from seven-day cycle (heavy wall) to one-hour cycle (light wall). The predominant frequency for heating/cooling equipment is in the range of ten minutes to one minute; whereas the control system time constant is less than three minutes. The advantage of spectrum analysis for the entire building as well as for its components is that the sensitivity of certain components to annual energy consumption characterized by their predominant frequency would appear as distant peaks on the energy spectrum. For example, if energy spectrum showed large peaks for three to one minute cycle, it would be obvious that the control characteristics are very important for building energy consumption. Figure IV-1 shows the conceptual spectra schemes for the weather data envelope response function. Similar spectra should be developed for typical weather data, occupancy data, and operational data together with the frequency response functions for various envelope systems, HVAC systems, and for controls.



Conceptual Spectrum of Building Frequency Response

Fig. IV-1 Conceptual Spectra Schemes for Weather Data

A) MOISTURE MOVEMENT (Chronological Order)

1. PERMEABILITY OF MEMBRANES TO WATER VAPOR WITH SPECIAL REFERENCE TO PACKAGING MATERIALS; Carson; US Dept of Commerce - National Bureau of Standards; Aug 5, 1937
2. INFLUENCE OF ATMOSPHERIC HUMIDITY AND TEMPERATURE ON THE MOISTURE CONTENT OF PAPER BOARD; R.W.K. Ulm; Paper Trade Journal; Feb 24, 1938
3. MOISTURE MOVEMENT IN WOOD ABOVE THE FIBER-SATURATION POINT; L.W. Rees & S.J. Buckman; Journal of Agricultural Research Vol. 57, No. 3; US Govt Printing Office, 8/1/38
4. MOISTURE CONDENSATION IN BUILDING WALLS; Harold W. Woolley; Building Materials & Structures, US Dept of Commerce; US Govt Printing Office, 1940
5. METHODS OF MOISTURE CONTROL & THEIR APPLICATION TO BUILDING CONSTRUCTION; Rowley, Algren & Lund; Bulletin of the Univ. of Minnesota; Bulletin No 17; April 10, 1940
6. STRUCTURAL, HEAT-TRANSFER, AND WATER-PERMEABILITY PROPERTIES OF FIVE EARTH-WALL CONSTRUCTIONS; H.L. Whittemore, A. H. Stang, E. Hubbell, & R.S. Dill; Building Materials & Structures, US Dept of Commerce, Report BMS78; US Govt Printing Office, Washington, 1941
7. CONDENSATION PROBLEMS IN MODERN BUILDINGS; L.V. Teesdale; US Dept of Agriculture, Forest Svc, No R1196; May, 1941
8. CONDENSATION OF MOISTURE & ITS RELATION TO BUILDING CONSTRUCTION AND OPERATION; Rowley, Algren, & Lund; Bulletin of the Univ of Minnesota, No 18; Sept 10, 1941
9. COMPARATIVE RESISTANCE TO VAPOR TRANSMISSION OF VARIOUS BUILDING MATERIALS; L.V. Teesdale; Heating, Piping, & Air Conditioning, Dec 1942
10. PSYCHROMETRIC CHARTS FOR HIGH AND LOW PRESSURES; Donald B. Brooks; National Bureau of Standards, Misc Publ M 146; US Govt Printing Office, 1943
11. AN EXPLANATION OF CONDENSATION AND VAPOUR BARRIERS; Housing Administration, Dept of Finance, July 14, 1943
12. COMPARISON OF METHODS FOR THE DETERMINATION OF WATER VAPOR PERMEABILITY; Sears, Schlagenhauf, Givens, & Yett; Paper Trade Journal, Jan 20, 1944
13. WATER VAPOR PERMEABILITY OF SHEET MATERIALS AT HIGH TEMPERATURE AND HUMIDITY; Technical Association of the Pulp & Paper Industry, T 464 m-44; July 1944
14. VAPOR TRANSMISSION ANALYSIS OF STRUCTURAL INSULATING BOARD; Rowley & Lund; Bulletin of the Univ of Minnesota, Bulletin No 22; Oct 9, 1944
15. VAPOR BARRIERS (A BIBLIOGRAPHY); J. Louis York; Office of Production Research & Development War Production Board; Feb 1, 1945
16. INSTRUMENTATION STUDIES LII. PENETRATION OF PAPERS BY WATER VAPOR. VI. PROGRESS REPORT ON THE DEVELOPMENT OF TWO NEW ELECTRIC METHODS FOR THE MEASUREMENT OF WATER VAPOR PERMEABILITY; The Staff of the Institute of Paper Chemistry; Paper Trade Journal; Jan 3, 1946
17. DAMPNESS IN BASEMENTS AND GROUND FLOORS; R.S. Dill & D.E. Parsons; US Dept of Commerce, National Bureau of Standards, Letter Circular LC-813; Jan 25, 1946
18. INSTRUMENTATION STUDIES. LIV. PENETRATION OF PAPERS BY WATER VAPOR VIII; The Staff of the Institute of Paper Chemistry; Paper Trade Journal; Feb 21, 1946
19. INSTRUMENTATION STUDIES. LIV. A CONTROLLED RELATIVE HUMIDITY CABINET IN WHICH SPECIMENS MAY BE WEIGHED WITHOUT REMOVAL FROM THE CONDITIONED ATMOSPHERE; The Staff of the Institute of Paper Chemistry; Paper Trade Journal; Feb 21, 1946
20. WATER-VAPOR PERMEABILITY TESTER; Carson, Worthington; National Bureau of Standards; Paper Industry & Paper World; March 1946
21. DETERMINING THE MOISTURE EQUILIBRIUM CURVES OF HYGROSCOPIC MATERIALS; Willmer Wink; Industrial & Engineering Chemistry; April 15, 1946
22. FACTORS AFFECTING HEAT TRANSMISSION THROUGH INSULATED WALLS; Rowley & Lund; Bulletin of the Univ of Minnesota, Bulletin No 24; April 25, 1946
23. THERMAL SHORT CIRCUITS IN A METAL WALL; R.M. Olson; Institute of Technology-Univ of Minnesota, Engineering Experiment Station, Technical Paper No 54; May 1946
24. VAPOR RESISTANT COATINGS FOR STRUCTURAL INSULATING BOARD; Rowley, Lajoy, & Erickson; Bulletin of the Univ of Minnesota, Bulletin No 25; Sept 15, 1946
25. APPARATUS FOR DETERMINING WATER-VAPOR PERMEABILITY OF MOISTURE BARRIERS; Carson & Worthington; US Dept of Commerce, National Bureau of Standards, Circular of the National Bureau of Standards - C 453; US Govt Printing Office; Nov 8, 1946
26. MOISTURE EQUILIBRIUM; Willmer A. Wink; Modern Packaging Magazine, Feb 1947
27. HEAT AND MOISTURE TRANSFER IN ALL-METAL HOUSES; F.G. Hechler, E.R. Queer, & E.R. McLaughlin; Heating & Ventilating, April 1947
28. DIFFUSION OF WATER THROUGH PLASTICS; G. Deeg Jr; Engineering Societies Library; June 1947
29. DAMPNESS IN MASONRY WALLS ABOVE GRADE; US Dept of Commerce, National Bureau of Standards-Letter Circular LC 865; June 23, 1947
30. FACTORS IN THE RESISTANCE OF BRICK MASONRY WALLS TO MOISTURE PENETRATION; C. C. Connor; Transactions; ASTM; 1948
31. "THE WORLD IS SOPPING WET!" THE MOISTURE IN OUR ATMOSPHERE - ITS NATURE, BEHAVIOR, AND MEASUREMENT; E.R. Queer & E. R. McLaughlin; Pgh Lectrodryer Corp; Undated-(1948?)
32. WHAT TO DO ABOUT CONDENSATION; E.R. Queer & E.R. McLaughlin; Housing & Home Finance Agency; May 1948
33. PAINT AS A VAPOR BARRIER IN DWELLINGS; G.G. Sward; National Paint, Varnish & Lacquer Association, Circular 728; Sept 1948
34. HOW TO AVOID CONDENSATION TROUBLES WHEN USING COLD PRIMARY AIR DUCTS - TESTS YIELD DATA ON INSULATION METHODS; John Everetts Jr.; Heating, Piping, & Air Conditioning; Nov 1948
35. CONDENSATION IN THE HOME; Better Building Bulletin #1; Division of Building Research, National Research Council; June 1949
36. WATER VAPOR RESISTANCE OF BUILDING MATERIALS; R.R. Britton & R.C. Reichel; Housing & Home Finance Agency, Technical Bulletin No 11; Sept-Nov 1949
37. MOISTURE CONTENT AND HEAT-INSULATING PROPERTIES OF BUILDING MATERIALS; G. Hobohm; National Research Council of Canada, Translation TT-95; Dec 14, 1949
38. CONDENSATION CONTROL IN DWELLING CONSTRUCTION; Forest Products Laboratory, Forest Service, US Dept of Agriculture & Housing & Home Finance Agency; US Govt Printing Office; 1950
39. VAPOR BARRIERS FOR DEHUMIDIFICATION; Queer & McLaughlin; Pgh Lectrodryer Corp; 1950
40. WHAT TO DO ABOUT CONDENSATION; Housing & Home Finance Agency; US Govt Printing Office; 1950
41. THE DETERMINATION OF THE PERMEABILITY TO WATER VAPOUR OF SHEET MATERIALS; Patra Packaging Research Report-No 2, 1948; Reprint from B.T.L. Bulletin No 16 - May 1950; Baird & Tatlock (London) Ltd.
42. WET-COLD I EFFECT OF MOISTURE ON TRANSFER OF HEAT THROUGH INSULATING MATERIALS; Woodcock & Dee; US Dept of Commerce, Environmental Protection Section - Report No 170 (PB 111639); Dec 1950
43. BASIC CONCEPTS OF WATER VAPOR MIGRATION AND THEIR APPLICATION TO FRAME WALLS; F.A. Joy; The Penn State College Engineering Experiment Station, Technical Paper No 89, Special Technical Publication No 119; ASTM; 1951
44. MOISTURE AND THE DURABILITY OF WOOD-FRAME WALLS; R.C. Reichel; Housing & Home Finance Agency, Housing Research Paper 16; US Govt Printing Office; Sept 1951
45. METHODS OF MEASURING HUMIDITY AND TESTING HYGROMETERS; A. Wexler & W.G. Brombacher; National Bureau of Standards - Circular 512; US Govt Printing Office; Sept 28, 1951
46. CONDENSATION IN SIDEWALLS - A SELECTED BIBLIOGRAPHY; National Paint, Varnish & Lacquer Association, Inc; Nov 15, 1951
47. THE EFFECT OF MOISTURE ON HEAT TRANSMISSION THROUGH BUILDING AND INSULATING MATERIALS; J.S. Cammerer; National Research Council of Canada, Technical Translation TT-317; 1952
48. SYMPOSIUM ON THERMAL INSULATING MATERIALS (see 43); ASTM, Cincinnati Spring Meeting - 3/7/51, Baltimore, MD.; Special Technical Publication No 119; ASTM; Jan 1952
49. CONDENSATION CONTROL IN BUILDINGS AS RELATED TO PAINTS, PAPERS, & INSULATING MATERIALS; Building Research Advisory Board, Conference Report No 4; February 26 & 27, 1952
50. EFFECT OF CONVECTION AND MOISTURE DEPOSITION ON HEAT TRANSMISSION THRU COLD STORAGE TEST WALLS; H.C. Brown Jr & L.E. Bish; Refrigerating Engineering; Jan 1953
51. HUMIDITY STUDIES; Francis D. Horigan; Technical Library - QM Research & Development Laboratories; Sept 4, 1953
52. PERFORMANCE OF DESICCANTS IN THE DRY PAN TEST FOR WATER VAPOR PERMEANCE OF MEMBRANES; S.C. Change & N.B. Hutcheon; Canadian Journal of Technology; Sept 1953
53. OSMOTIC PRESSURE, SEMIPERMEABLE MEMBRANES, AND THE BLISTERING OF PAINT; J. D. Babbitt; Canadian Journal of Technology; March 1954
54. MOISTURE MIGRATION FROM THE GROUND; Housing & Home Finance Agency, Housing Research Paper No 28; Oct 1, 1954
55. SAVE YOUR HOME FROM THE MENACE OF MOISTURE; National Paint, Varnish & Lacquer Association; (1955)
56. SURVEY & ANALYSIS OF THE VAPOR TRANSMISSION PROPERTIES OF BUILDING MATERIALS; H.M. Whippo & Arnberg; US Dept of Commerce; Engineering Experiment Station, Univ of Colorado; Jan 1955
57. REMEDIAL MEASURES FOR BUILDING CONDENSATION DIFFICULTIES; L.V. Teesdale; US Dept of Agriculture, Forest Service, Forest Products Laboratory; No R1710; March 1955
58. DECAY AND PERMEABILITY TESTS OF SHEET MATERIALS USED AS SOIL COVERS IN BASEMENTLESS HOUSES; C.S. Moses; US Dept of Agriculture, Forest Service, Forest Products Laboratory; No 2007; May 1955
59. PERMEANCE MEASUREMENT IMPROVED BY SPECIAL CELL; F.A. Joy & E.R. Queer; ASHVE Journal Section; Oct 1955
60. MOISTURE IN INSULATION; R.D. Morse; Research Project 60740; E.I. duPont de Nemours & Co; Nov 1955
61. HUMIDITY IN CANADIAN BUILDINGS; N.B. Hutcheon; National Research Council; Building Note No 19; May 1956
62. THE CONTROL OF MOISTURE IN BASEMENTS; W. H. Ball; Building Note No 27; National Research Council; July 1956
63. THERMAL CONDUCTIVITY OF INSULATION CONTAINING MOISTURE; F.A. Joy; The Penn. State Univ. Dept of Engineering Research; Aug 25, 1956
64. ONLY GOOD FILMS BLISTER; Matt Taggart; Paint Oil & Chemical Review; June 27, 1957
65. DON'T BLAME THE WEATHER; F.A. Joy; The Industrial Reference Viewer pg. 15, Penn State University Vol 2, No 2; 1958
66. BITUMEN AS A VAPOUR BARRIER; R.P. Bell; Insulation Review; Feb 1958
67. THE MECHANISM BY WHICH WATER MOVES THROUGH A POROUS MATERIAL SUBJECTED TO A TEMPERATURE GRADIENT: 2. SALT TRACER & STREAMING POTENTIAL TO DETECT FLOW IN THE LIQUID PHASE; J.M. Kuzmak & P.J. Sereda; National Research Council Canada 4529, Division of Building Research; Reprint from Soil Science, Vol 84, No 5, Nov 1957, pg 419-422; March 1958
68. EFFECTIVENESS OF CONCRETE ADMIXTURES IN CONTROLLING TRANSMISSION OF MOISTURE THROUGH SLABS-ON-GROUND; Building Research Advisory Board to the Federal Housing Administration, Publication 596; National Academy of Sciences; National Research Council; July 29, 1958
69. VAPOR PROBLEMS IN THERMAL INSULATION; N.B. Hutcheon; Division of Building Research Technical Paper No 55; National Research Council-NRC 4920; ASHAE Journal Section, Heating, Piping & Air Conditioning; Aug 1958
70. PROBE FOR THERMAL CONDUCTIVITY MEASUREMENT OF DRY AND MOIST MATERIALS; W. Woodside; Division of Building Research Paper No 69; National Research Council-NRC 4938; ASHAE Journal Section, Heating, Piping & Air Conditioning; Sept 1958
71. WATER-VAPOR PERMEABILITY OF MATCHED BARRIER MATERIALS AS YIELDED BY TWO METHODS; Forest Products Laboratory, US Dept of Agriculture, No 2131; Sept 1958
72. EFFECT OF TEMPERATURE DISTRIBUTION ON MOISTURE FLOW IN POROUS MATERIALS; W. Woodside & J.M. Kuzmak; Division of Building Research Paper No 68; National Research Council-NRC 4748; Transactions, American Geophysical Union Vol. 39, No 4, Aug 1958; Oct 1958
73. MOISTURE TRAVEL THROUGH SLAB STRUCTURES POSES SERIOUS AIR CONDITIONING PROBLEM; Air Conditioning & Refrigeration News; Nov 3, 1958
74. IMPROPER INSTALLATION OF PIPE INSULATION CAN CAUSE SERIOUS CONDENSATION PROBLEMS; Air Conditioning, Heating & Refrigeration News; Dec 8, 1958
75. GERÄT ZUR MESSUNG DER DURCHLASSIGKEIT VON KUNSTSTOFF-FOLIEN FUR FEUCHTE GASE; N. Buchner & G. Schricker; Kunststoffe; Bd. 50-1960-Heft 3
76. HUMIDITY IN CANADIAN BUILDINGS; N.B. Hutcheon; Canadian Building Digest-CBD 1; Jan 1960
77. RAIN PENETRATION OF WALLS OF UNIT MASONRY; T. Ritchie; National Research Council Canada; Canadian Building Digest-CBD 6; June 1960
78. INTERACTION OF MOISTURE AND WOOD; Harold Tarkow; Forest Products Laboratory, No 2198; Sept 1960
79. MEASUREMENT OF EFFECT OF MOISTURE ON HEAT TRNASFER THROUGH INSULATED FLAT-ROOF CONSTRUCTIONS; F.J. Powell & H.E. Robinson; Special Technical Publication No 312; Symposium on Testing Building Construction; ASTM; 1961
80. HOUSE BASEMENTS; C.R. Crocker; Canadian Building Digest-CBD 13; Jan 1961
81. EFFECTIVENESS OF STABILIZED SURFACE LAYERS OF WOOD AS MOISTURE BARRIERS; H. Tarkow & S.M. Ishaq; Forest Products Journal; April 1961
82. WATER VAPOR TRANSMISSION OF PLAIN CONCRETE; US Naval Civil Engineering Lab; Technical Report 130; May 16, 1961
83. CAVITY WALLS; T. Ritchie; National Research Council Canada; Canadian Building Digest - CBD 21; Sept 1961
84. TESTS REVEAL MOISTURE MIGRATION RATES THROUGH VARIOUSLY-CONSTRUCTED WALLS; R.J. Zablodil; Heating, Piping & Air Conditioning; Sept 1961
85. STUDIES ON MOISTURE TRANSMISSION RATES THROUGH QUARTER-INCH PLYWOOD AT DIFFERENT MOISTURE CONTENT LEVELS; R.D. Ziegler; Tappi, Vol 44, No 9; Sept 1961
86. ALUMINUM FOIL'S THERMAL PROPERTIES OFFER PACKAGING ADVANTAGES; A.B. McKee & D.B. Strohm; Package Engineering; Oct 1961
87. AIR LEAKAGE IN BUILDINGS; A.G. Wilson; Canadian Building Digest-CBD 23; Nov 1961
88. NORWEGIAN TEST METHODS FOR RAIN PENETRATION THROUGH MASONRY WALLS; O. Birkeland & S.D. Svendsen; Transactions; ASTM; 1962
89. METHOD OF DETERMINING THE DRYNESS OF THE SUB-FLOOR; Building Research Station Digest-2nd series; John Blackburn Limited; Her Majesty's Stationary Office; Jan 1962
90. EFFECTIVENESS OF SEPARATE AND CONTINUOUS VAPOR BARRIERS FOR FRAME WALLS; Penn State University Form 73-11705; Aluminum Co of America; Aug 15, 1962
91. VAPOR DIFFUSION AND VAPOR SEALING; Dr. Francis L. Levy; Insulation Journal; Sept-Oct 1962 to March-April 1965 (London)
92. CONTROL OF CONDENSATION IN CURLING RINKS; G.O. Handegord & C.R. Crocker; Canadian Building Digest-CBD 35; Nov 1962
93. PAINTS: PROTECTION OF THERMAL INSULATION AGAINST WATER VAPOR; G. Yate Pitts; Abstract Review No.301 - National Paint, Varnish & Lacquer Association, Inc; B. Jaquiss & Sons Ltd, Manchester, England; Nov 1962
94. APPENDIX A. DISCUSSION OF CHANGE IN MOISTURE TRANSFER RATE THROUGH INSULATION WITH DECREASING TEMPERATURES VOL 2; Building Research Advisory Board Committee; Nov 5, 1962
95. TEMPERATURE GRADIENTS THROUGH BUILDING ENVELOPES; J.K. Latta & G.K. Garden; Canadian Building Digest-CBD 36; National Research Council; Dec 1962
96. FUNDAMENTALS OF MOISTURE TRANSFER RATE AND EFFECT THROUGH INSULATION WITH DECREASING TEMPERATURES; Building Research Advisory Board; Cold Storage Facilities; 1963
97. RAIN PENETRATION AND ITS CONTROL; G.K. Garden; Canadian Building Digest-CBD 40; April 1963
98. 1963 INTERNATIONAL SYMPOSIUM ON HUMIDITY AND MOISTURE - MEASUREMENT AND CONTROL IN SCIENCE AND INDUSTRY; Sponsored by: ASHRAE, American Meteorological Society, Instrument Society of America, National Bureau of Standards, and US Weather Bureau; Washington, D.C.; May 20-23, 1963
99. HEAT AND MOISTURE FLOW THROUGH OPENINGS BY CONVECTION; W.G. Brown, A.G. Wilson & K.R. Solvason; ASHRAE 70th Annual Meeting, Milwaukee, Wisconsin, June 24-26, 1963; ASHRAE 1963
100. HUMIDIFIED BUILDINGS; N.B. Hutcheon; Canadian Building Digest-CBD 42; June 1963

101. WATER VAPOR TRANSMISSION OF CONCRETE AND OF AGGREGATES; US Naval Civil Engineering Lab; Technical Report R244; US Dept of Commerce; June 30, 1963

102. STUDY OF TEMPERATURE IN WOOD PARTS OF HOUSES THROUGHOUT THE UNITED STATES; Otto C. Heyer; Forest Products Laboratory - FPL 012; Aug 1963

103. MODIFICATIONS IN MERCURY POROSIMETRY; L.K. Frevel & L.J. Kressley; American Instrument Co Reprint #177; Analytical Chemistry Vol 35; Sept 1963

104. PRIMER ON PSYCHOMETRICS; A. Donald Hoy; Air Engineering; Sept 1963

105. FUNDAMENTALS OF VAPOR TRANSFER AND CONDENSATION IN COLD-ROOM INSULATION; F.A. Joy; Penn State University Draft of Oct 21, 1963

106. REQUIREMENTS FOR EXTERIOR WALLS; N.B. Hutcheon; Canadian Building Digest-CBD 48; Dec 1963

107. INDOOR WEATHER PREDICTIONS; Wm. T. Tucker III; ASHRAE Journal; Dec 1963

108. PRINCIPLES APPLIED TO AN INSULATED MASONRY WALL; N.B. Hutcheon; Canadian Building Digest-CBD 50; National Research Council; Feb 1964

109. THE WATER ABSORPTION & WATER VAPOR PERMEABILITY OF CLEAR ORGANIC COATINGS; Ashton; Research Paper No 217 of the Division of Building Research; Ottawa; April 1964

110. VAPOUR DIFFUSION AND CONDENSATION; J.K. Latta & R.K. Beach; Canadian Building Digest-CBD 57; Sept 1964

111. HUMIDITY AND BUILDINGS; N.B. Hutcheon; Building Materials News Vol 20, April 1964; National Research Council of Canada; Sept 1964

112. PLASTIC FILMS: THEIR USEFULNESS IN THE FABRICATION OF TRANSPARENT BARRIER MATERIALS; L.W. Lynch; Report No 64-1763; DA Project No 1-A-0-24401-A-110-05; AMC Code No 5025.11.84205; Clearinghouse for Federal Scientific & Technical Information of the US Dept of Commerce; May 25, 1964

113. RECENT FINDINGS IN COLD STORAGE INSULATION HEAT, AIR, AND VAPOR TRANSFER; Wm. A. Lotz; ASHRAE Semiannual Meeting June 30, 1964

114. VAPOR BARRIER DESIGN CONSIDERATIONS FOR COLD STORAGE; Wm. A. Lotz; ASHRAE Semiannual Meeting June 30, 1964

115. A FASTER WVT METHOD; Ranger & Gluckman; Modern Packaging; Technical/Engineering Section; July 1964

116. THERMAL & MOISTURE DEFORMATIONS IN BUILDING MATERIALS; M.C. Baker; Canadian Building Digest-CBD 56; Aug 1964

117. VAPOR BARRIER DESIGN, NEGLECTED KEY TO FREEZER INSULATION EFFECTIVENESS; Wm. A. Lotz; Quick Frozen Foods; Nov 1964

118. INTERIOR FINISHES FOR COLD STORAGE FACILITIES; W.P. Ellis; ASHRAE 71st Annual Meeting in Cleveland, June 29 - July 1, 1964; ASHRAE Journal; Dec 1964

119. VAPOR PRESSURE STUDY SHOWS HOW TO MATCH BARRIER PROPERTIES TO SHIPPING, STORAGE REQUIREMENTS; A.A. Mohaupt; Package Engineering; Dec 1964

120. SYMPOSIUMS ON WATER: ITS EFFECT ON PAINT FILMS AND SUBSTRATES AND THE WOOD-PAINT INTERFACE; Federation of Societies for Paint Technology; Official Digest Journal of Paint Technology & Engineering, Vol 37, June 1965

121. WATER: ITS EFFECT ON PAINT FILMS AND SUBSTRATES; Official Digest Vol 37, No 485; June 1965

122. FUNDAMENTALS OF ROOF DESIGN; G.K. Garden; Canadian Building Digest-CBD 67; National Research Council; July 1965

123. THERMAL CONSIDERATIONS IN ROOF DESIGN; G.K. Garden; Canadian Building Digest-CBD 70; National Research Council Canada; Oct 1965

124. CONTROL OF AIR LEAKAGE IS IMPORTANT; G. K. Garden; Canadian Building Digest-CBD 72; Dec 1965

125. MOISTURE CONSIDERATIONS IN ROOF DESIGN; G.O. Handegord; Canadian Building Digest CBD 73; Jan 1966

126. HUMIDITY: ITS EFFECTS AND CONTROL; Harold Alstedt; Heating, Piping & Air Conditioning; Feb 1966

127. NOMOGRAPHY DETERMINES DENSITY OF MOIST OR DRY AIR - HPAC DATA SHEET; F. Caplan; Heating, Piping & Air Conditioning; March 1966

128. USE THESE CHARTS TO AVOID CONDENSATION ON DUCTS; American Artisan; April 1966

129. PROBLEM: HIGH HUMIDITY, LOW SENSIBLE LOAD SOLUTION: USE RE-HEAT; Julian R. Fellows; American Artisan; April 1966

130. MERCURY POROSIMETRY: FILLING OF TOROIDAL VOID VOLUME FOLLOWING BREAKTHROUGH BETWEEN PACKED SPHERES; R.P. Mayer & R.A. Stowe; American Instrument Company, Reprint #292; June 13, 1966

131. MOISTURE ACCUMULATION IN WALLS DUE TO AIR LEAKAGE; A.G. Wilson & G.K. Garden; Technical Paper No 227 of the Division of Building Research; National Research Council; July 1966

132. MOISTURE ACCUMULATION IN ROOF SPACES UNDER EXTREME WINTER CONDITIONS; H.B. Dickens & N.B. Hutcheon; Technical Paper No 228 of the Division of Building Research; National Research Council; July 1966

133. CONDENSATION IN INSULATED MASONRY WALLS IN SUMMER; A.G. Wilson; Technical Paper No 226 of the Division of Building Research; National Research Council; July 1966

134. WHAT YOU SHOULD KNOW ABOUT DEWPOINT TEMPERATURE; The Air Conditioning & Refrigeration Bus; Sept 1966

135. INDOOR SWIMMING POOLS; G.K. Garden; Canadian building Digest-CBD 83; Nov 1966

136. AN INFRARED INSTRUMENT FOR THE RAPID MEASUREMENT OF WATER VAPOR PERMEATION THROUGH BARRIER WEBS; R.M. Husband & P.J. Petter; Tappi; Vol 49, No 12; Dec 1966

137. HUMIDITY AND TEMPERATURE CONTROL IN THE TOBACCO INDUSTRY; Max Samfield; ASHRAE Journal; Feb 1967

138. RELATIONSHIP OF WVTR. WATER VAPOR PRESSURE AS A DETERMINANT IN PREDICTING PACKAGE LIFE; D. Minuti; Aeronautical Materials Laboratory; Naval Air Engineering Center; June 30, 1967; AD 658 748

139. SURFACE AREAS FROM MERCURY POROSIMETER MEASUREMENTS; H.M. Rootare & C.P. Prenzlow; Journal of Physical Chemistry, Vol 71; No 8; July 1967; American Instrument Co Reprint #320

140. A CONDUCTIVE SHEER ANALOGUE FOR SOLVING A NUMBER OF PROBLEMS RELATING TO WATER VAPOUR DIFFUSION THROUGH INSULATING MATERIAL; J.A. Knobbout; The Journal of Refrigeration; July 1967

141. KINETIC SORPTION & DESORPTION OF WATER VAPOR IN PAPER; Sheldon Brooks; Tappi Aug 1967; Vol 50, No 8

142. PRECAST CONCRETE WALLS-PROBLEMS WITH CONVENTIONAL DESIGN; J.K. Latta; Canadian Building Digest CBD 93; Sept 1967

143. PRECAST CONCRETE WALLS-A NEW BASIS FOR DESIGN; J.K. Latta; Canadian Building Digest CBD 94; Oct 1967

144. ROOFING MEMBRANE DESIGN; M.C. Baker; Canadian Building Digest CBD 95; Nov 1967

145. DETERMINING THE RELATIVE HUMIDITY FOR DIFFERENT ELEVATIONS; F. Caplan; Plant Engineering; Nov 1967

146. TEST RESULTS FROM PAST WVT UNIT; Elais J. Amdur; McGraw-Hill 1967; Modern packaging, Dec 1967

147. ELECTRICAL ANALOG METHOD FOR STUDYING THE VAPOUR DIFFUSION WITH CONDENSATION IN THE WALL THERMIC BRIDGES; A. Radu & L. Biborosch; Kaltetechnik-klimatisierung 20 Jahrgang Heft; Jan 1, 1968

148. MOISTURE DISTRIBUTION IN WOOD-FRAME WALLS IN WINTER; H.E. Duff; Forest Products Journal, Vol 18, No 1, Jan 1968

149. FAST WVTR READINGS BY INFRARED BEAM; PJ Petter; Modern Packaging; Jan 1968

150. VENTILATION & VAPOR BARRIERS-FLAT ROOFS & CATHEDRAL ROOF CONSTRUCTION (WOOD FRAMING); D.E. Morganroth; Owens/Corning Fiberglas; March 1968

151. LA PROTECTION DES ISOLATIONS CONTRE LA PENETRATION DE LA VAPEUR D'EAU; Paul Clement; Revue Generale Duo Froid; May 1968

152. THERMAL INSULATION FROM WOOD FOR BUILDINGS: EFFECTS OF MOISTURE AND ITS CONTROL; Wayne C. Lewis; U.S.D.A. Forest Service; Research Paper; FPL 86; July 1968

153. MOISTURE MOVEMENT UNDER THE COMBINED EFFECT OF TEMPERATURE AND PARTIAL VAPOUR PRESSURE GRADIENT - ITS INFLUENCE ON PREFABRICATED COLDSTORE DESIGN; T. Ambrus, T.J. Komoly; The Journal of Refrigeration; July 1968

154. INDUSTRIAL HUMIDITY CONTROL: HOW TO FIGURE THE LOAD; Arther H. Farr; The Air Conditioning & Refrigeration Business; August 1968

155. SOLVING TEMPERATURE, MOISTURE PROBLEM FOR COMPUTERIZED DEVICE; Alfred D. Sullivan; Heating, Piping & A/C; Aug 1968

156. HEATING AND COOLING REQUIREMENTS; D.G. Stephenson; Canadian Building Digest CBD 105; Sept 1968

157. THE BASIC AIR-CONDITIONING PROBLEM; N. B. Hutcheon; Canadian Building Digest CBD 106; Oct 1968

158. WATER VAPOR DIFFUSION THROUGH PROTECTIVE COATINGS. PART 1. A METHOD OF MEASURING WATER VAPOR PERMEABILITY OF COATING FILMS BY RADIOISOTOPE TRACER TECHNIQUE AND ITS APPLICATION; E.S. Matsui; Technical Note N-992; Naval Civil Engineering Laboratory; Oct 1968

159. AIR CONDITIONING PROCESSES; K.R. Solvason; Canadian Building Digest CBD 108; Dec 1968

160. WOOD MOISTURE CONTENT IN CONTROLLED ENVIRONMENTS; Csiro Forest Products Newsletter No 357; Dec 1968

161. AIR CONDITIONING SYSTEMS; K.R. Solvason Canadian Building Digest CBD 109; Jan 1969

162. NOMOGRAPH DETERMINES SPECIFIC VOLUME, DENSITY OF MOIST AIR; J.K. O'Hara; HPAC Data Sheet; Heating, Piping & A/C Feb 1969

163. RAPID METHOD OF FINDING WATER VAPOR TRANSMISSION RATES; Morris W. Kane; Package Engineering; May 1969

164. CONDENSATION; Building Research Station; Her Majesty's Stationary Office; Oct 1969

165. CONDENSATION CONTROL IN METAL BUILDINGS; E.R. Queer & E.R. McLaughlin; Actual Specifying Engineer; Oct 1969

166. NOMOGRAPH GIVES QUICK ESTIMATE OF WATER VAPOR NEEDED TO SATURATE AIR; Javier F. Kuong; HPAC Data Sheet; Heating, Piping & Air Conditioning; Oct 1969

167. DAS MESSEN DER FEUCHTIGKEIT IN ESTRICHEN Vor-und Nachteile; Bodenwand & Decke; Dec 1969

168. MEASURING MOISTURE CONTENT IN UNDERLAYMENTS; Siegfried Kranz; Bodenwand & Decke; 12/69

169. THICKNESS TO PREVENT SURFACE CONDENSATION; ASHRAE Handbook 1977 Fundamentals; Chapter 19; (1970?)

170. MOISTURE AND VAPOR EFFECTS ON BUILT-UP ROOFING; Donald E. Brotherson; March 1970; Roofing, Siding & Insulation

171. A CONSULTANT LOOKS AT ASHRAE SYMPOSIUM ON TEMPERATURE AND HUMIDITY CONTROL; Joe B. Olivieri; Air Conditioning, Heating, & Refrigeration; News March 23, 1970

172. THE STRUCTURE OF POROUS BUILDING MATERIALS; P.J. Sereda; National Research Council of Canada; Canadian Building Digest-CBD 127; July 1970

173. WOOD-FRAME HOUSE CONSTRUCTION; L.O. Anderson; USDA-Forest Service-Agriculture Handbook; No 73 Revised July 1970

174. DIFFUSION OF SORBED WATER VAPOR THROUGH PAPER AND CELLULOSE FILM; Arne T. Ahlen; Tappi Vol 53, No 7; July 1970

175. COATINGS AND VAPOR BARRIERS FOR CELLULAR PLASTIC FOAM; Irv. J. Steltz; July & Aug 1970; Roofing, Siding & Insulation

176. WETTING & DRYING OF POROUS MATERIALS; P.J. Sereda & R.F. Feldman; National Research Council of Canada; Canadian Building Digest-CBD 130; Oct 1970

177. VAPOR BARRIERS; Nov. 1970; Roofing, Siding & Insulation

178. METHOD OF EVALUATING MOISTURE BARRIER PROPERTIES OF ENCAPSULATING MATERIALS; James E. Webb; Administrator of the NASA; USP 3,548,633; Dec 22, 1970

179. AIR LEAKAGE MEASUREMENTS OF THE EXTERIOR WALLS OF TALL BUILDINGS; C.Y. Shaw, D.M. Sander & G.T. Tamura; National Research Council of Canada; Research Paper No 601 of the Division of Builders Research; NRCC 13951; ASHRAE Transactions, Vol 79, Part 2, 1973

180. PROCEDURE AND EVALUATION OF TEST FOR DETERMINATION OF THE VAPOR DIFFUSIONS RESISTANCE FACTOR FOR FLAT SHEET SPECIMENS; W. Kast; Institute for Thermal Processing & Heating Technology; Technical College of Darmstadt, W. Germany; 1/15/73

181. MOISTURE AND THERMAL CONSIDERATIONS IN BASEMENT WALLS; C.R. Crocker; National Research Council of Canada; Canadian Building Digest-CBD 161; 1974

182. SOME CONSIDERATIONS ABOUT THE MEASUREMENT OF THE DIFFUSION RESISTANCE NUMBER OF BUILDING AND INSULATING MATERIALS; Ir. H. Hens, K.U. - Leuven; CIB Working Group W 40; Washington Meeting; Undated (1976 see at 197)

183. HUMIDITY-AND ITS SENSING; C.L. Nelson & C.D. Gustus; Air Conditioning, Heating & Refrigeration News; Feb 4, 1974

184. CONDENSATION PROBLEMS IN YOUR HOUSE: PREVENTION & SOLUTION; L.O. Anderson & G.E. Sherwood; USDA Forest Service Sept 1974 Agriculture Information Bulletin No 373

185. CONDENSATION CONTROL BY POROUS INSULATING MATERIALS; D.A. Lovett; Trans Instn Chem Engrs Vol 53, 1975

186. CONDENSATION IN ROOFS; Building Research Establishment Digest; Digest 180; Her Majesty's Stationary office-England; Aug 1975

187. DETERMINATION OF WATER CONTENT USING MASS SPECTROMETRY; NASA Tech Brief; B75-10157; Aug 1975

188. CONDENSATION IN CAVITIES OF BUILDING STRUCTURES; H. Trethowen; Building Research Association of New Zealand; Research Report No R5; 1976?

189. STUDIES ON EXTERIOR WALL AIR TIGHTNESS AND AIR INFILTRATION OF TALL BUILDINGS; G.T. Tamura & C.Y. Shaw; Division of Building Research Paper No 706; ASHRAE Transactions Vol 82, Part 1; 1976

190. ON THE MEASUREMENT OF THERMAL CONDUCTIVITY IN MOIST POROUS MATERIALS; H. Auracher; Meeting of IIR Commission B1, Washington, 1976 (see at 230)

191. VAPOUR BARRIERS: WHAT ARE THEY? ARE THEY EFFECTIVE? J.K. Latta; Division of Building Research; National Research Council Canada; Canadian Building Digest CBD 175; March 1976

192. NUMERICAL CONSIDERATIONS ON THE PHYSICAL BEHAVIOR OF THERMAL BRIDGES WITH RESPECT TO STANDARDIZATION; A.C. Verhoeven & T.H.J. Liem; Delft Univ of Technology; Mar 1976 (see at 301)

193. VENTING ON FLAT ROOFS; M.C. Baker & C. P. Hedlin; National Research Council Canada; Canadian Building Digest CBD 176; May 1976

PAPERS PRESENTED AT WASHINGTON MEETING MAY 4-6 1976 (RILEM-CIB W40)

194. L'INFLUENCE DUE REGIME DE MICROCLIME ET D'HUMIDITE SUR LES DEGRADATIONS SUPERFICIELLES ET MESSURES DE PROTECTION AUX MONUMENTS; Dr. Ing. Eugene Dimitriu-Valcea

195. COMPORTMENT THERMOTECHNIQUE DE QUELQUES TYPES DE MURS EXTERIEURS A PONTS THERMIQUES DES CONSTRUCTIONS DE LOGEMENTS; Dr. Ing Eugene Dimitriu-Valcea

196. RAIN PENETRATION THROUGH THE OUTER WALLS OF CAVITY-STRUCTURES; Bob H. Vos & Eltjo Tammes

197. INTERNAL CONDENSATION & BUILDING MOISTURE PROBLEMS IN NON VENTILATED FLAT ROOFS; Dr. Ir. H. Hens

198. EXPERIENCE WITH ELECTRO-OSMOTIC DAMP-PROOFING SYSTEMS IN GREAT BRITAIN; D.B. Honeyborne, A.T. Coote, & D. Whiteside

199. MOISTURE TRANSFER IN INSULATED METAL DECK; Ingemar Samuelson

200. PRELIMINARY REPORT ON THE USE OF HEAT FLOW METERS IN BUILDING CONSTRUCTIONS; Gudni Johannesson

201. CALCULATION METHOD OF TRANSIENT THERMAL RESPONSE OF COLD BRIDGES; K. Eguchi & K. Bohgaki; Building Research Institute, Ministry of Ciustruction, Japanese Government

202. SUGGESTED UNIFIED METHOD OF BUILDING DIAGNOSIS FOR DETERMINING THE ORIGIN WALL MOISTURE; Michael Zador; Dept of History of Architecture; Budapest Technical University

203. THE INFLUENCE OF HUMIDITY ON HUMAN THERMAL COMFORT; Dr. Nalinaksha Biswas; Dept of Building & Civ. Engr'g Leeds Poly

204. MOISTURE DISTRIBUTION IN BUILDING STRUCTURES AND PERMANENT MOISTURE; Frantisek Mrlik

205. MOISTURE ATTACK ON INSULATIONS IN PROTECTED MEMBRANE ROOFING; Charles P. Hedlin; National Research Council of Canada

206. MOISTURE CONTENT IN SITU, EXAMPLES OF FAILURE & NON-FAILURE CASES, SUMMARY; Aulis O. Miettunen

207. L'HUMIDITE DE CONSTRUCTION DES MURS AVEC STRUCTURES DIVERSES; Virgil C. Focsa

208. CONDENSATION IN ELECTRICALLY HEATED HOUSES; Harold W. Orr; National Research Council of Canada

209. CONDENSATION PROBLEMS IN FLAT WOOD-FRAME ROOFS; G.T. Tamura, G.H. Kuester, & G.O. Handegord; National Research Council of Canada

210. MOISTURE TRANSPORT IN CELLULAR CONCRETE ROOFS; Jan van der Kooi; Delft University of Technology

211. CONDENSATION IN STEEL DECK-AN INVESTIGATION ON BUILDINGS IN USE; Ingemar Samuelson; Division of Bldg Technology, Lund Institute of Technology

212. BITUMEN FELT ROOFING ON POLYSTYRENE INSULATED ROOFS; Trygve Isaksen & Helge Juul; Norwegian Building Research Institute

213. CONDENSATION RISK IN INTERMITTENTLY HEATED ROOMS; D.P. Bloomfield; Building Research Station England

214. CALCULATION OF CONDENSATION (EVAPORATION) OF INTERNAL SURFACES OF ENCLOSING STRUCTURES; P.M. Brdlik & I.S. Molchadsky

215. PERMEABILITY OF LIGHTWEIGHT-AGGREGATE CONCRETE; I. Soroka & Ch. H. Jaegermann; Building Research Station-Israel

216. SEASONAL VARIATION OF MOISTURE IN WALL AND ROOF SECTIONS EXPOSED TO NATURAL WEATHER CONDITIONS; K.R. Rao & S.P. Jain

217. WATERPROOFING OF MUD WALLS; M. Aslam & R.C. Satiya

218. AN EXPERIMENT ON MECHANISM OF RAIN PENETRATION THROUGH HORIZONTAL JOINTS IN WALLS; H. Ishikawa

219. ETUDE DE L'ASSECHEMENT DES MURS SOUMIS A DES REMONTEES CAPILLAIRES; M. Mamillan & A. Bouineau

220. MOISTURE SORPTION IN POROUS BUILDING MATERIALS; L. Ahlgren

221. CAPILLARY ABSORPTION OF BUILDING MATERIALS; M. Uyan

222. STUDY ON THE MOISTURE DISTRIBUTION OF DRYING CONCRETE; K. Shiina

223. THE CAPILLARY MOTION OF MOISTURE IN BUILDING MATERIALS; W.F. Cammerer

224. THE MOISTURE CONDUCTIVITY & DIFFUSIVITY OF WOOD FOR ESTIMATION OF ROOM AIR HUMIDITY VARIATION; M. Matsumoto & R. Fujihana

225. CONDENSATION & OTHER LOSSES OF VAPOUR FROM AN ENCLOSURE; M.G. Davies

226. THE MOISTURE LOAD OF DOMESTIC KITCHENS, MOISTURE REMOVAL & STORAGE IN THE STRUCTURES; K. Petzold, W. Kunze, G. Eisold

227. MOISTURE TRANSFER IN AIR CONDITIONED ROOMS AND COLD STORAGE; P.V. Nielsen

228. INTRODUCTION TO THE SECOND INTERNATIONAL SYMPOSIUM ON MOISTURE PROBLEMS IN BUILDINGS; B.H. Vos

229. CONDENSATION IN STRUCTURES; B.H. Vos & E. Tammes

****

PAPERS PRESENTED AT NBS/INTERNATIONAL INSTITUTE OF REFRIGERATION B-1, SEPTEMBER 14-16, 1976

230. COMPARISON OF THE THERMAL PERFORMANCE OF THREE INSULATING MATERIALS COMMONLY USED TO RETROFIT EXTERIOR RESIDENTIAL WALLS; D.M. Burch, C. Siu, F.J. Powell

231. VAPOR CONDENSATION IN AIR-PERVIOUS INSULATION; T. Kusuda & W. Ellis

232. MEASUREMENT OF THE FROST-POINT OF AIR IN SEALED INSULATING GLASS; F.J. Powell & M.H. Hahn

233. HEAT AND MASS TRANSFER DURING PRECOOLING; S. Yavuzkurt, A.Y. Gogus, H.T. Ceylan

234. THERMAL CONDUCTIVITY OF CONCRETE; MEASUREMENT PROBLEMS & EFFECT OF MOISTURE; R.P. Tye & S.C. Spinney

****

235. PREDICTING AVERAGE MOISTURE CONTENT OF WOOD IN A CHANGING ENVIRONMENT; Eugene M. Wengert; Forest Products Laboratory; Wood & Fiber Winter, 1976, V 7 (4)

236. REASONS AND METHODS FOR CONTROLLING HUMIDITY IN THE PLANT; Bradley T. Carroll; Plant Engineering - 11/25/76

237. POROSITY OF BUILDING MATERIALS - A COLLECTION OF PUBLISHED RESULTS; P. Whoteley, H.D. Russman & J.D. Bishop; J. Oil Col. Chem. Assoc. 1977

238. THERMAL CONDUCTIVE PROPERTIES OF WOOD, GREEN OR DRY, FROM -40° TO PLUS 100°C: A LITERATURE REVIEW; H. Peter Steinhagen; USDA Forest Service, General Technical; Report FPL-9; 1977

239. MOISTURE CONDITIONS IN WALLS & CEILINGS OF SIMULATED OLDER HOME DURING WINTER; G.E. Sherwood, C.C. Peters; Forest Products Laboratory; FPL 290; 1977

240. IMPREGNATION AS A TECHNIQUE FOR MEASURING ZERO POROSITY OF POROUS MATERIALS; R.F. Feldman & J.J. Beaudoin; Division of Building Research Paper No 704; Cement & Concrete Research Vol 7, No 2, Mar 1977

241. TESTS SHOW INCREASED INDOOR HUMIDITY CAN SAVE ENERGY; Air Conditioning, Heating & Refrigeration News; March 28, 1977

242. VAPOR BARRIER CRITICAL FOR GOOD THERMAL PERFORMANCE; Mike Miller; Air Conditioning, Heating & Refrigeration News; Oct 24, 1977

243. A TECHNIQUE FOR PROTECTING RETROFITTED WOOD-FRAME WALLS FROM CONDENSATION DAMAGE; D.M. Burch & S.J. Tuesdo; ASHRAE Transactions Vol 84, Part 1, No 2481, 1978

244. MERCURY INTRUSION POROSIMETERS; Aminco-The American Instrument Co; May 22, 1978

245. GRAVIMETRIC DETERMINATION OF WATER VAPOR TRANSMISSION RATE OF SHEET MATERIALS AT HIGH TEMPERATURE AND HUMIDITY; Technical Assoc of the Pulp & Paper Industry; Draft #2; Nov 21, 1978

246. RESIDENTIAL THERMAL LOAD ANALYSIS AND VALIDATION; R.B. Blancett, M.P. McBride, C.P. Sepsy, C.D. Jones; ASHRAE Transactions 1979, Vol 85, Part 1, PH-79-7A No 2

247. AIR INFILTRATION EFFECTS ON THE THERMAL TRANSMITTANCE OF CONCRETE BUILDING SYSTEMS; J.B. Funkhouser; ASHRAE 1979 Vol 85, Part 1; PH-79-11 No 4

248. AIR TIGHTNESS & AIR INFILTRATION OF SCHOOL BUILDINGS; C.Y. Shaw, L. Jones; ASHRAE 1979 Vol 85, Part 1; No 2515

249. THE CALCULATION OF HOUSE INFILTRATION RATES; G.T. Tamura; ASHRAE 1979 Vol 85, Part 1; No 2513

250. INFILTRATION-PRESSURIZATION CORRELATIONS: DETAILED MEASUREMENTS ON A CALIFORNIA HOUSE; D.T. Grimsrud, M.H. Sherman, R.C. Diamond, P.E. Cordon, A.H. Rosenfeld; ASHRAE 1979 Vol 85, Part 1; PH-79-10 No 5

251. SUMMERTIME INFILTRATION RATES IN MOBILE HOMES; V.W. Goldschmidt, D.R. Wilhelm; ASHRAE 1979 Vol 85, Part 1 PH-79-10 No 4

252. AIR INFILTRATION MODEL FOR RESIDENCES; G. Reeves, M. McBride, C.F. Sepsy; ASHRAE 1979 Vol 85, Part 1 PH-79-7A No 1

253. RESIDENTIAL AIR INFILTRATION; Garry E. Caffey; ASHRAE 1979 Vol 85, Part 1 No 2512

254. APPROACHES TO EVALUATION OF AIR INFILTRATION ENERGY LOSSES IN BUILDINGS; Ake K. Blomsterberg, David T. Harrje; ASHRAE 1979 Vol 85, Part 1; PH-79-10; No 1

255. ESTIMATING AIR INFILTRATION INTO HOUSES; Joel E. Peterson; ASHRAE Journal Jan 1979

B) HUMIDIFICATION OF INSULATION AND WATER-TIGHTNESS

1. TESTS ON INSULATION OF COLD ROOMS. A. Watzinger. Kyltekn. Tidskr., Swed. (Aug 15th, 1952), pp. 33, 34, 37-40, 13 fig.

2. DESIGN OF CHAMBERS FOR VERY LOW TEMPERATURES. G.H.W. Richards. Mod. Refrign, U.K. (Jan 1953), pp. 11-12.

3. INFLUENCE OF MOISTURE DISTRIBUTION ON THE CONDUCTIBILITY OF COLD ROOM WALLS. W. Schley. Kältetechnik, Ger. (March 1953), 5, No 3, pp. 77-78, 2 fig., 3 tabl.

4. CONSTRUCTION OF COLD ROOMS INSULATED WITH POROUS CONCRETE. P. Pirog. Holod. Toch., USSR (Jan-March 1953), 30, No 1, pp. 43-46, 3 fig.

5. MOISTURE CALCULATIONS IN INSULATING WALLS IN REFRIGERATED WAREHOUSES. J. Douchkine Holod. Techn. USSR (July-Sept 1953), 30, No 3, pp. 34-39, 4 fig.

6. A VAPOUR BARRIER OF LAMINATED MYLAR AND ALUMINUM. J.G. Macormack. Refrigg Engg. USA (July 1954), 62, No 7, pp. 58-60, 98-99, 7 fig., 1 tabl.

7. THE <<MINIKAY>> SYSTEM. P. Harsen. Kyltekn. Tidskr., Swed. (Feb 1954), 13, No 1, pp. 2-3, 4 fig.

8. NEW REFRIGERATED WAREHOUSE FOR AMERICAN BREWERY. Mod. Refrign, U.K. (Jan 1955), pp. 11, 30, 1 fig.

9. IMPROVED COLD STORAGE INSULATION THROUGH DEHUMIDIFICATION. O.D. Colvin and H.R. Numann. Mod. Refrign, U.K. (July 1955), pp. 253-256; (Aug 1955), 1 fig., 1 tabl.

10. VAPOUR BARRIER. REQUIREMENTS FOR COLD STORAGE STRUCTURES. S.J. Stachelek. Indus. Refrign, USA (June 1955), pp. 34-38, fig., 1 tabl.

11. HEAT, AIR AND MOISTURE CURRENTS IN THE INSULATED WALLS OF REFRIGERATED WAREHOUSES. Warme-, luft- og fuktighetsbevaegelse i isolerte fryseromsvaegger. A. Watzinger, Kulde, Den. (June 1955), 9, No 3, pp. 25-31, 11 fig.; (Oct 1955), 9, No 5, pp. 75-81, 6 fig.

12. VAPOURPROOF AND GAS-TIGHT INSULATION FOR REFRIGERATED WAREHOUSES (Wasserdampf- und Gas-dichte Isolierung von Kaltlagerräumen für Obst). T. Van Hiele, P. Noordzu I.B.V.T., Neth., No 46, 4 p., 7 fig.

13. VAPOURPROOF AND GASPROOF INSULATION IN COLD ROOMS FOR FRUITS (Wasserdampf- und Gas-dichte Isolierung von Kaltlagerräumen für Obst). T. Van Hiele, P. Noordzu and J.C. Tol. Kältetechnik, Ger. (Sept 1955), 7, No 9, pp. 262-265, 7 fig.

14. INVESTIGATION ON THE WATER ABSORPTION OF INSULATION MADE OF CORK SLABS IN REFRIGERATING WAREHOUSES. (Untersuchungen über die Durchfeuchtung von Kühlhausisolierungen aus Korkplatten). J.S. Cammerer. Kältetechnik, Ger. (Sept 1955), 7, No 9, pp. 258-261, (Oct 1955), 7, No 10, pp. 296-299, 8 fig., 8 tabl.

15. A FIELD EVALUATION OF THE PERFORMANCE OF VAPOR-VENTED INSULATION IN A LARGE FREEZER WAREHOUSE. E.R. Queer and E.R. McLaughlin. Refrigg Engg. USA (Jan 1956), 64, No 1, pp. 29-34, 84, 6 fig., 2 tabl.

16. THE LIFE OF THE WALLS OF COLD ROOMS FOR THE PRESERVATION OF SAUSAGES IN SLAUGHTER HOUSES. (O dol'goveenostiograzdajuseikh konstrukeij kholodil'nokolbasnykh korpusov mjasokombinatov). P. Pirog. Mjasnaja Indus. SSSR, USSR (March 1956), No 3, pp. 27-32, 6 fig., 1 tabl.

17. TEST REVEAL MOISTURE MIGRATION RATES THROUGH VARIOUSLY-CONSTRUCTED WALLS. R.J. Zablodil, Htg. Pip. Air Condg, USA (Sept 1961), 33, No 9, pp. 148-150, 1 diag., 1 phot., 1 tabl.

18. CONTROL OF WATER VAPOUR DIFFUSION IN REFRIGERATING PLANTS (El control de la difusion de vapor de agua en contrucciones frigorificas). J. Kirchmayr. Rev. AATRAA, Arg. (1960), No 13, pp. 16-20, 3 fig. and (1961), No 14 pp. 16-22, 4 fig.

19. ON THE MECHANISM OF WATER-VAPOUR PENETRATION INTO THE INSULATING WALL OF THE REFRIGERATED WAREHOUSE AND THE CORROSION CAUSED BY IT. T. Takashi. Refrigeration, Jap. (May 1962), 37, No 415, pp. 1-15, 10 fig., 8 ref. (In Japanese).

20. MEASUREMENT OF EFFECT OF MOISTURE ON HEAT TRANSFER THROUGH INSULATED FLAT-ROOF CONSTRUCTIONS. P.J. Powell and H. E. Robinson. Amer. Soc. Testg. Mater., USA (1961), Special Techn. Public. No 312, pp. 35-66, 12 fig., 4 tabl., ref.

21. THE EFFECT OF MOISTURE ON HEAT TRANSFER THROUGH INSULATED FLAT-ROOF CONSTRUCTION P.J. Powell, Annex 1962-1 Bull. I.I.R., pp. 61-70, 4 fig., 1 ref., disc.

22. COLD STORES FOR FRESH VEGETABLES (Maschinengekühlte Lagerhäuser für Frischgemüse). I.P. Noordzu. Bauen auf dem Lande, Ger. (Dec 1962), 13, No 12, pp. 302-305, 12 fig.

23. THE ALLOWABLE DIFFUSION OF WATER VAPOUR THROUGH WALLS OF COLD STORES, THE COMPUTATION OF THE DIFFUSION FLUX AND THE CASE WHEN THE WALLS ARE INSULATED WITH VAPOUR PROOF MATERIAL (Die zulässige Dampfdiffusion durch Kühlauswände, deren Berechnung und die Verhältnisse bei völlig dampfdichten Kälteisolierungen). J.S. Cammerer. Kältetechnik, Ger. (Oct 1964), 16, No 10, pp. 301-307, 8 fig., 4 tabl.

24. THE VAPOUR BARRIER. G. Yate Pitts. Annex 1964-2, Bull. I.I.R., pp. 89-98, 3 fig., 1 tabl.

25. THE MINIKAY INSULATION DEHYDRATION SYSTEM ADDS TO THE ECONOMY OF COOLING AND FREEZING PLANTS. (Minikay dehydreringssystem för ekonomi i kyl- och frysanläggningar). G. Sandberg. Kyltekn. Tidskr., Swed. (Oct 1964), 23, No 5, pp. 97-103, 10 fig., 13 ref.

26. WRAP YOUR COLD STORAGE ROOM IN A VAPOUR BARRIER. A.R. McGarvey, ASHRAE J., USA (Dec 1964), 6, No 12, pp. 42-46, 9 fig., 8 ref.

27. VAPOUR BARRIER DESIGN FOR COLD STORAGE APPLICATIONS. W.A. Lotz, ASHRAE J., USA (Dec 1964), 6, No 12, pp. 46-48, 1 ref.

28. INTERIOR FINISHES FOR COLD STORAGE FACILITIES. W.P. Ellis. ASHRAE J., USA (Dec 1964), 6, No 12, pp. 48-50, 9 ref.

29. WATERPROOF LININGS FOR CONTROLLED ATMOSPHERE ROOMS USED FOR THE STORAGE OF FRUIT. F. Bonomi. Annex 1966-1, Bull. I.I.R., pp. 121-128, 139-140, 5 fig.

30. MOISTURE PROBLEMS IN COLD STORAGE CONSTRUCTION. I.S. Dewhurst. Austral. Refrign. Air Condg. Htg. Austral. (April 1966), 20, No 4, pp. 21-23, 26-27, 4 tabl., 2 ref.

31. INVESTIGATIONS ON ICE FORMATION DUE TO AIR LEAKAGE IN THE MINERAL WOOL INSULATION OF COLD STORES. V. Korsgaard and Th. Lund Madsen. Thermal Insulation Laboratory, Technical University of Denmark, Lyngby and J. Irgens and I. Ostrup. Development Group, A/S Rockwool, Hedehusene (Danmark), XIIth Int. Congress Refrign. Madrid (Sept 1967), Vol. II.

32. CHARACTERISTICS OF VAPOUR BARRIER (Zur Charakteristik von Dampfsperren). A.W. Rick. Bitumen Teere Asph. Peche Verw. Stoffe, Ger. (1967), 18, No 7, pp. 255-256.

33. CONTRIBUTIONS TO THE ACHIEVEMENT OF A VAPOUR BARRIER FOR COLD STORAGE STRUCTURES (Contributii la realizarea unei bariere de vapori pentru izolarea construcțiilor frigorifice). G. Lascu. Lucrarile Inst. Cerc. Alim., Rum. (1966-67), 8, pp. 159-164, 1 tabl., 6 ref.

34. MOISTURE--ITS EFFECT ON THE EFFICIENCY OF VARIOUS INSULATING MATERIALS AND DETERMINATION OF MOISTURE TAKE-UP BY EXTRUDED POLYSTYROL FOAM IN THE CASE OF AN ASSEMBLY WITHOUT WATERPROOF COATING (Feuchtigkeit--ihr Einfluss auf die Wirksamkeit verschiedner Dämmstoffe und die Bestimmung der Wasseraufnahme in extrudiertem Polystyrolschaum beim Einbau ohne Dampfsperre). H. Seihmann. Kälte, Ger. (March 1968), 21, No 3, pp. 114-122, 11 fig., 4 tabl.

35. PRACTICAL DIFFUSION PROBLEMS OF THE INSULATION OF OLDER TYPE COLD STORES (Praktische Diffusions probleme der Isolierungen von Altkühlhaüsern). C. Fritzsche. Luft Kältetchn., Ger. (June 1968), 4, No 3, pp. 126-130, 7 fig., 1 tabl., 23 ref.

C) INSULATING TECHNIQUES: PROTECTION AGAINST WATER VAPOUR

1. WATER VAPOUR BARRIERS. Quick Fzn Foods, USA (Jan 1953), p. 112.

2. MODERN TRENDS IN INSULATION DESIGN. A. F. Lusch, Indus. Refrign, USA (Sept 1953), pp. 40-44, 4 fig.

3. DEHYDRATION OF INSULATIONS. G. Vassogne. Rev. prat. Froid, Fr. (Jan 1954), pp. 17-21, (Feb 1954), pp. 26-29, 13 fig.

4. MEASURING HEAT AND VAPOUR TRANSMISSION THROUGH INSULATED PANELS. Refrigg Engg. USA (Dec 1954), 62, No 12, pp. 42, 104, 106, 1 fig.

5. DRY WALL CONSTRUCTION. Refrigg Engg. USA (July 1955), p. 58, 1 fig.

6. INSULATION OF REFRIGERATING PLANT WITH RUBBERISED BITUMEN VAPOUR SEAL. C.J. Moss and P. Stevenson, World Refrign. U.K. (Aug 1955), 6, No 8, pp. 431-434, 3 fig.

7. EXTENDING THE LIFE OF INSULATION BY DEHYDRATION WITH SOME THOUGHTS ON AIR LOCKS. G.E. Jennings and W.R. Michael. Mod. Refrign, U.K. (April 1957), 60, No 709, pp. 149-152 and (May 1957), 60, No 710, pp. 190-194, 5 fig., 1 tabl.

8. BITUMEN AS A VAPOUR BARRIER IN THERMAL INSULATION. R.P. Bell. Annex 1957-1 to the Bull. I.I.R., pp. 181-193, 8 fig., 1 tabl., disc.

9. SPECIAL PAPER USED AS VAPOUR-BARRIER IN AIR-CONDITIONED ROOMS (Spezialpapier als Dampfsperre für klimatisierte Räume). Schwim-Bauztg. Switz. (Nov 16th 1957), 75, No 46, pp. 735-736.

10. SURFACINGS FOR GLASS FIBRE AND FOAM THERMAL INSULATION. W.P. Ellis. Htg. Pip. Air Condg. USA (July 1958), 30, No 7, pp. 136-139, 8 fig.

11. VAPOUR PROBLEMS IN THERMAL INSULATION. N.B. Hutcheon. Htg. Pip. Air Condg. USA (Aug 1958), 30, No 8, pp. 150-152.

12. THE INFLUENCE OF THE CAPILLARY SUCTION EFFECT ON THE INFILTRATION OF MOISTURE IN SHEET INSULATIONS OF ASPHALT IMPREGNATED PAPER. M. Backström. Stockholm (Sweden). Xth Int. Congress Refrig., Copenhagen (Aug 1959)

13. SIMPLIFIED CALCULATION OF WATER VAPOUR DIFFUSION IN COMPOUND WALLS WITH ACCUMULATION OF WATER AND ICE (Vereinfachte Berechnung der Dampf-Diffusion durch geschichtete Wände bei Ausscheidung von Wasser und Eis). H. Glaser. Kältetechnik, Ger. (Nov 1958), 10, No 11, pp. 358-364 and (Dec 1958), 10, No 12, pp. 386-390, 19 fig., 5 tabl., 7 ref.

14. COEFFICIENT OF WATER VAPOUR DIFFUSION (Diffusionszahlen für die Diffusion von Wasserdampf in Luft). H. Glaser Kältetechnik, Ger. (Dec 1958), 10, No 12, DKV Arbeitsblatt 3-22, 1 chart, 1 tabl., 6 ref.

15. TEST OF SOAKING CAPACITY AND FREEZING TESTS OF INSULATION MATERIALS IN THE REFRIGERATION TECHNIQUE. F. Rendla and D. Konopkova. Annex 1958-4 to the Bull. I.I.R., pp. 131-140, 8 fig.

16. DEHYDRATION OF INSULATION (Deshidratacion de aislaciones). E.G. Starke. Rev. A.A.T.R.A.A., Arg. (June 1959), 3, No 9, pp. 35-37.

17. THE ABSORPTION OF WATER VAPOURS BY HEAT INSULATION AT LOW TEMPERATURES. (Poglosenie vlagi teploizoljaciej pri nizkih temperaturah). B.S. Korsunov. Kislorod, USSR (1959), 12, No 1, pp. 19-22, 8 fig., 2 tabl.

18. THE INFLUENCE OF CAPILLARITY ON MOISTURE MIGRATION IN INSULATIONS COMPOSED OF ASPHALT IMPREGNATED PAPER (Kapillärsugningseffektens inflytande pa fuktvandingen i isoleringar av asfalt impregnerad papper). M. Bäckström. Kyltekn Tidskr., Swed. (1960), 19, No 3, pp. 39-42, 4 fig., 3 ref.

19. PREMEABILITY AND VAPOUR BARRIERS. R.T. B. McKenzie. Refrign J., Austral. (April 1960), 13, No 10, pp. 27-33, 57; (May 1960), No 11, pp. 29-33, 5 fig.

20. MEASUREMENT OF COEFFICIENTS OF RESISTANCE TO DIFFUSION (Messungen von Diffusionswiderstandsfaktoren). K. Seiffert Kältétechnik, Ger. (July 1960), 12, No 7, pp. 187-190, 2 fig., 7 tabl., 1 ref.

21. WETTING OF THE INSULATION OF COLD STORAGE WAREHOUSES AND VAPOUR DIFFUSION (A hütöhazak höszigetelesenek elnedvesedese es a vizgözdiffuzio). J. Kertesz Hütöipar, Hung. (1960), No 3, pp. 68-76, 9 fig.

22. INFLUENCE OF THE CAPILLARY SUCTION EFFECT ON MOISTURE LEAKAGE INTO INSULATING MATERIALS MADE OF SHEETS OF PAPER IMPREGNATED WITH ASPHALT (La influencia del efecto de succion capilar sobre la infiltracion de la humedad en las aislaciones de hojas de papel impregnado de asfalto). M. Bäckström. Rev. Arg. Frio. Arg. (July-Sept 1960), 22, No 174, pp. 17-25, 4 fig.

23. THE EFFECT OF MOISTURE ON INSULATION MATERIALS MADE OF PLASTIC FOAM, IMPREGNATED MINERAL WOOL, VERMICULITE AND CONCRETE CLINKERS. H.B. Jespersen. Annex 1960-2 Bull. I.I.R., pp. 63-78, 5 fig., 10 tabl., 10 ref.

24. THE PROTECTION OF HEAT INSULATION FROM WATER VAPOUR. G. Yate Pitts. Annex 1960-2 Bull. I.I.R., pp. 33-44, 6 fig., 2 tabl.

25. VAPOUR PROBLEMS WITH INSULATION. M. Ramsey. Air Condg Htg Ventg, USA (May 1961), 58, No 5, pp. 93-95, 2 fig.

26. CONTROLLING VAPOUR TRANSMISSION THROUGH INSULATED WALLS WITH THE AID OF DIAGRAMS (Diagramme zur Beherrschung des Dampfdurch ganges durch isolierte Wände) P.E. Levy, Kältetechnik, Ger. (Feb 1962) 14, No 2, pp. 42-44, 3 fig., 2 ref.

27. MOISTURE ABSORPTION ON THERMAL INSULATING MATERIALS. A. van Ittorbeek, H. Mynckc, W. van Dael and R. Hellemans. Annex 1961-3 Bull. I.I.R., pp. 107-122, 10 fig., 10 tabl.

28. A STUDY ON THE PREVENTION OF MOISTURE IN INSULATIONS (Ein Beitrag zum thema Minikay). H.H.R. Niemann. Ned. Ver. Koeltechn. Meded., Neth. (Sept-Oct 1960), 53, No 5, pp. 131-145, 6 fig., 2 tabl., 8 ref.

29. COLD INSULATION AND ITS DEHYDRATION (Koleisolering og dens dehydrering). G. Sandberg. Kulde. Den. (April 1962), 16, No 2, pp. 9-14, 9 fig., 7 ref. (In Swedish).

30. PLASTERING ON POLYSTYRENE FOAM. R.E. Platts. Can. Refrign Air Condg. Can. (Oct 1963), 29, No 10, pp. 26, 27, 1 tabl.

31. THE APPLICATION AND IMPLEMENTATION OF INSULATIONS. P. Clement. Rev. gen. Froid, Fr. (May 1964), 55, No 5, pp. 457-469, 13 fig., 2 tabl.

32. SOME CONSIDERATIONS OF THE EFFECTS OF INSULATION ON THERMAL STORAGE. M.V. Griffith. Annex 1964-2, Bull. I.I.R., pp. 99-106, 2 fig., 1 tabl., 2 ref.

33. TECHNICAL ASPECTS OF THERMAL INSULATION IN BUILDINGS. A.W. Pratt. Buildg Res. Sta. Current Pap., U.K. Engineering Series No 17, 10 p.

34. MOISTURE EQUILIBRIUM AND MIGRATION IN BUILDING MATERIALS. P.J. Sereda and N.B. Hutcheon. A.S.T.M. spec. techn. Publ., USA (1964), No 385, pp. 3-18.

35. CONDENSATION PROCESS IN AN INSULATED WALL (Voorkomen van condensatie in wandconstructies met een isolatielaag). G.G. Franke. Koeltechniek, Neth. (June 1965), 58, No 6, pp. 104-106, 3 fig.

36. PREDICTION OF LONG-TERM EFFECTS OF HUMIDITY ON CAST EPOXIES. R.W. Hefty. Mod. Plastics. USA (Apr. 1966), 43, No 8, p. 163.

37. NEW INSULANTS AND MODERN INSULATING TECHNIQUES. F. Mattarolo. Centro Studi per le applicazioni del Freddo, Facolta di Ingegneria, Universita di Padova, Padoue (Italie). XII Congres Int. Froid, Madrid (Sept 1967), Vol. II.

38. PROBLEMS AND TRENDS IN THE DEVELOPMENT OF SHIP INSULATION. (Probleme und Entwicklungstendenzen bei Schiffsisolierungen). K.H. Heller. Luft Kältetechn., Ger. (1966), 2, No 5, pp. 165-168, 2 fig., 3 tabl., 14 ref.

39. METHODS OF INSULATING PIPE WITH POLYURETHANE FOAMS. F.K. Brochhagen and W. Schmidt. Plast. Inst., Trans. J., U.K. (1967), 35, No 117, pp. 499-503.

40. COMPLAINTS ABOUT REFRIGERATING INSULATIONS AND THEIR REMEDIES (reklamationen bei Kälteisolierungen und ihre Vermeidung). I. Sauerbrunn, Kälte, Ger. (Sept. 1967), 20, No 9, pp. 443-449, 5 fig., 2 tabl.

41. INSULATING TECHNIQUES IN PETROLEUM AND OIL-CHEMISTRY INDUSTRY. R. Gasquet. Rev. Assn. fr. Technic. Petrole, Fr. (1968). No 187, pp. 23-32, 34.

D) MOISTURE IN MATERIALS: EFFECT ON THERMAL CONDUCTIVITY

1. ESTIMATING THE EFFECT OF MOISTURE ON THE THERMAL CONDUCTIVITY OF BUILDING AND INSULATING MATERIALS. C. Cammerer and J. Achtziger. Ziegel-industrie, Ger. (1965), 18, No 2, pp. 22-25.

2. CONTRIBUTION TOWARDS SOLVING PROBLEMS ASSOCIATED WITH VAPOUR DIFFUSION (Beitrag zur Losung von Diffusionsproblemen. I. Teil). F.L. Lovy. Kältetechnik, Ger. (Oct 1965), 17, No 10, pp. 302-308, 4 fig., 2 tabl., 4 ref., (Nov 1965), No 11, pp. 347-350, 1 fig., 1 tabl., (Dec 1965), No 12, pp. 374-378, 3 fig., 1 ref.

3. THERMAL CONDUCTIVITY OF FROZEN GAS CONCRETES (Przewodnosc cieplna gazobetonow zamrozonych). A. Stefanski. Cement, Wapno, Gips, Pol. (1965), No 5, pp. 142-146, 8 fig.

4. MAINTENANCE OF DRYNESS IN COLD ROOM INSULATION (Die Trockenhaltung von Kühlraumisolierungen). K. Seiffert. Luft Kältetechn., Ger. (1966), 2, No 3, pp. 78-83, 8 fig., 3 tabl.

5. WATER VAPOUR DIFFUSION THROUGH POROUS INSULATING MATERIAL. E. Bettanini. Istituto Fisica Tecnica e Centro Studi per le Applicazioni del Freddo, Padova (Italy). XIIth Int. Congress Refrign, Madrid (Sept 1967). Vol. II.

6. EQUATIONS FOR TEMPERATURE AND VAPOUR DIFFUSION IN THE WALLS OF A REFRIGERATED ROOM. B.R. Djakovic. University of Beograd, Faculty of Agriculture, Zemun-Beograd (Yugoslavia). XIIth Int. Congress Refrign, Madrid (Sept 1967). Vol. II.

7. CONDENSATION IN CAVITY WALLS. B.H. Vos. Institute TNO for building materials and building structures, Rijswijk, Z.H. (The Netherlands). XIIth Int. Congress Refrign, Madrid (Sept 1967), Vol. II.

8. SOME NEW POINTS OF VIEW CONCERNING CONDENSATION OF WATER VAPOUR IN STRUCTURES. B.H. Vos. Heat add Moisture Transport Division, IBBC-TNO, Delft (The Netherlands). XIIth Int. Congress Refrign. Madrid (Sept 1967). Vol. II.

9. THE EFFECT OF HUMIDITY ON THERMAL CONDUCTIVITY OF INSULATING MATERIALS (L'influenza dell'umidita sulla conducibilita termica dei materiali isolanti). E. Bettanini and G. Trapanese. Freddo, It. (Nov-Dec 1966), 20, No 6, pp. 11-16, 14 fig., 5 ref.

10. WATER VAPOUR DIFFUSION THROUGH PIPE INSULATION (Wasserdampfdiffusion in Rohrisolierungen). H. Glaser. Kältetechnik, Ger. (May 1967), 19, No 5, pp. 129-133, 4 fig., 7 ref.

11. A CONDUCTIVE SHEET ANALOGUE FOR SOLVING A NUMBER OF PROBLEMS RELATING TO WATER VAPOUR DIFFUSION THROUGH INSULATING MATERIAL. J.A. Knobbout. J. Refrign, U.K. (July 1967), 10, No 7, pp. 184-188, 8 fig., 2 ref.

12. THE CONDENSATION OF WATER VAPOUR IN PIPE INSULATIONS CAUSED BY VAPOUR DIFFUSION (Feuchtigkeitsaus-scheidung in Rohrisolierungen durch Dampfdiffusion). H. Glaser. Kältetechnik, Ger. (Jan 1968), 20, No 1, pp. 6-11, 6 fig., 5 ref.

13. THE INVESTIGATION OF DIFFUSION PROCESSES BY THE MEASUREMENT OF TEMPERATURE GRADIENTS (Die Beobachtung von Diffusionsvorgängen durch Messung des Temperaturgefälles). J.S. Cammerer. Kältetechn. Klimatis., Ger. (July 1968), 20, No 7, pp. 218-224, 7 fig., 3 tabl., 2 ref.

E) NATURAL DAYLIGHTING

1. EFFECTIVE DAYLIGHTING IN BUILDINGS--PART 1, Stephen Selkowitz, Lighting Design and Application, Feb 1979.

2. RECOMMENDED PRACTICE OF DAYLIGHTING, IES Daylight Committee, Lighting Design and Application, Feb 1979.

3. EFFECTIVE DAYLIGHTING IN BUILDINGS--PART 2, Stephen Selkowitz, Lighting Design and Application, Mar 1979.

CHAPTER V

HUMAN FACTORS

Committee:

Ralph F. Goldman, U.S. Army Research Institute of Environmental Medicine (Chairman)
Lawrence Bergland, J.B. Pierce Foundation Laboratories
Fred Rohles, Kansas State University

HUMAN FACTORS IN DYNAMIC CONTROL OF ENVIRONMENTAL CONDITION

1.0 BASIS OF COMFORT

There are two major facets to any working definition of comfort. One considers the state of mind, which is psychological comfort, and one considers the state of body, which is physiological comfort. ASHRAE has defined thermal comfort as "that condition of mind which expresses satisfaction with the thermal environment" (ASHRAE Standard 55-74). This definition requires identification of the thermal environment. Indeed ASHRAE Standard 55-74 specifies the steady state dry bulb temperature, relative humidity, mean radiant temperature and air velocity for thermal comfort (see Fig. V-1). It also includes, within the specification, a given level of clothing and activity. The other part of the definition, involving the condition of mind, is more difficult to study. In general, it has been approached by a variety of questionnaires, comfort votes, thermal sensation ballots, and other affective scales of the subjective quality of the environment based on value judgement of satisfaction or dissatisfaction (see Fig. V-2).

The thermodynamic state of the body involves assessment of the physiological balance between heat production, heat storage and heat loss. To determine this balance the following parameters must be known: mean skin temperature, rate of change of mean skin temperature, homogeneity of skin temperature at various points, skin wettedness (% sweat wetted surface area) and core temperature.

The heart rate is also an important factor, increasing in parallel with metabolic rate and therefore useful in estimating heat production, while the change in heat content is important in determining the heat storage or heat debt. The change in heat content is derived from a change in the "mean body temperature". The "mean body temperature" is obtained from various weighted averages of the skin temperature ($\overline{T}_s$) and the core temperature, ($\overline{T}_{core}$) (e.g. $1/3\ \overline{T}_s + 2/3\ T_{core}$).

The state of body aspect of thermal comfort introduces the need to be aware of individual variability in thermal responses to environment. In extreme heat, both physiology and psychology correlate almost perfectly and there is little difference between individuals. In extreme cold, again there is little variability and a good correlation exists between psychology and physiology. It is within the "thermal comfort zone" that we are most acutely aware of individual variability, in both state of body and state of mind perceptions of comfort.

The history of scientific studies of comfort predates ASHRAE, but not its predecessor organizations. The studies of comfort only really began with the ability to do something about discomfort, i.e. using some form of heating, ventilation or air conditioning. Back in the 1940's, the ASHVE produced a comfort chart which included many of the parameters we still use today. Air temperature, relative humidity and air motion were incorporated in terms of Effective Temperature lines, with a summer comfort zone differentiated from a winter comfort zone. It recognized the fact that the percentage of subjects feeling comfortable varied from zero up to as high as 97 or 98% (but not 100%) and back down to zero again as one moved across a range of Effective Temperatures. The concept of an average comfort zone, as differentiated from an optimum comfort line, also appears in the literature of some 35 years ago.

2.0 MEASUREMENTS OF COMFORT

2.1 Psychological Comfort

The classic comfort ballot, developed in the 1940's, attempted to assess the state of mind with respect to comfort. It consists of a seven point scale ranging from cold with a value of 1, cool at 2, slightly cool at 3, comfortable at 4, slightly warm at 5, warm at 6, and hot at 7. This concept has been modified and expanded:

In 1967, Gagge and Stolwijk substituted the term neutral for the original comfortable vote of 4 in the 7-category scale;

Fanger modified the comfort ballot further by setting neutral equal to zero rather than 4, and using $\pm$ 1 and $\pm$ 2 and $\pm$ 3 to cover the entire 7-point range;

Rohles added a very cold and a very hot judgement, thus shifting the neutral vote to a value of 5 and extending the scale to a 9-point scale (See Fig. V-2).

Thermal satisfaction with the environment can be taken to be the central point plus or minus one scale division (e.g. a vote of 3,4 or 5 on the original seven point scale). The widths of the three central categories of the seven point scale have been investigated in field studies. The central category (i.e., 4 on the 7-point scale) has a temperature width of about 4.7°C, while the widths of the categories just above or below the central temperature are narrower, about 3.8°C. The standard deviation of a boundary of this seven-point scale was found to be about 2.9°C for studies where several observations were taken from the same subject, and about 2.8°C from studies where only one observation per subject was made; it appears that the between subjects and within subjects variation is similar.

Other scales used, include a 5-category scale ranging from very pleasant, through pleasant and indifferent to unpleasant and very unpleasant. More recently, the concept of preferred temperature has been investigated, i.e. the temperature at which the subject requests no change in temperature. It is usually studied experimentally by direct determination of where a subject sets his temperature, or in a questionnaire by asking such questions as "would you like the temperature in here higher, just as it is, or lower?" In contrast with neutral temperature (which is the temperature corresponding to the central category of the 7 or 9-point scales of warmth) preferred temperature is apparently invariant for a given level of clothing and activity, while neutral temperature changes depending on the thermal experience of the subject group. Part of the explanation lies in the meaning of words warm and cool. In cold climates people prefer to be warm rather than "neutral" while in a hot climate, cool is seen as the desired state.

In climatic chamber investigations of comfort, it was found that the neutral temperature (T_n in °C) can be expressed mathematically as a function of the mean ambient temperature (T_m) by the relationship: $T_n = 2.56 + 0.83\ T_m$. Field surveys on thermal comfort by Humphries showed comfortable votes at ambient temperatures ranging from 17 to 32°C. More recent studies show that neutral temperature is strongly and linearly related to the mean ambient temperature. When buildings were neither heated or cooled there was a strong linear relation between the monthly mean outdoor temperature (T_m) and the indoor neutral temperature (T_n) (i.e., comfort vote 4) which follows the equation: $T_n = 11.9 + 0.534\ \overline{T}_m$. These observations cover the range from 10°C to 33°C. When heated and cooled buildings were included, a curvilinear relationship was found. While some of the variations in neutral temperature and seasonal differences are easily explained in terms of behavioral adjustments (i.e., adjustments of clothing, opening or closing of windows to manipulate air movement, etc.) a person's judgement of neutral temperature is definitely affected by his thermal experience. In chamber studies of the preferred temperature, the thermal experience with subjects just before an experiment does not generally affect the preferred temperature, nor does their general thermal experience. Preferred temperature does not appear to vary throughout the day despite the natural 24 hour rhythms of body temperature. Variation in preferred temperature between subjects has a standard deviation of 1.3°C, while the preferred temperature of a given individual measured on separate occasions has a standard deviation of about .6°C. The value of preferred temperature for a total exposure of 3 hours is 25.6°C and is the same for men and women provided the conditions are standardized (wearing 0.6 clo; <45 ft/min air motion).

Most of the recent experiments on the seven-point comfort scales have been conducted in environmental chambers with fairly rigorously controlled conditions of equal air and mean radiant temperature, low air speed, sedentary activity, and light clothing (about 0.6 clo intrinsic). As with the studies of preferred temperature, the thermal experience of the subjects just before the experiment does not affect the neutral temperature. No seasonal differences are generally found. The central categories of the seven point scale have equal psychological widths. A move from 3 to 4 represents the same change in sensation as a move from 4 to 5. The comfort votes of a sample of people are normally distributed between the vote range of 2 to 6. The category widths of the central three categories of the 7-point scale are 2.5, 3.8 and 3.1°C respectively, with a standard deviation of 2.3°C between the boundary of a vote of 3 and 4, and of 3.2°C between a vote of 4 and 5. The standard deviation of a set of comfort votes obtained from a group of people at a fixed temperature under constant standard conditions is about 0.8 of a comfort vote scale unit. If slight variations in clothing or activity are allowed, the standard deviation rises to about 1 scale unit. A given individual, measured on separate occasions, shows a standard deviation of about 1 comfort vote scale unit. His comfort vote measured at intervals of about an hour during a long exposure to a constant temperature, has a standard deviation of about 0.8 of a comfort vote scale unit. A neutral temperature, estimated from comfort votes obtained over a number of conditions, has a standard deviation of about 1.2°C. Obviously then, one must be very careful in what scales are used and must be acutely aware that psychological comfort represents a band of environmental, clothing, and air motion conditions. Thus there are a variety of factors that allow it to be manipulated.

2.2 Physiological Comfort

It is the body's responses to the four key environmental factors (air temperature, humidity or more appropriately vapor pressure, air motion and mean radiant temperature) interacting with the person's clothing and metabolic heat production which determines his physiological comfort. The metabolic heat production at rest is 1 Met or 50 kcal. m^2.hr; it increases to 2 or 3 Met with work and may be as high as 10 or 15 Met for short periods of time.

Three parameters are needed to determine the influence of clothing on comfort: 1) the insulation per se (usually expressed in clo value units), 2) the permeability index (i_m) and 3) a pumping coefficient.

Of particular interest for warmer environments is the ratio i_m/clo. This expresses the limit imposed by the clothing to the evaporative heat transfer process (i.e., the maximum sweat evaporation cooling allowed between the skin and the environment.

The pumping coefficient describes how both insulation and permeability are modified by wind speed and/or wearer motion. In essence, the insulation decreases and the permeability increases with increased air and/or wearer motion. This latter coefficient is not as yet well explored, but is heavily involved in the area of functional clothing design; simply this means that the clothing has to have some adjustability to allow maximum insulation when the individual is inactive, and maximum ventilation (to reduce insulation and increase permeability) when the subject is most active.

The physiological parameters that affect comfort include: mean skin temperature, the rate of change of skin temperature, body core temperature, the induced change in body heat content, and skin sweat secretion. The induced change in body heat content has a strong effect, and is derived from consideration of body mass, body specific heat and a mixing of skin and deep body temperature. The various mixing coefficients range from half and half for extreme cold conditions, to 0.1 skin and 0.9 core for an inactive subject in the heat.

The important factor in the skin sweat secretion is the amount of skin surface that is sweat wetted.

Mean skin temperature ($\overline{T}_S$) during comfort has been described by McNall as:

$$\overline{T}_s = 35.7 - 0.0276 \times \text{metabolic heat production}$$

while sweat secretion (SW) during comfort has been described as:

$$SW = 0.42\ (\text{metabolic heat} - 58)$$

where 58 is the metabolic rate in watts per unit of body surface area (i.e., watts per m^2). Thus, during sedentary activity people prefer a skin temperature of about 34°C, while at 3 Met of activity the preferred skin temperature is about 31°C.

Similarly, at rest people prefer no active sweat secretion (although diffusion of moisture through the skin represents about a 6% skin wettedness). At higher activity levels they prefer a sweat secretion which produces a latent heat loss of 42% of the increased heat production of the body. The required evaporative cooling (E_{req}) is the sum of the metabolic heat production plus (or minus) non-evaporative heat losses by radiation and convection. The required evaporative cooling may be larger than the maximum evaporative cooling allowed by the environment. The maximum evaporative cooling allowed by the environment (E_{max}) is limited by: 1) the difference between the vapor pressure of sweat at skin temperature (at $\overline{T}_s = 35°C$, $\overline{\rho}_s \approx 42$ mm Hg) and the ambient vapor pressure, 2) the permeability ratio of the clothing worn (usually about 30%) which allows only a percentage of the maximum potential evaporative cooling allowed by the skin vapor pressure to air vapor pressure gradiant, to be actually achieved by the body and 3) the rate of sweat production, which has a maximum of about 1 liter an hour, corresponding to a maximum evaporative cooling of about 600 kilocalories per hour or about 700 watts. The ration of E required to E maximim (E_{req}/E_{max}) has been used by Belding as a heat stress index and, as formulated by Gagge, it represents the percent sweat wetted area of the skin. For comfort, E_{req}/E_{max} (i.e., percent skin area sweat wetted) should be less than 20 to 25%.

A final factor which must be considered in physiological comfort is that the change in local temperatures, particularly those of the extremities, should be limited. Finger temperatures below 60°F and toe temperatures below about 65°F are unacceptably cold for comfort. Indeed, the usual onset of thermal discomfort is frequently triggered by the sensation of cold feet.

A great deal more could be said about the differences of comfort voting and comfort perception, using the various state of mind and state of body measurements, but the foregoing is considered adequate to introduce the potential confusion for the uninitiated.

A state definition of thermal comfort as adopted by ASHRAE for steady state conditions is presented in ASHRAE Standard 55-74. It involves an air temperature between about 72 to 78°F, with relative humidity from 30 to 70%, a mean radiant temperature equal to air temperature, sedentary or near sedentary activity level and air velocity in the 30 to 45 ft./min. range. Two levels of clothing are considered. The KSU-ASHRAE comfort envelope was developed for persons dressed in 0.5 to 0.7 clo units of clothing insulation. The ASHRAE Standard 55-74 envelope covers the 0.7 to 1.0 clo range. Adjustments are not required for time of day, season, state of acclimatization, physical fitness, state of nutrition, recency of nutrition, age or sex.

3.0 STRATEGIES FOR MODIFICATION OF STEADY STATE COMFORT CONDITIONS

Obviously, the comfort zone can be modified if one modifies: 1) the heat production of the individual (i.e., activity level); 2) his clothing; 3) the air motion; 4) the mean radiant temperature or 5) humidity. Air temperature can be offset by mean radiant temperature in a one to one relationship, i.e. a decrease of 1°F in air temperature can be offset by an increase of 1°F in mean radiant temperature. However, where one or more surfaces have temperatures which are different from those in the remaining surfaces, the asymmetric radiation field may cause severe discomfort and it is not possible to adjust air temperature to compensate. The recommendation is that wall, ceiling and floor surfaces should be held as near equal in temperature as possible (or practicable) although a maximum difference in surface temperatures of 20°F can exist without significant influence on comfort. The applicability of this recommendation to spot radiant heaters has not been adequately explored.

Clothing adjustments are also easily adopted. Levels of clothing insulation are shown in Figs. V-3 A&B. At sedentary to medium activity levels (100 to 200 kcal per hour or 105 to 135 watts) the temperature should be displaced from its normal value by 1°F for each 0.1 clo insulation deviation from the standard 0.6 clo insulation value; at higher activity levels the temperature displacement should be 2°F for each 0.1 clo insulation change. The air temperature should be increased as clothing insulation is reduced and vice versa. Starting with the 0.6 clo of clothing insulation as a base, this means that air temperature could, in theory, be increased by 4°F (leaving 0.2 clo for modesty) and decreased by up to 14°F (if people would wear 2 clo of clothing). The practicality of such clothing adjustments is sure to be tested during the coming energy crunch, and testing is required. The steady state implications of the interchange between clothing and comfort are shown in Fig. V-4. Although it seems possible that more clothing than the 1.4 clo presented could be worn, there might still be a problem of cold hands and feet.

Higher heat production by the individual obviously decreases the air temperature at which the individual will be comfortable. The effect of working heat production is most dramatic. It has been suggested that the air temperature can be decreased by 3°F for each 25 kcal per hour increase in metabolic rate above the resting level. Also, there must be the stipulation that relative humidity must be maintained at or below 60% to allow sufficient evaporation to avoid sweat accumulation and/or skin wetting with sweat.

Increasing air velocity also increases the efficiency with which the body can lose heat. The recommendation is that the air temperature be increased by 1°F for each 20 ft/min increase in velocity above 40 ft. per min. As with most of the other changes, (i.e., activity, clothing, mean radiant temperature and the like) there are limits as to how far this can be taken. For air velocity this has been spelled out to a maximum increase of 5°F in air temperature corresponding to a maximum of 100 ft. per min. increase in air velocity above the 40 ft. per min. level. Air velocity increments above this are ineffective. Also, if the air temperature itself is higher than skin temperature, increasing air velocity will simply increase the rate of heat loading and not necessarily provide any non-evaporative cooling benefit.

The time of exposure used to develop the comfort charts was 3 hours. As shown from earlier work, adaptation is quite rapid and there is no compensation for the expected actual time of occupancy. However, within certain limits, fluctuating conditions are allowable. If the maximum peak to peak dry bulb temperature variations are greater than 2°F, their peak to peak variation should not be greater than that calculated by the following relationship

$$\Delta T = 15 * \sqrt{PERIOD}$$

Relative humidity fluctuations of 10%, with rates of change of less than 20% per hour are also acceptable.

The extent to which a strategy of physically conditioning or specifically acclimatizing the subject to heat or cold conditions will be successful is unknown. However, there is no question that the first day of warm weather is sensed as less acceptable than the same conditions at the end of a summer. Similarly there is a natural acclimation to cold which occurs over a winter season. While these do not change things much in the normal comfort zone, the altered perceptions at the boundaries of the comfort zone are certainly modulatable by the physiological changes which accompany altered acclimatization to heat or cold. Incidentally, acclimatization to heat and cold can coexist since they involve rather different mechanisms. Finally, within the comfort zone it would probably not have much effect, but as one approaches the outer bounds of the comfort zone, the extra heat production which follows feeding (specific dynamic action preferably termed the thermogenic effect of feeding) or the change in heat content which can be induced by drinking a pint of hot or cold beverage (i.e., coffee or tea at 65°C or cold lemonade or iced tea at 1 or 2°C) can modulate body temperature. The effects at the boundaries of thermal discomfort are unknown but it is recognized that we can alter heat content by some 14 kilo-calories when a pint of liquid is ingested at about 30°C above or below body temperature. This amounts to roughly a 0.4°F change in mean body temperature. Studies which involve letting environmental conditions drift to the edge of the discomfort zone, offer the most potential for modulating the boundaries of discomfort by these various intervention strategies.

Most of what has been discussed so far is state of the art and reasonably well validated. However, some of the strategies for steady state modulation of comfort, as suggested above, might profitably be the subject for specific research. These will be addressed after we conclude our discussion of prediction models for steady state, and the possibilities for comfort under dynamic control of the environment.

4.0 CURRENT COMFORT PREDICTION MODELS

Just as buildings can be modeled to predict energy flows, inside air and wall temperatures, the effects of weather, ventilation and many other aspects, people can be modeled to predict their thermal and psychological responses to the environment. The simulation of buildings using such models as the NBS Predicted Indoor Habitability Index (PIHI), has become a necessity for the successful thermal and economic design of buildings. Human simulation is becoming an equally valuable tool to assess the comfort aspects of a space or the heat and cold stress potential of an environment. Human thermal simulation models are of various types. Some are empirical and therefore, limited to conditions similar to the underlying tests. Some are rational with a broader range of applicability and many are a combination of the two. Some of the models predict physiological responses and other models predict just the comfort response of people. A few predict both comfort and physiological responses. An example of some of the empirical models is the Goldman-Givoni model which is a physiological predictor. It can predict rectal temperature, skin temperature, sweat rate, metabolic rate and heart rate from environmental conditions. It is widely used throughout the world to predict the response of individuals to various environments. Another model which is primarily empirical is the Belding heat stress equation or heat stress index HSI. This model predicts the sweat rate of an individual and forms a ratio of this predicted sweat rate to the maximum rate at which water can evaporate from the skin in the environment. The ratio is used as an indicator of the stress that the environment imposes. It is widely used in industrial situations for predicting stress and comfort. Another empirical method is to use the comfort regression equations developed by Nevins, Rohles and McNall at Kansas State University. The equations are based on comfort test results from a large number of subjects in various standard situations. With the appropriate equation and the temperature and humidity, the thermal sensation (hot, warm, slightly warm, neutral, slightly cool, cool, cold) of an average person can be predicted.

In the rational model category there are three models which predict comfort. They are the Fanger model, the KSU model, and the Pierce model. The KSU and Pierce models also predict physiological responses to the environment.

The mathematical model developed by P.O. Fanger is the oldest and probably the most well known and widely used of the comfort models. The model makes a rigorous analysis where all of the energy loss mechanisms from the body are quantified, but with the skin temperature and evaporative sweat rate constrained to correspond to those of a comfortable person. The calculations quantitize the respiratory heat loss, the heat loss to convection, radiation and evaporation and also to diffusion through the skin. The effects of work efficiency and clothing are also included. The calculated heat loss is then compared to the person's total metabolism. If the person is to be comfortable, then according to the Fanger theory, the heat losses should equal metabolism. If the losses are greater than metabolism the person feels cold. If the losses are less than metabolism the person would be gaining heat and feeling warm. The thermal sensation then is a graded response to the deviation between losses and the metabolic rate. The relationship between this difference and thermal sensation is based on data from 1400 subjects at Kansas State University and the Technical University of Denmark. The calculated thermal sensation is called the Predicted Mean Vote or PMV. The computations involved for a PMV solution to one environmental condition are rather time consuming if done by hand and not very appealing for every day engineering applications. To make the PMV determinations less tedious Fanger prepared tables of PMVs for various combinations of activity, clothing, and environmental conditions. The tables make thermal sensation predictions quite manageable so that for a particular situation the PMV can usually be determined in less than 10 minutes. Another very useful feature of the Fanger comfort model is the prediction of the percentage of persons' dissatisfied (PPD) with the environment. The criteria used here is that when an individual feels slightly warm or slightly cool he would also be dissatisfied with the environment. From the distribution of votes at any given condition or PMV, Fanger determined the percent that would be dissatisfied based on this criteria. Therefore, by calculating the predicted mean vote for an environment one can determine the percentage of persons likely to be dissatisfied with the environment. This is a very useful engineering tool for determining the acceptability of a space. It is the only model that currently has this feature. Fanger's analytical methods for predicting thermal sensation were developed for steady-state conditions near thermal neutrality. The accuracy of the predictions may deteriorate as conditions deviate from comfort.

In an effort to formulate a new rational effective temperature scale A.P. Gagge developed a simple mathematical model of the human thermal regulatory system. The resulting new Effective Temperature scale (ET*) has been adopted by ASHRAE. Gagge's experimental work at the Pierce Foundation Laboratory showed that skin temperature is a good indicator of both thermal sensation and comfort in cold environments, but at conditions where sweating occurs, skin temperature changes are small and in this region skin wettedness or the fraction of the skin surface covered by water is a better indicator of discomfort than skin temperature. To predict skin temperature and skin wettedness in any environment, Gagge developed a physiological thermal model of a standard man suitable for low and medium activity levels. The model was a simplification of more complicated thermal regulatory models previously developed by Stolwijk (7). The simple lumped parameter model considers man as two concentric thermal compartments, one compartment representing the skin and the other representing the core. The temperature within a compartment is assumed to be uniform so that the only temperature gradients are between compartments. All of the metabolic heat is assumed to be generated in the core compartment of the two-node model. In the cold, shivering and muscle tension may generate additional metabolic heat. This increase is related to skin and core temperature depressions from their set point values. The core loses energy when the muscles do work on the surroundings. Heat is also lost from the core through respiration. This model uses Fanger's method for calculating the respiratory heat losses. In addition, heat is conducted passively from the core to the skin. This is modeled as a massless thermal conductor. The controllable heat loss path from the core consists of pumping variable amounts of warm blood to the skin for cooling. The heat reaching the skin is dissipated by the conventional means of convection, radiation, evaporation of sweat and the diffusion of water through the skin to the surrounding environment. If there is clothing, all heat and vapor flowing from the skin are assumed to have passed through this impedance. By considering the preceding discussion about heat production and dissipation mechanisms an energy balance can be written on the skin and core compartments.

Core:
heat + shivering = work + respiration + conduction + convection by blood + the rate of increase in internal energy of the core.

Skin:
heat from the core = radiation + convection + diffusion + evaporation + the rate of increase of internal energy of the skin.

The equations can be rearranged as first order differential equations for skin and core temperature. These differentials can be numerically integrated to find the skin temperature and core temperature at any time. The model also determines the rate of weight loss and skin wettedness. To determine the thermal sensation, the Pierce model calculates the temperature of a standard environment that would produce the same physiological strain. The person in the standard environment would have the same skin temperature and skin wettedness and transfer the same amount of heat as in the actual environment. The standard environment was chosen to be rather typical of man's indoor environment (50% RH, still air, wearing 0.6 clo). Then from the standard effective temperature representing the physiological strain of the actual physical environment one can use the regression equation, based on extensive testing at Kansas State, to predict the thermal sensation. Since the thermal sensation data base is from sedentary subjects, the accuracy of the predicted responses would be expected to deteriorate at higher activity levels. At the higher activity levels or during transients, thermal sensation can be predicted from an adjusted skin temperature. The Pierce model also predicts the level of discomfort a person will experience in a particular environment. The discomfort scale ranges from comfortable to very uncomfortable. In warm enviroments discomfort increases less with increasing temperature than does thermal sensation. Discomfort is predicted from mean body temperature.

The human thermal sensation prediction model developed at Kansas State University was first published in 1974. The form to be discussed here is an improved version published in 1977 (8). It is a two-node model and except for the prediction of thermal sensation is basically similar to the Pierce two-node model. The control equations for sweat rate and blood flow are only slightly different. The major difference is in how the KSU model predicts thermal sensation. In cold environments it predicts thermal sensation from changes in overall conductance between the core and the skin. That is, the passive conductance plus the conductance due to blood flow. In warm environments thermal sensation is predicted from changes in skin wettedness.

The comfort model by Fanger and the two-node models by Pierce and KSU do quite well for steady-state uniform environments. The two-node models are also good predictors for transients into warm environments. However, in cold or asymmetric environments or during heavy exercise the single skin and core compartments of the two-node model with their uniform temperatures are too simplified to adequately model the physics and physiology. In the cold to preserve the temperature of vital organs, blood circulation to the appendages may be reduced. This action causes a drop in temperature of extended peripheral areas resulting in nonuniform skin and core temperatures. Under asymmetric conditions physiological strain as well as skin and core temperatures may not be uniform. For these cases the simulation model should have about as many compartments or as many body segments as the human. Stolwijk (7) has developed a successful multi-node, multi-body segment model. In his model each segment is composed of a skin, muscle, fat and core compartment. The Stolwijk model predictions of skin and core temperature and evaporative weight loss and metabolic rate agree quite well with experimentally measured values. Montgomery has modified and applied this model to simulate a cold water diver. With this modification he has been successful in predicting skin temperatures of the finger and abdomen of working divers. To date these more complicated multi-node models have not been programmed for comfort or acceptability predictions nor for the effects of clothing. There are many applications in hot industries where the multi-node comfort model could be of benefit for assessing and reducing the stress and discomfort of a work space. The multi-node comfort model could also be applied to the problems of comfort for sedentary persons working and living in energy conserving environments such as the 18 to 20°C currently being advocated. With these models, various types of spot heating and local increases in clothing insulation could be explored for design purposes.

The three comfort models reviewed are similar in that they all use the heat balance equation together with some physiological parameters to predict the thermal sensation of a person in an environment. The Pierce and KSU models couple the energy balance with a physiological thermal regulatory control system. All three predict neutral conditions well for various envionments. As conditions deviate from the neutral, the predictions by the two-node model are more accurate. The KSU and Pierce models also have some transient capabilities. There are other considerations as well. The Fanger model predictions can be made from prepared tables and graphs. This model also predicts the percentage of persons dissatisfied in an environment. To the practicing engineer seeking to make a thermal sensation prediction for a particular situation, the KSU and Pierce models are more formidable and require computer assistance. The KSU and Pierce models give a rather complete prediction of the thermal physiological response or state of a person, providing estimates for sweat rate, skin and core temperatures and skin wettedness. This information is often essential for heat and cold stress applications. For accurate predictions of human response to cold or asymmetric environments, or during heavy exercise, the more complicated body segment multi-node models are better models thermally and physiologically. Comfort assessment capabilities should be added to these as there are many industrial and residential applications for which the simpler models are inappropriate.

Another model of a different sort is the Predicted Indoor Habitability Index developed by Powell, Kusuda and Hill (10). The development of this index was undertaken to help decide when air conditioning was justified in residential structures. With NBSLD they predicted the conditions inside an unairconditioned apartment. From the predicted inside condition they determined various parameters associated with comfort and heat stress such as predicted mean vote, effective temperature, heat stress index and the thermal sensation from the KSU regression equations. Then they correlated these various comfort parameters with the outside weather such as maximum air temperature, wet bulb, daily mean temperature, etc. The correlation of the KSU thermal sensation with the mean daily temperature was about the best but it still contained a great deal of scatter. A multiple correlation is probably called for to correlate maximum thermal sensation with mean daily temperature, absorbed solar energy, and building characteristics such as mass and orientation.

As indicated, some validation of the various models has been undertaken but more is needed. The human models are somewhat in the same position as building model validation. Certainly the comfort models have not been adequately validated for slowly changing conditions as in temperature drifts.

5.0 DYNAMICS STATE

ASHRAE Standard 55-74 "Thermal Environmental Conditions for Human Occupancy" specifies the conditions for comfort steady-state criteria. While it does not identify the factors to be considered in unsteady or dynamic conditions, three variables must be defined. These are a) the basal temperature (T_B) about which the temperature fluctuates; b) the amplitude (A) of the temperature change; and c) the rate (R) that the temperature is changing. The dynamic response also must be considered in light of three conditions: a) discrete relationships i.e., the thermal conditions that one experiences when going from one locale to another - the house to the automobile to the office; b) the cyclical variation of the thermal conditions which are a function of the furnace cycling, or thermostat accuracy; and c) the ramp condition - the thermal conditions that one experiences when the temperature of a space is allowed to drift, i.e., permitting one's house to cool down following the night set-back of the thermostat. Each of these conditions, the discrete step change, the cyclic change and the ramp, will be considered separately in light of our present knowledge and suggested strategies for delaying the period of discomfort.

5.1 Discrete Exposures

The "super-market effect" represents an excellent example of the discrete exposure condition. This is characterized by the complaint of coolness that is universally voiced when people go into air conditioned stores from outside during the summer. As such, the question arises - for whom do you air-condition - the customer or the employee? Research on this question has shown that if the store environment is comfortable for the employees - 74°F/4% RH - the customer, upon entering this climate from the 90°F outdoors will feel cool, but probably for no longer than 5 to 10 minutes. Thus, the discrete condition is of little engineering significance.

5.2 Cyclical Conditions

A series of ASHRAE-supported tests have recently been completed at Kansas State University which has examined the responses of lightly clothed sedentary humans at a variety of basal temperatures, amplitudes and rates under cyclical conditions. This analysis, when complete, will provide models for predicting the thermal sensations at the high and low points of the cycle both when the cycle is initially decreasing and then increasing and when it is initially increasing and then decreasing. These relationships are pictured graphically in Fig. V-5. The equations for predicting the thermal sensation (TS) are presented below; the coefficients of determination (i.e., the correlation coefficient squared) range from 0.94 to 0.96 for these equations.

<u>Regression Equations</u>

$$TS/a+ = -8.673 + .183\ T_B + .172A - .149\ r_1$$

$$TS/a- = -6.921 + .162\ T_B - .228A - .178\ r_1 + .212\ r_2$$

$$TS/d- = -6.703 + .153\ T_B - .085A - .065\ r_1$$

$$TS/d+ = -9.395 + .192\ T_B + .137A - .121\ r_1 + .045\ r_2$$

where:

TS/a+ = Thermal Sensation; Mode: ascending; temperature: maximum
TS/a- = Thermal Sensation; Mode: ascending; temperature: minimum
TS/d- = Thermal Sensation; mode: descending; temperature: minimum
TS/d+ = Thermal Sensation; mode: descending; temperature: maximum

T_B = basal temperature (°F)

A = amplitude - (peak-to-peak in °F)

r_1 = initial rate (°F/hr)

r_2 = subsequent rate (°F/hr)

TS category ratings are: 1=very cold; 2=cold; 3=cool; 4=slightly cool; 5=neutral; 6= slightly warm; 7=warm; 8=hot; 9=very hot. These equations do not consider other features of the thermal environment which may also change i.e., humidity, air motion and radiant heat loads. When completed the results of the study will also predict thermal comfort, the weighted mean skin temperature and the percentage of occupants who will be comfortable under various combinations of the independent variables.

5.3 Ramp Conditions

Numerous studies have been conducted to determine man's response to both increasing and decreasing thermal conditions. In general, the results demonstrate that, for sedentary persons, slow temperature drifts (± 0.5°C/hr) about the thermal neutral temperature are almost indistinguishable from the traditionally preferred, constant temperature conditions. The neutral temperature is determined by the clothing level of the occupants in the space; about 24.9°C for 0.5 clo, 24.2°C for 0.7 clo and 23.5°C for 0.9 clo of clothing insulation. According to our studies, a 0.5°C/hr drift which causes the ambient temperature to deviate from the neutral point by 2°C will only reduce thermal acceptability to about 80%. With faster rates of temperature change, the permissible deviation for 80% acceptability is larger. The 8 hour ramp studies at high and low humidity levels indicate that, for sedentary applications, humidity effects can be expected to be small when applying slow rates of air temperature change, as long as the dew point is below 20°C.

These results provide a basis from which to formulate energy conservation and load shedding strategies that consider occupant comfort and thermal acceptability. For example, large office buildings whose interior zones need cooling all year could consider allowing temperature to ramp during the working day from 22 to 27°C in the summer, when the people normally wear light weight clothing, from 21 to 26°C in the spring and fall, and from 20 to 25°C in the winter when people wear warmer office attire. Such drifting schedules could make good use of the outside air for cooling (economizer cycle). The savings potential will depend on the building, local climate and internal loads. Presumably the acceptance level would be improved over those found in this study if the occupants made clothing adjustments, like adding or removing a sweater, as a normal population might be expected to do during the course of a temperature drift. Temperature drifting is particularly attractive for existing buildings where energy conservation possibilities are more limited than in the design of a new building.

It should also be pointed out that the equations from the KSU Study for predicting the thermal sensation at the maximum temperature for the ascending mode (TS/a+) can be used for increasing ramp conditions; conversely, the equation for predicting (TS/d-) can be used for estimating the thermal sensation for decreasing ramp conditions.

In view of these findings, the ramp condition or drift appears to be a most fruitful area for examining strategies for maintaining thermal comfort. Starting from a comfortable thermal condition, an individual will become progressively uncomfortable as the temperature rises. When he becomes uncomfortably warm (warm discomfort) he can employ several strategies. First he can decrease the humidity level, which for all practical purposes is probably unrealistic. Second, he can increase the air velocity in his work station by the use of fans. Finally, he can remove as much of his clothing as is practical. If these fail to reduce his discomfort, the ambient temperature must be reduced. However, shielding of any radiant heat sources should be the first strategy before the actual thermostat setting is reduced.

In the area of cool discomfort, opposite behaviors are suggested. For example, when the temperature decreases from a comfortable condition to an uncomfortable condition, the humidity level can be increased; as in warm discomfort, this is probably impractical. Second, he can put on more clothes, then he could increase his metabolic rate by getting away from his desk periodically or spend some time in a warmer area. Finally, increasing the air temperature is an option, but use of radiant heat (open window blinds or local radiant heaters) should be considered before the room air thermostat setting is raised.

The relative effectiveness that these strategies enjoy, either individually or collectively, in minimizing thermal discomfort has not been explored systematically. Moreover, the few studies which have been conducted require validation. Study of these strategies represent areas of needed research.

6.0 SUMMARY OF RECOMMENDED RESEARCH RELEVANT TO ENERGY CONSERVATION

6.1 Studies of Off Design Conditions for Steady State Environments

1. Validation of steady state models at the boundaries and outside ASHRAE 55-74.
2. Utility and acceptability of improved insulation in extending comfort to cooler temperatures.
   a) The value of warmer footwear, since onset of thermal discomfort sensation is cold feet; what is the equivalent ΔT_A effect of 0.1 clo of footwear.
   b) altered clothing levels for men and women in general.
   c) value of wearing a warm hat to minimize heat loss from head.
3. The minimum air temperature, given adequate clothing elsewhere for unimpaired manual dexterity; estimated to be about 58°F.
4. The effects of vapor barrier or reduced permeability clothing on the lower boundaries of comfort temperature.
5. Effects of acclimatization/acclimation on the upper and lower boundaries of comfort.
6. Effects of short occupancy or sudden transients across the comfort zone.
7. Development and evaluation of such indices as the predicted indoor habitability index (PIHI of Natl. Bureau of Standards) and the Air Distribution Performance Index (ADPI of ASHRAE).

6.2 Studies of Auxiliary Heating and Cooling

1. Use of local auxiliary heat (convective or radiant) to the hand or foot area of the working station.
2. Use of overall auxiliary heat (convective, radiant, conductive - e.g. electric blanket) for specific work areas, rest areas (TV viewing; nursing; home bed or bedside chairs) etc.
3. Use of auxiliary cooling: air jets, cool cushions, evaporative coolers, etc. focused at the work site.

6.3 Studies of Design Conditions for Dynamically Altering Environments

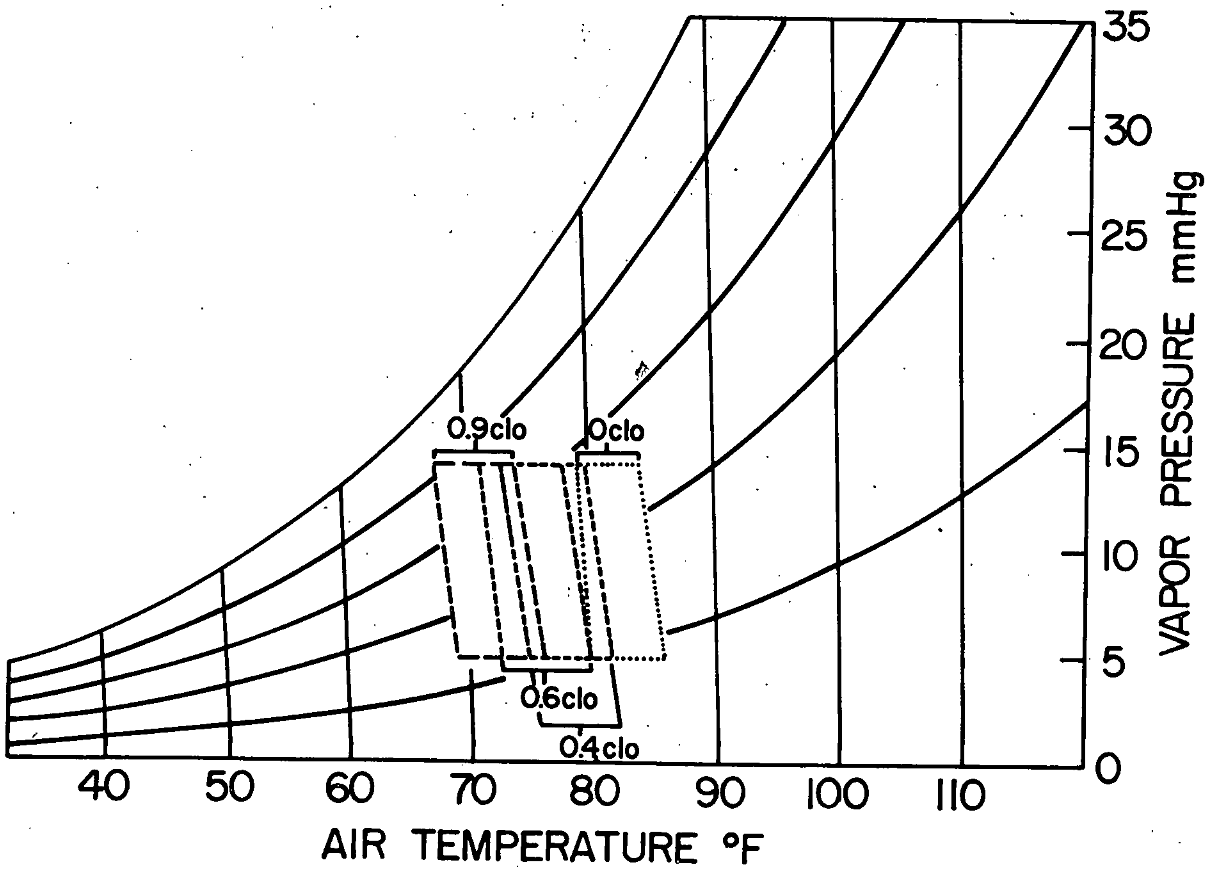
1. Applicability of steady state models to slow drift ramps.
2. Validation of dynamic response comfort prediction model.
3. Applicability of the dynamic cycles model to ramps.
4. At dynamically reached boundaries of comfort, explore adjustments of:
   a) clothing
   b) air motion
   c) relative humidity
   d) mean radiant temperature
   e) hot/cold drinks
   f) work/rest cycles; work space-recovery room times of exposure (recovery); or even cross over from perimeter to building core working areas which may be at opposite ends of the comfort boundaries for hot and cold conditions.

REFERENCES

1. Givoni, B. and R.F. Goldman. Predicting effects of heat acclimatization on heart rate and rectal temperature. J. Appl. Physiol. 35:875-879, 1973.
2. Belding, H.S. and T.F. Hatch. Index for evaluating heat stress in terms of resulting physiological strains. ASHRAE Trans. 62: 216-236, 1956.
3. Nevins, R.G., F.H. Roheles, W. Springer and A.M. Feyerherm. A temperature-humidity chart for thermal comfort of seated persons. ASHRAE Trans. 72(I): 283-291, 1966.
4. McNall, P.E., Jr., J.Jaax, F.H. Rohles, R.G. Nevins and W. Springer. Thermal comfort (thermally neutral) conditions for three levels of activity. ASHRAE Trans. 73(I),1967
5. Fanger, P.O. Thermal Comfort, McGraw-Hill (New York), 1972.
6. Gagge, A.P., J.A.J. Stolwijk and Y. Nishi. An effective temperature scale based on a simple model of human physiological regulator response. ASHRAE Trans. 70(I), 1970.
7. Stolwijk, J.A.J. A mathematical model of physiological temperature regulation in man. NASA-9-9531. September 1970.
8. Azer, N.Z. and S. Hsu. The prediction of thermal sensation from a simple model of human physiological regulatory response. ASHRAE Trans. 83(I), 1977.
9. Montgomery, L.D. Simulation of Heat Transfer in Man Under Immersed Conditions. Ph.D. dissertation. University of California, Los Angeles, 1972.
10. Powell, F.J., T. Kusuda and J.E. Hill. Predicted Indoor Habitability Index. National Bureau of Standards, 1974.

Fig. V-1 COMFORT ZONES FOR SEDENTARY OR SLIGHTLY ACTIVE PERSONS

Clo	Typical Indoor Attire for the Season of	Description
0.9	winter	heavy slacks, long sleeved shirt, sweater or jacket
0.6	spring-fall	long sleeved shirt, skirt or trousers
0.4	summer	Short light dress, light trousers, short sleeved shirt
0		no clothing



Vote No._______ Test No. _____

Name & No. ____________________________

____

Circle the number beside the adjective that best describes how you feel.

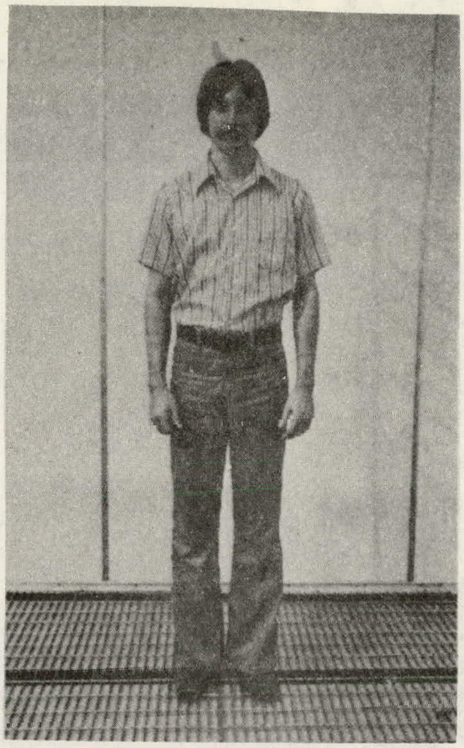
9	Very hot
8	Hot
7	Warm
6	Slightly warm
5	Neutral
4	Slightly cool
3	Cool
2	Cold
1	Very cold

Name ______________________________________ Test No. _________

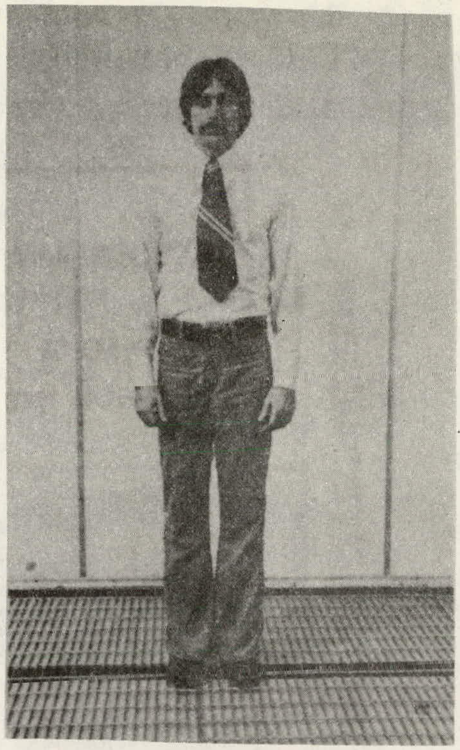
Vote No. _________

comfortable	___:___:___:___:___:___:___:___:___	uncomfortable
bad temperature	___:___:___:___:___:___:___:___:___	good temperature
pleasant	___:___:___:___:___:___:___:___:___	unpleasant
good ventilation	___:___:___:___:___:___:___:___:___	poor ventilation
unacceptable	___:___:___:___:___:___:___:___:___	acceptable
uncomfortable temperature	___:___:___:___:___:___:___:___:___	comfortable temperature
satisfied	___:___:___:___:___:___:___:___:___	dissatisfied

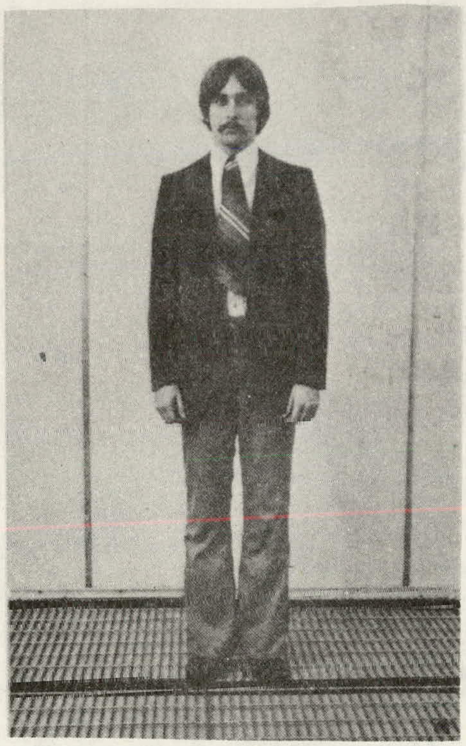
Fig. V-2 The nine point comfort vote and seven item semantic differential scale ballot used at KSU by Rohles



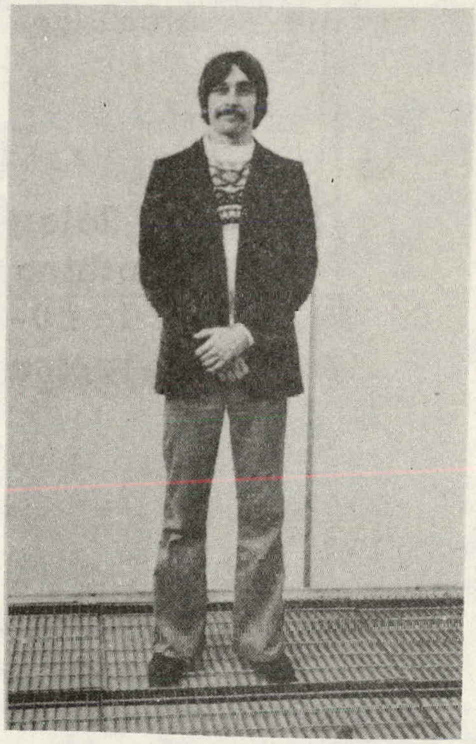
0.3 0.4 clo
Summer - FEA



0.4 0.6 clo
Summer - Normal

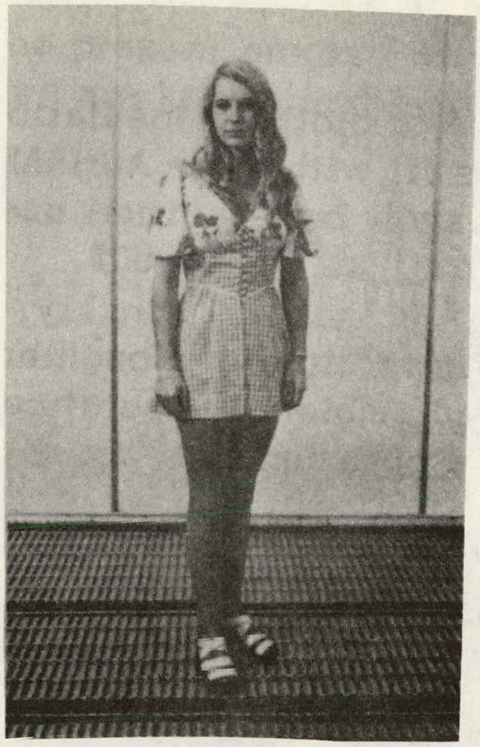


0.7 0.9 clo
Winter - Normal

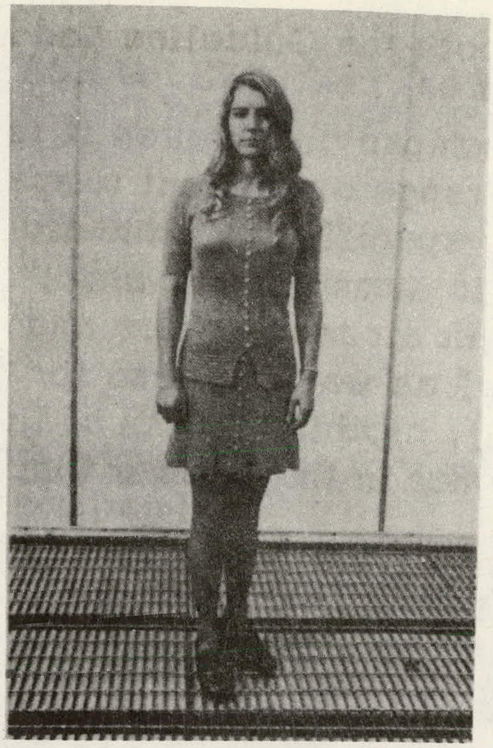


1 1.1 clo
Winter - FEA

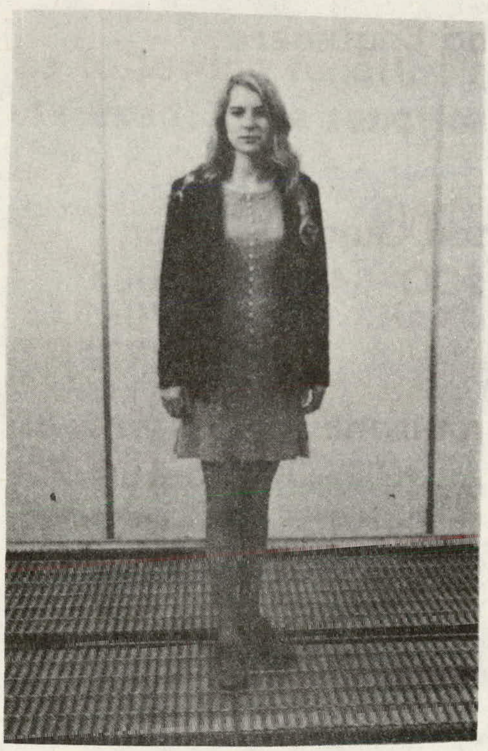
Fig. V-3A Clothing Ensembles for FEA Summer and Winter Guideline Temperature Ranges



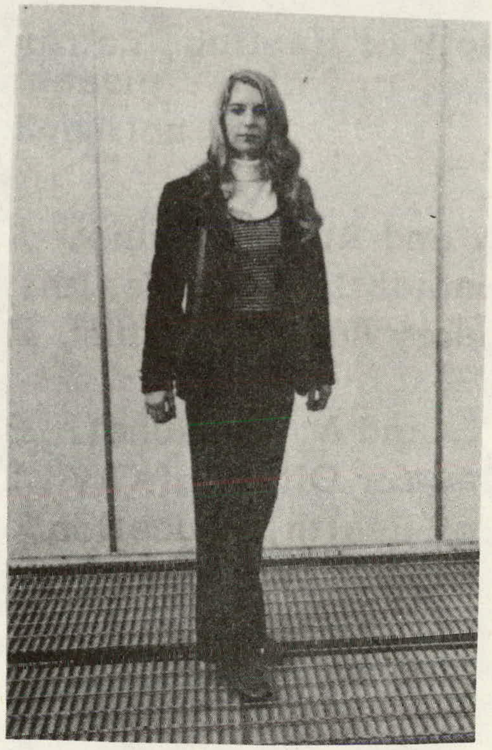
0.15 0.25 clo
Summer - FEA



0.4 0.5 clo
Summer - Normal

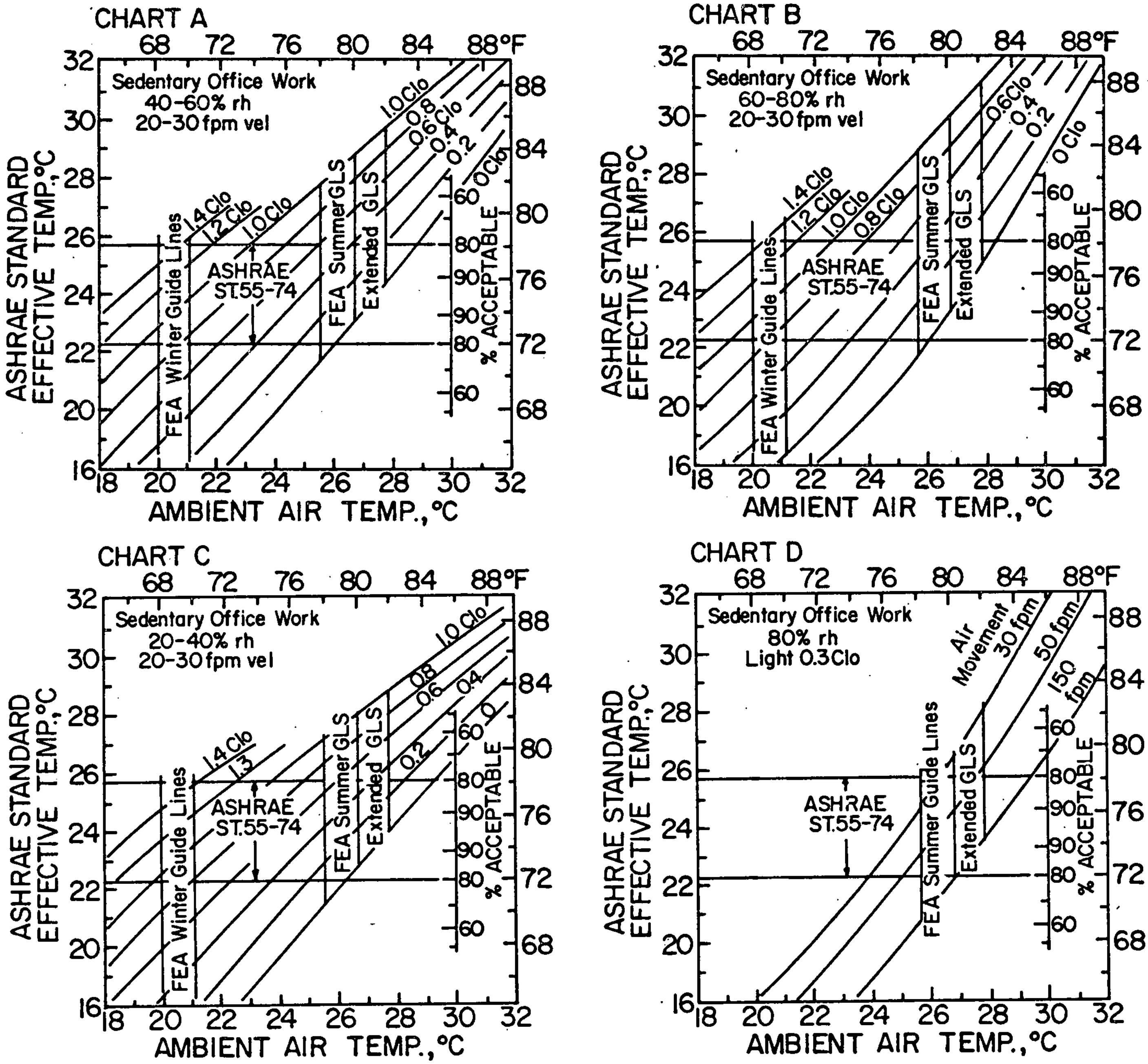


0.7 0.8 clo
Winter - Normal



0.9 1.1 clo
Winter - FEA

Fig. V-3B Clothing Ensembles for FEA Summer and Winter Guideline Temperature Ranges



[a]The range for 80% acceptable is shown by two horizontal lines between 72 and 78F (22.2 and 25.6°C) on ordinate, as specified by Standard 55-74A. Chart A describes conditions for normal air movement and average humidity; for the locus with 0.6 clo, ET* always equals T_a by definition; Chart B describes conditions with high humidity, as might occur during summer in New York or the tropics; Chart C covers low humidity conditions, as would occur indoors in winter or in desert areas; Chart D shows the effect of air movement, such as would be expected from a ceiling fan, For practical application of charts, optimum clothing insulation is shown that should be worn when offices are conditioned under FEA Summer and Winter Guidelines' temperatures necessary for energy conservation.

Fig. V-4 Evaluation of ASHRAE Standard ET* for Sedentary (Office Work), in Terms of Ambient Air (or Adjusted Dry-Bulb) Temperature, Clothing Insulation (I_{cl}), Relative Humidity, and Air Movement[a]

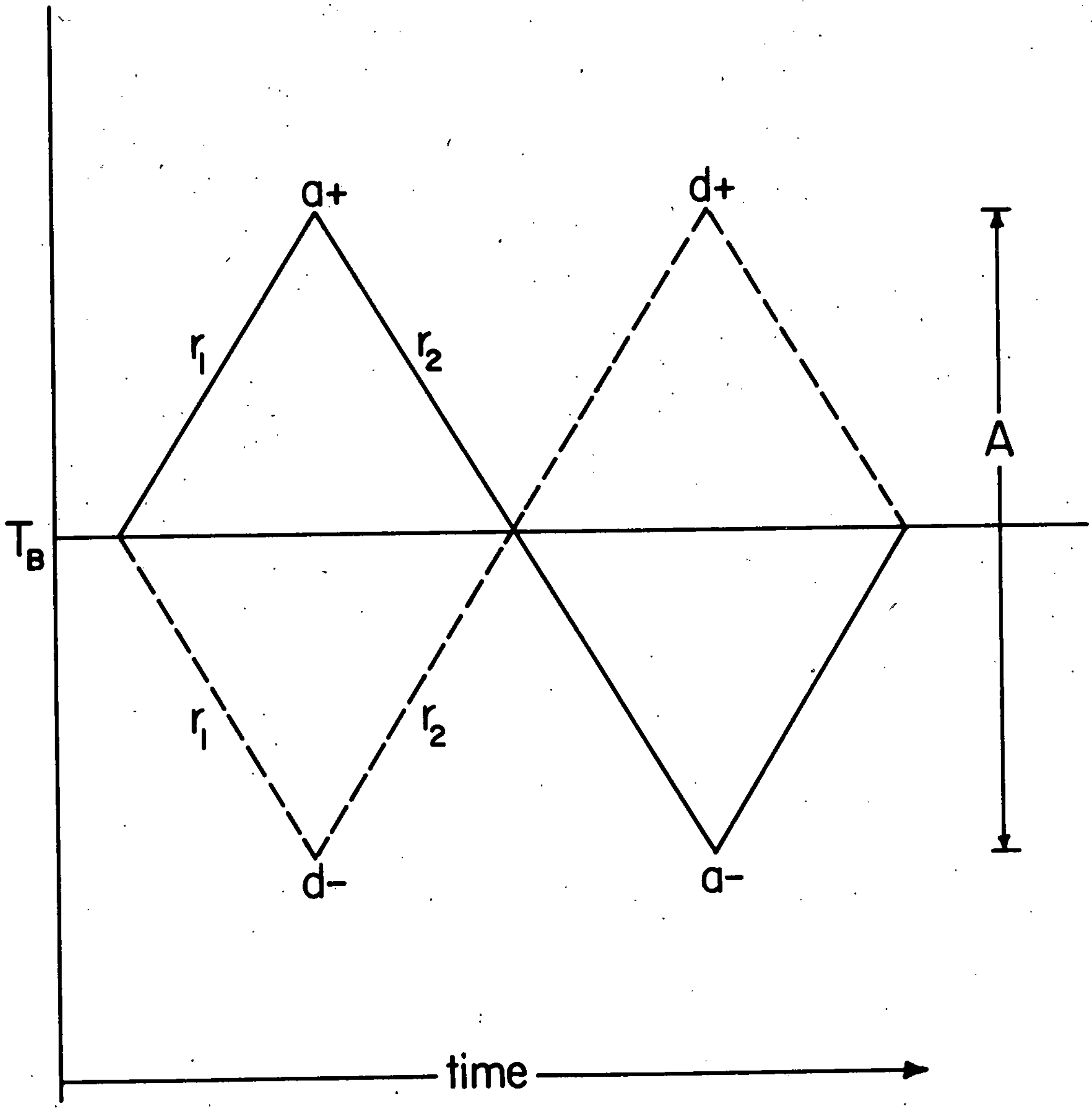


Fig. V-5 Schematic Representation of the Conditions of the Cyclical Study

CHAPTER VI

CIRCULATION/DISTRIBUTION

Committee:

Herman F. Behls, Sargent & Lundy (Chairman)
Harold E. Straub, Environmental Elements Corporation
J. Richard Wagner, The Poole and Kent Company
Frederick B. Morse, Purdue University

AIR/HYDRONIC CIRCULATION

1.0 INTRODUCTION

The process of moving air and water through a building is extremely dynamic. If the dynamic response of systems, components, and controls were taken into account significant variation in energy requirements would be observed. Typically the design engineer selects either an all-air system, air-and-water system, or all-water system based on the type of structure, space, and economics. However, to include minimum energy requirements in the analysis requires either 1) a dynamic simulation of structure, equipment, air/hydronic circulation, and controls, or 2) an energy budget study to establish incremental energy differences due to systems, equipment, and controls.

2.0 HVAC SYSTEMS

Common HVAC (Heating, Ventilating, and Air-Conditioning) systems designed and installed are:

1. All-Air Systems[1]

   a. Single-Path Systems:
      Single Duct, Constant Volume
      Single Duct, Variable Volume
      Single Duct, Reheat

   b. Dual-Path Systems:
      Dual-Duct, including Dual-Duct Variable Volume
      Multizone

2. Air-And-Water Systems[2]

   These systems are comprised of central air-conditioning equipment, a duct distribution system, and a room terminal. The hydronic circuits may be either two-pipe, three-pipe, or four-pipe arrangements.

3. All-Water Systems[3]

   These systems accomplish cooling solely by distributing chilled water to terminals located in the habitable spaces throughout the building. Dehumidification occurs at the terminal unit.

---

[1]ASHRAE Handbook, 1976 Systems, Chapter 3

[2]ASHRAE Handbook, 1976 Systems, Chapter 4

[3]ASHRAE Handbook, 1976 Systems, Chapter 5

Each system has its own characteristics. Some systems utilize energy more efficiently than others, all have a definite dynamic response to a specific building. The effect of time lag depends on the type of HVAC system being considered. The time lag or system response is most pronounced in systems using on-off fan control. Here, the system starts from rest with unconditioned air which must be circulated through the space and back to the heat exchanger. In constant flow variable temperature systems, the problem of startup is eliminated but the effects of variable temperature remain. Variable volume/constant temperature systems are least affected by thermal time lag. Except for the slight effects of variable flow rates on heat gains and losses through the duct walls, variable flow systems are in thermal equilibrium.

3.0 HVAC SYSTEM CONSIDERATIONS

Factors other than the basic system, such as the 1) supply ductwork, 2) return air ductwork, 3) hydronic piping, 4) terminal boxes, 5) coils, and 6) fans, are discussed herein to demonstrate the need to consider all factors when establishing the overall dynamic response of a system designed for a specific application.

3.1 Duct Network Design

Duct systems are usually designed for steady state, design-load conditions. Even in constant flow systems, this does not assure optimum results with regard to overall system first cost, performance, and operating economy. The determination of duct pressure losses is an area which frequently receives too little attention. One reason is that, in spite of recently renewed efforts, the design data on duct fittings which is available to designers is still rather limited. It is not uncommon to have significant differences between calculated conditions and those which occur in the field. Quality of workmanship has a pronounced effect on the performance of individual duct systems. Presently, there is consideration toward standardized duct fittings by ASHRAE Technical Committee 5.2, AIR DUCT DESIGN & CONSTRUCTION, to minimize the need for completely customized duct systems on every job and to assure predictable system responses.

In variable air volume (VAV) systems, the optimization of duct network layout and design by manual calculations would be prohibitive, if not impossible. To fully analyze such systems, the dynamic load changes of the building must be considered. Also, the dynamic performance characteristics of the terminal boxes are a factor. The economics of operation which VAV systems offer is only realized when the load changes in the space are reflected back to the fan and the fan operates at both the minimum required flow and pressure. The layout and sizing of the duct system affects the pressure requirements. Ideally, it should be possible to reduce the required fan pressure as the system flow decreases. However, this rarely occurs because of some long duct run which needs full pressure at all times.

In the past, return air duct systems have been treated as an "orphan." Return air duct networks must be designed in the same detail as the supply system when considering system dynamics. A return duct system, both ducted and non-ducted, must pick up air at a temperature which is representative of the space load or at least not detrimental to the operation of the system. This necessitates a dynamic simulation of the air distribution within a space, including the size and location of return air inlets with respect to the space heat gains and losses. Non-ducted returns are another matter. They frequently involve ceiling plenums which are highly subject to leakage and infiltration of unconditioned air from outside of the controlled area. Ceiling returns on top floors are particularly susceptible to high heat gains from the roof. The performance of return light troffers is still not very well established, even under steady state conditions. Under actual field conditions, they are frequently affected by short-circuit air paths within the space which, therefore, diminish their effectiveness.

The duct layout should recognize areas which have special heating or cooling requirements which do not match those of the surrounding areas. If providing for these special areas will have a detrimental effect on the overall performance of the system, they then should be segregated and handled separately.

A condition which is frequently overlooked when designing VAV systems is that they operate at full flow during startup and at any other time when the proper temperature supply air is not available. Diversity does not exist under those conditions. If diversity was considered in the fan selection or duct design, then such conditions represent an "overload" on the system. The uniformity of distribution and dynamic response of the system under such conditions depends on the duct layout and design. The failure to consider such off-normal modes frequently results in control problems and inefficient operation.

An increasingly common control scheme for VAV systems is to reset the supply air temperature as the load changes. This introduces another dynamic consideration. Although operating at the highest possible air temperature for cooling may reduce the load on the refrigeration equipment, it tends to diminish the diversity in the air system to the point that there may be no savings in fan power.

In VAV systems, the particular fan control scheme used and the location of the various sensors for pressure and velocity have a significant affect on the dynamic performance of the system. There may be major differences in performance and energy consumption between two otherwise identical systems if they had different control schemes or even the same control scheme with different locations for the duct sensors. Also, the results will vary for different control set-ups such as proportional band, etc.

3.2 Duct Leakage

Duct leakage is a particularly difficult problem to deal with because of the many variables involved. In some cases, leakage is not particularly detrimental when it occurs within the "thermal envelop" of the conditioned space. However, when it occurs outside of the envelop, it can be a complete loss to the system. The location or distribution of the points of leakage is an important factor. Two otherwise identical systems will respond differently if one has uniformly distributed leakage and the other has equal, but concentrated leakage. In constant flow or on-off fan systems leakage will tend to stabilize, but in variable flow systems the leakage pattern will change as the pressure and flow conditions change within the system.

The problem of leakage is not limited to supply ducts. Return, exhaust, and outside air ducts are also subject to leakage, as well as shafts and plenums. It is not uncommon for leakage into outside air ducts and plenums to render an outside air economizer cycle completely ineffective.

The current trend toward specifying sealed ductwork, even on low pressure systems, is encouraging. Minimizing duct leakage increases the reliability of dynamically simulating a system with both supply and return air ductwork, specific equipment, and specified controls.

3.3 Stratification

Stratification of air temperatures is a common field problem, and does affect time lag or the dynamic response of a system significantly. Stratification happens any time two air streams at different temperatures are mixed and will occur most frequently in mixed air plenums, after steam heating coils, after face-and-bypass dampers and after zone mixing dampers. The most common problems are coil freezeups, nuisance freezestat tripping, and the inability to get uniform supply air temperatures throughout the duct system. Locating temperature control sensors in stratified areas introduces an almost unpredictable element of uncertainty and instability.

3.4 Duct Insulation

Heat gains or losses throughout a system have a definite affect on a system and its controls. As a result, insulated or uninsulated ducts must be considered when dynamically evaluating a system. Analysis of insulation throughout a duct system based on known response factors would result in the minimum energy requirement for a building.

3.5 Hydronic Piping Design

Many of the considerations for the layout and design of duct systems also apply to piping systems. In some respects, the calculation of pipe pressure losses is more definite than calculating duct losses because of the relatively standardized fittings. Thermal time lag is normally more pronounced in water systems than in air systems due to the higher mass flows and lower velocities.

The layout and design of piping systems warrants the same approach recommended for duct systems, i.e., examining the "worst" branch and trying to improve the design by eliminating poor conditions and lowering the pressure losses. Common practice is to design water systems on the basis of preselected water temperature difference such as 10°F, 15°F, or 20°F. Using these temperature differences, design flow rates are calculated from the design space heating or cooling loads. When used to select coils or other heat transfer equipment, the design water flow rates are usually considered as the maximum allotted flow for the given coil. Selecting a coil which does not require more than the allotted flow usually results in an "oversized" coil in the sense that it will carry the required load with significantly less than the allotted water flow. The "oversize" is even more if the load calculations include any safety factors or contingencies. A 10% safety factor on the air-side of a coil can result in a much higher factor on the water-side. Water systems typically operate with a good bit of unnecessary excess flow. In contrast, air systems are typically light on air. The load matching characteristics of hydronic heat transfer equipment is one of the principal factors when considering the dynamic behavior of systems.

Water systems differ from air systems in that various water circuiting arrangements are possible such as primary/secondary pumping. However, the basic system concepts are similar with regard to constant or variable flows and temperatures. The relationship between required flow and load is somewhat more complicated in water systems than in air systems. In water systems, the required flow depends on the characteristics of the particular coils or heat transfer equipment specified. Two otherwise identical systems could respond differently if equipment from two manufacturers were used. In air systems, the relationship is more direct. If 100 cfm is required in an air system, the terminal box or diffuser will not change the effectiveness so long as they deliver 100 cfm. In water systems, passing 10 gpm through a coil does not ensure that it will transfer the desired amount of heat.

While the use of variable flow systems offers opportunities for energy savings, some designers are reluctant to use them because of possible problems with low flows through chillers or other flow sensitive equipment or possible noise problems due to excessive pressure differentials. Designers prefer the assurances of 3-way control valves in spite of the continuous load that they place on the pumps. In addition to system analysis, training seminars and handbooks are necessary to assure efficient system design.

Fouling factor allowances on heat transfer surfaces, notably chiller tubes, can have a significant effect on performance and can cause periodic variations in capacity and power between cleaning. The "C" factors for the effect of surface roughness on the pipe friction losses are used to assure that design flows can be achieved even after the piping has corroded to some degree. When "old pipe" factors are used, the friction losses at startup with new pipe, and for some years thereafter, will be significantly less than calculated. Unless the system is throttled down, excessive flows will result. It is now becoming increasingly common for designers to calculate losses on the basis of new, clean pipe. Chemical treatment is used to keep it that way.

3.6 Terminal Boxes

The performance characteristics of terminal boxes and their degree of regulation will affect the extent to which load changes are reflected back to the fan. If boxes do not hold their set minimum and maximum flow rates, then the boxes themselves add a dynamic factor into the system which affects the duct design. When the terminal box minimum and maximum flows vary with pressure, then the duct system design will affect the flows by virtue of the pressure distribution established within the system.

Terminal boxes, including control devices, are either single or dual duct, both constant and variable volume. The control devices for these boxes on the market today vary from a plain damper to pressure compensated dampers, both with thermostatic controllers. Further sophistication of these control boxes will be rapidly forthcoming, and each will have its own response characteristics. Standards are available for determining the pressure requirements, sound generation and regulation characteristics and various controlled pressure and air flow rates. Studies are necessary to establish the time lag and efficiency, or inefficiency in terms of energy requirements, of terminal boxes and their controls on simulated systems. Any study should include methods of controlling the system pressures and flow beyond that controlled by the terminal unit.

3.7 Fans

Fans and their performance under actual operating conditions are an important factor in the dynamic behavior of air systems. Fans are usually selected on the basis of full-load, steady-state conditions. In constant flow or on-off fan systems, this is normally satisfactory. However, in variable flow systems, the fan selection must be looked at over the entire range of operation, including off-normal conditions.

In constant flow or on-off fan systems, the fan normally performs under steady-state conditions except for periodic variations in filter loading and non-linear flow through mixing dampers. Filter loading can be a problem under certain conditions. Many designers specify that fan systems be balanced with the equivalent of dirty filters, apparently thinking that this assures operation under the worst possible conditions. What they fail to realize is that when the filter pressure drop is a major portion of the total fan pressure requirement, changing the filters can cause problems with noise and moisture carry-over due to increased air flow if the cooling coil was selected with a high face velocity.

The performance characteristics of fans are of particular interest in variable flow systems where they are required to operate under varying conditions. Here, the method of fan capacity control is of major importance, yet most data available is very generalized. The relative performance of discharge dampers, variable inlet vanes, and speed control are frequently established only by characteristic curves with only a limited range of data. Although fan manufacturers do not recommend operation outside of a range of points, many fans do operate under such conditions with apparent success. More data is needed on fan capacity control and off-optimum operation.

The horsepower requirements of the fan are the key to the economics of variable flow systems and although power savings can be achieved during part-load operation, even greater savings are possible by designing the duct system for minimum pressure losses and by selecting the fans for minimum horsepower requirements. The proper application and selection of fans is not as well understood by many system designers as it should be. Although the AMCA (AIR MOVEMENT AND CONTROL ASSOCIATION) SYSTEM EFFECT FACTORS have helped bridge the gap between fan catalog ratings and actual field performance, fan problems continue to be a major source of trouble. Continuation of the SYSTEM EFFECT FACTOR studies is necessary to assure proper design and as a result minimum energy requirements.

3.8 Pumps

Pumps in water systems are analogous to fans in air systems except that the application and selection of pumps is better understood by system designers. Except for cavitation problems, pumps are generally less affected by adverse conditions of installation. One limitation with pumps is that their speeds cannot usually be adjusted in the field to match the system load. Pumps are usually direct-connected whereas most fans are belt-driven.

4.0 SPACE AIR DIFFUSION

The complexity of practical room air diffusion problems is due to innumerable variations in building construction, system design, and operating requirements, and makes knowledge of the basic character of air diffusion imperative. The theory of room air diffusion is not complete, but a considerable fund of knowledge supported by experimental guidance is available for the solution of many air diffusion problems. Over the years air diffusion studies have generally been conducted in two areas, each giving little attention to the dynamic performance of grilles, registers and diffusers. One area is the jet characteristics of the air flow from the diffusers or grilles; this method does not consider the comfort conditions in the space. In the other area, research studies were only concerned with air patterns in a space due to magnitude of air quantity and location. The Air Diffusion Performance Index (ADPI) attempts to bridge the gap between the dynamics of air flow from diffusers and the dynamics of air flow in a space. If many measurements of air velocity and air temperature were made throughout an occupied space, the ADPI would be defined as the percentage of the locations where measurements were taken which meet the previous specifications on effective draft temperature and air velocity. If the ADPI is maximum (approaching 100%), the most desirable conditions have been achieved.

Increased flexible environmental requirements will require joint air diffusion/human factor studies so that controlled varying degrees of comfort will be reflected in terms of time lags or system responses on both the air and hydronic systems. The pickup of the heating or cooling loads must be on important parameters in these studies. With respect to variable volume systems, low air flows must be considered when evaluating system pickup factors.

5.0 CONCLUSIONS

In terms of dynamically analyzing HVAC systems with the intent of minimizing building energy conservation, the following major items need to be evaluated and established:

1) Effectiveness or inefficiency of all types of HVAC systems.

2) Dynamic response of insulated/uninsulated supply and return air ductwork, including constant and variable volume terminal boxes, coils and fans.

3) Time lag or dynamic response of hydronic systems, including coils and pumps.

4) Response between space air diffusion and occupancy loads as a function of varying degrees of comfort (human factors).

5) Response of controls to any variation of the system parameters.

Of lesser importance, but significant, are such items as duct leakage and air stratification throughout air systems. To assure the design, installation, operation, and maintenance of energy efficient HVAC systems, specialized HANDBOOKS and WORKSHOPS will be necessary.

CHAPTER VII

DESIGN, OPERATION, USE PATTERNS

Committee:

Alfred Greenberg, GEO-Energy Limited (Chairman)
Rod Vial, Port Authority of New York
Walter D. Houle, IBM
Thomas Kinman, University of Cincinnati
Joseph T. Pearson, Purdue University

BUILDING DESIGN, USE AND OPERATION

1.0 GENERAL

Although building operations are profoundly influenced by those areas covered by Chapters II through VI and Chapter IV of these proceedings, the final energy consuming and operating characteristics of a given building are more than just the sum of these individual factors. End results are also affected by non-technical factors representing occupant, owner and regulatory activities. Two sessions of the workshop were planned to consider these interests as related to the theme of the workshop; these are 1) Design, Use and Operating Patterns and 2) Management and Codes. Because of the close relationship of these subjects, the two sessions were combined in the workshop. The end result of the combined sessions was to identify areas of dynamic response and interaction which ultimately influences energy utilization and operating characteristics of buildings. As a general overview, the committee determined that research and work projects for ASHRAE/DOE should take a total system approach including the involvement of disciplines and areas of activities not necessarily directly within ASHRAE's scope. Further, this work should be done in the field under actual operating conditions, as well as in the laboratory. The specific conclusions of the committee with respect to the two general areas covered are presented in the remainder of this chapter and in chapter VIII.

2.0 DESIGN, USE AND OPERATING PATTERNS

A general conclusion of the committee was that basic research is needed to determine how energy is used, and wasted, in modern buildings when considered as total systems. The outcome of this research will serve to: a. highlight common problems for all buildings in specific categories; b. furnish base data on energy utilization as well as operating and maintenance procedures; c. catalog systems in common use; d. determine the ranges of energy use (BTU/sq. ft-year) for categories of buildings and uses and e. indicate an overall potential for energy conservation. Fundamental to this research is the use of existing buildings as laboratories for the studies. In order to obtain the general goals, other areas of work were identified which must lead the overall study.

2.1 Buildings and Dynamics for Consideration

Preliminary to carrying out the study of energy use patterns in buildings, a uniform approach to characteristics to be considered and building classes is necessary. The building types to be considered should include at least the following:

a. Residential: single family; low rise; high rise; mobile; condominiums, etc.

b. Domiciliary: hotels; motels; nursing homes; dormitories; barracks, etc.

c. Industrial: warehouses; refrigerated buildings; manufacturing; assembly, etc.

d. Places of assembly: enclosed stadia; houses of worship; cultural centers; auditoria; theaters; community centers, etc.

e. Health care: hospitals; clinics; laboratories and other research facilities

f. Institutional: prisons; museums; governmental; libraries; fire houses; police stations; post offices; communications centers, etc.

g. Shopping Centers: Department stores; specialty stores, enclosed malls etc.

h. Commercial buildings: office buildings; stores; banks; computer centers; radio and television stations; restaurants; entertainment centers, etc.

i. Transportation terminals: airport; bus; railroad; ship; large garages

j. Swimming pools; gymnasia; laundries; health clubs; tunnels; etc.

The dynamic characteristics determined to be generally applicable in varying degrees to each of these categories are:

a) Weather

b) Occupancy Patterns and levels

c) Process, Functions, Operating Factors

d) Commercial Considerations (sales esthetics, image, contracts, etc.)

e) Management Concerns and Perceptions (productivity, acceptability to clients, etc.)

f) Occupant Acceptance, Tolerance and Psychological reactions

In addition, many buildings have special or unique functions or requirements which may make specific research necessary for better understanding and results.

2.2 Specific Steps in the Study of Existing Buildings

To obtain the data required to characterize energy use patterns in buildings a number of intermediate steps are necessary. Each of these may in themselves represent a specific area for a research project.

2.2.1 Energy Audit Procedure

A standard detailed energy auditing procedure (or "Technical Assistance" as it is called by the Federal Regulations) must be developed. This procedure shall provide a uniform methodology for recording and analyzing energy utilization characteristics common to all structures. These procedures should provide all data necessary for proper utilization of any computer simulation program currently available or for any other reasonable purpose. The factors relating the dynamic functions of the systems must be noted in the audit.

2.2.2 Building Instrumentation

Many buildings have very limited instrumentation to help determine how the systems and the equipment are functioning. Some buildings today include computer based monitoring systems. These buildings represent the potential of a ready made research laboratory. In order to realize this potential a number of steps are required; these include:

1. Standards for the instrumentation and measurement procedures required to obtain the energy use data needed must be determined. The instrumentation accuracy and the specific data requirements must be standardized.

2. Common procedures of operator education and training are needed in order to insure that they know what is expected for the studies as well as the objectives of the research. Operator interest, diligence and expertise will be necessary in order to minimize the number of uncontrolled variables in the experiments performed.

Because of energy costs as well as the awareness of their systems, many building managers are interested in research. Their participation in this effort is necessary and must be invited early in the effort.

2.2.3 Data Formats and Dissemination

A common format for the presentation of the data collected must be established. This not only includes the specific data recorded, but also the location of the data on the recording medium and the medium itself. A storage and dissemination source must be established and a method of publicizing the data available determined.

2.2.4 Determination of Characteristics

The primary research step is to extract from the building data the relationships between energy use and 1) HVAC system/building design, 2) building use patterns and 3) operating procedures. It is likely that each of these will require separate examination in the data base and then combined to develop areas of essential interest and overall conclusions. Specific areas which must be considered in these studies will include: 1) air and water distribution, 2) controls and 3) primary equipment. Research necessary in these areas is covered elsewhere in these proceedings, but the inclusion of field related verification of rating is essential. Other potential considerations specific to building design and operation are:

1. Internal shading devices are utilized almost universally on a voluntary basis. For energy optimization, manual control is not practicable. Consideration of automated internal and/or external solar shading should be studied for feasibility and effective energy management.

2. Since mean radiant temperature (MRT) can be used as one effective measure of comfort and can also be potentially helpful in reducing energy consumption, an inexpensive, easily installed and usable space MRT thermostat would be useful if developed and made available.

3. Buildings must be looked at from the viewpoint of determining if a rational number of minimum design systems can be established which are applicable to most buildings. This would reduce design time, construction costs, operator training periods and troubleshooting time and costs. The feeling is prevalent that too many designed systems are one of a kind with little rational justification for their uniqueness and no demonstrable added benefits in the ultimate results.

This work will lead to the organization of information on the sources of energy use not directly related to the hardware systems of the buildings. This information can be used to evaluate present and future design and operation.

3.0 SUMMARY

It was concluded that a necessary part of future efforts in energy conservation must be to include the consideration of operation and use patterns in buildings, as well as characteristics of specific designs. Little information is presently available on these subjects. Research is identified to obtain this information. This research includes work on:

1. Energy audit procedures
2. Instrumentation and data standards
3. Data formats and dissemination policies
4. Characteristic identification

These research needs should be addressed by ASHRAE Technical Committees and Task Groups.

A number of more general conclusions and observations resulted from the committee's discussions; these included:

1. Numerous sources verify that of all the buildings which will be in operation in the year 2010, 80-90% are now in operation. It follows inevitably that the major long term impact in energy reduction in buildings is to start now to reduce energy consumption in existing buildings. New technology research efforts, while important, are secondary at this point and can be paid for in large part from the energy we conserve now.

2. Initially, most of the research expertise will have to come form the academic and industrial world. This will serve a most worthwhile purpose in acquainting all sides with the real needs and problems encountered in buildings. This will inevitably result in improved products, performance, operation and measurement. Laboratory research alone is not an adequate approach to help improve the operations of buildings. A substantial part of the work must be done in the field if the results are to be beneficial to buildings. The team approach developed will stand our entire industry, as well as our country, in good stead.

3. Within the framework discussed above, all applications oriented Technical Committees and Task Groups within ASHRAE should prepare appropriate work statements for the various building types within their scope. Since there is so much overlapping, also areas not covered yet within ASHRAE, new groups may have to be set up or other organizations may have to be approached to assist or perform some of the work required.

CHAPTER VIII

MANAGEMENT and CODES

Committee:

Alfred Greenberg, GEO - Energy Limited
Rod Vidal, Port Authority of New York
Walter D. Houle, IBM
Thomas Kinman, University of Cincinnati
Donald L. Weast, Purdue University

MANAGEMENT and CODES

1.0 INTRODUCTION

The codification and implementation of safety and structural codes for buildings has always followed demonstrated needs and sometimes tragedy and public opinion. Today, the inclusion of energy conservative systems and equipment in new and existing buildings requires that effort and money be expended by those who may not directly benefit and who may not be held accountable for the building's energy consumption. The end beneficiaries of all energy savings are the public, the owner and the operator, but they are frequently not in a position to:

a. knowledgeably demand energy conservation features from the construction team.

b. resist tenant and management pressures for more energy in the form of excess air conditioning, heat, lighting, etc.

c. measure the performance of the building when completed.

d. obtain satisfaction from the design team after acceptance when defects are discovered.

It is in the national interest that all buildings be constructed and operated so that minimal energy is expended. Standards and operating codes, therefore, must be instituted which will require that minimum energy consumption, like safety, sanitation and other public benefiting standards, be achieved. Regulatory, as well as market pressure generated by energy costs, is needed to make real progress toward reducing (or eliminating) building energy waste.

In order to achieve these standards and codes, considerable research and data collection must be accomplished. ASHRAE should provide basic data and recommendations to the governmental and industry code makers. Code makers should not and do not take a leadership role in the development of criteria and standards for effective energy management. Their prime role is to disseminate that which is developed by others and attempt to educate and assist in the implementation by legislative and enforcement groups. ASHRAE can and should assume the task of proposing energy codes and energy standards for new and existing buildings. This should include the evaluation of present codes, standards and regulations relating to energy conservation.

The recommendations by the Management and Codes section of the Workshop for ASHRAE/DOE research projects fall in the legislative, as well as the technical areas. Although a departure from the traditional ASHRAE concerns with hardware and technical data, legislative input has become equally important and necessary to help achieve the necessary results.

2.0 ENERGY DESIGN REQUIREMENTS

Research studies are needed to define energy use requirements and guidelines for new and existing buildings. This study would define mandatory tasks to be performed by the design team when proposing a design for erecting a building and by the owner when operating it. Included might be:

a. requirements that energy use profiles be submitted to the owner as part of the design package.

b. requirements that sufficient instruments, meters, etc. be included in the building to assure the owner of means to measure and record energy usage.

c. definition of minimum education, operating procedures and instructions for the owner and his staff to operate the building at maximum energy efficiency.

d. definition of an accounting and reporting procedure for energy use and recommendations of how this data might be accumulated by some legal or quasi-legal agency.

e. requirements for ongoing accountability by the design team to measure and adjust the building to assure proper energy use.

The need for such requirements and approaches to implementation are discussed in the following paragraphs:

2.1 Management Elements

There are many management elements in the construction process. They all interrelate in some fashion at some time. A listing of the major groups is:

a. Owner	e. Utilities	i. Space user
b. Designer	f. Manufacturer	j. Trade associations
c. Contractor	g. Regulatory agencies	k. Code makers
d. Operator	h. Financial institution	(NCSBCS, BOCA, etc.)

Most of the above are not involved in a project from inception to operation, but each plays an essential role at the right time in a project's development. The only one who can be counted to be involved in all phases of a project is the owner.

Although the owner initiates the building and has an idea of what the total final energy bill should be, (from past experience or trade association data) he frequently does not have the knowledge or input to place exact energy use requirements on the design team. These consultants, even though agents of the owner, have limited authority during design and construction to initiate energy conserving measures and little accountability for eventual operation. When completed, the building is operated by a staff which has usually received little training and has only limited ability and little incentive to maximize energy efficiency. Once the building is completed and in operation the owner has little recourse if the final energy design is unsatisfactory or deficient.

2.2 Design Team

It would be appropriate to define and develop requirements for the design team's role in the design and operation of the building with respect to energy use. This responsibility might include, but not be limited to:

1) profile analysis for building usage and energy utilization

2) monitoring and auditing

3) operating and maintenance procedures and instructions

4) accountability for results specified

5) adequate documentation for construction and operation

6) adequate calculation procedures to provide verifiability and reproducibility of energy use data

In order to insure that the functions determined to be necessary are carried out, codes, standards and guidelines are needed. Although it is doubtful that one set of rules can be established which will assure uniform administration and results, defined common energy goals for the design group will help. Standardization of energy related tasks would make it easier for the industry to move forward on energy conservation.

A requirement for continuous involvement in energy utilization characteristics by the designers and builders would automatically modify the present involvement patterns and improve the end result of energy management.

3.0 ENERGY BUDGETS

The establishment of energy codes, standards and guidelines which define, for the designers, the requirements for energy based designs would be impossible without, at the same time, establishing data which would define energy criteria for particular types of buildings. Unfortunately, there is now no body of data from which present actual energy use can be extracted and no meaningful way to accurately predict what energy a building should use. Building energy performance studies are based on theoretical figures not actual field results. Correlation of actual to theoretical results requires monitoring and analysis of deviations. In time this will enable better estimating accuracy if operations are predictable. Research projects should be initiated by ASHRAE to provide the basic data which would aid in the development of minimum energy use designs. The results of this research would be:

a. a standard detailed energy auditing procedure with a methodology which could be applied to all types of structures.

b. a definitive base line energy use budget for all types of buildings in each geographic area of the country. These figures would be used to evaluate building energy performance and to provide the design standards which would have to be met.

c. proposals for enforcing attainment of the energy use budget. This would include a measuring and reporting procedure and possible penalties and incentives for compliance.

d. a proposal for an energy simulation model which could be used to evaluate and prove changes in equipment and design before construction or implementation.

e. a defined education and certification program for building operators. Compliance with an energy use budget depends on a reporting mechanism which must be administered by trained personnel.

These results would be of benefit to those agencies responsible for the generation of codes and regulations.

Energy budgets for existing buildings are not practical because of the wide range of BTU/sq.ft.-yr. for different building types as well as within a given building type. A study should be initiated to determine if a system can be developed whereby existing buildings must reduce energy consumption based on a per cent of previous use, tailored to the building's standing in the base rate range for its particular class.

4.0 DATA SHARING

Aside from data maintained by some Trade Associations and governmental agencies, the substantial body of energy use data which exists today has been taken by energy utilities. In order to conduct their business, these companies have had to assemble vast amounts of information regarding use patterns, growth trends, etc. An ASHRAE utilities study project is needed to examine the sharing of utilities energy use data. This may include:

a. assembly of energy use data on a nationwide basis.

b. recommendations to improve the usefulness of energy data.

c. cooperative efforts in the monitoring of energy use by means of checks and submetering.

ASHRAE might also sponsor, with the utilities' participation, an educational program or manual which could be used by owners, operators and designers to take better advantage of rate structures and fuel supplies. This probram would also provide a common language for improved communications between all parties.

5.0 TECHNICAL PROGRAMS

Present codes and regulations establish minimum and fixed requirements for air conditioning, heating and lighting. These requirements have been established for occupied and unoccupied periods. ASHRAE research projects should be developed which will examine the impact on energy use of providing variable code features which would allow designers and operators more flexibility while assuring minimum code compliance. Some of these might be:

a. minimum outside air based on actual occupancy.

b. lighting based on actual occupancy and outside conditions.

c. hot water requirements based on use patterns and instantaneous need.

d. modulation of comfort based on weather, wind, etc.

6.0 OTHER AREAS

The following suggestions are illustrative of the types of creative thinking and action that may provide the impetus and means to rapidly achieve part of our energy conservation goals:

a. study establishment of energy insurance system comparable to philosophy of life or fire insurance.

b. set up the implementation procedures for mandatory installation of non-depletable energy resources systems for domestic hot water, energy storage systems, etc.

c. require all buildings to install or be connected to a suitable automated energy management system.

d. develop a system of penaliies, incentives and operating modes for achieving minimum base energy use such as fines, rationing, extra energy, beneficial expansion and business benefits, rationing, reduced taxes, rate escalation, shutting down building or reducing hours of use, government to take over and initiate energy conservation measures, etc.

7.0 SUMMARY

It is recognized that many of the above are beyond the current scope of ASHRAE activities. However, if ASHRAE is to provide leadership in the overall conservation of energy in buildings new areas of participation must receive serious consideration. The legislative enactment of codes and regulations will proceed. ASHRAE, with its depth of expertise in buildings and energy use, can and should play a major role in this legislation.

CHAPTER IX

ENERGY STORAGE

Committee:

Calvin D. MacCracken, Calmac Manufacturing Corporation (chairman)
Robert T. Tamblyn, Engineering Interface Limited
John A. Clark, University of Michigan
Gerald Lawson, Tennessee Plastic Incorporated
Wolfgang Leidenfrost, Purdue University

ENERGY STORAGE

1.0 INTRODUCTION

Our work is primarily in the field of new technology, new systems and new applications, but also, particularly in rock bed storage, finding out precisely what is going on and being able to predict performance.

The working group have many comments and recommendations, many of which should lead to research projects.

2.0 GENERAL

The group is primarily interested in active responsive storage and the system concepts which permit and encourage its use. The biggest incentive to storage is the need by the electric utilities for load leveling or load management by off-peak rates. At this time, solar energy storage by itself is secondary in importance. Solar and off-peak storage may be combined in the same equipment. The working group feels that cooling storage and heating storage are, across the board, of equal importance and both should be used together to promote maximum benefit from storage.

Storage is an ideal answer, as well as the practical answer to dynamic response. Storage allows equipment, controls, structures, human factors, and circulation/distribution to be managed in a simple, steady state condition with storage picking up the dynamics.

The size and cost of storage, as with almost everything else in the HVAC field, comes down as conservation techniques are applied. We strongly encourage such design features as initial passive design, good insulation, and low infiltration.

3.0 PROJECTS

The following recommendations are made:

1. All new construction with central heating, or cooling systems be designed with distribution systems that can deliver full load at 105°F. This allows for use of storage for heat pumps and for solar energy on an efficient basis.

2. Usage of dryness storage in buildings, so that a space, its envelope and its contents could be brought down to low relative humidity at night and thus day-time cooling loads could be lower.

3. Chilled water storage systems for large buildings be broadly encouraged and engineers educated as to its cost effectiveness and energy and cost savings. That both "small storage" (24 hour chillers) and "large storage" (off-peak chillers) be explained.

In addition to help develop needed additional information, the following research projects are recommended:

1. seasonal losses in heating and air conditioning due to storage in ducts and pipes. The seasonal losses in heating and air conditioning that may be incurred, as well as the loss of response, from unwanted storage of heat or cooling in ducts, and to perhaps a lesser extent in pipes may be larger than expected. Lower mass of ducts or internal insulation may secure large savings. A research study should be made of the actual seasonal energy consumption of a low mass and an all fiberglas duct system in a house compared with conventional system. The energy savings from such a system may be larger than suspected.

2. a project on means of retrofitting a low mass low temperature, hydronic radiant heating system into a building in a cost-effective manner.

3. the study of radiant room cooling with the use of a non-ducted dehumidifier.

4. a study of off-peak heat pumps which store both cooling and heating and pick up heat from low cost unglazed, or unspaced glazing, solar collectors and from the ground, as well as from the ambient air. This should be implemented by an ASHRAE Task Group on Multi-mode Heat Pumps which has already been unofficially formed.

5. that bulk-tank eutectic salt thermal storage systems be studied in the light of new developments.

6. that rock bed studies be made to improve analysis and experiment with different designs and materials. Chanelling in horizontal beds and cooling storage should also be researched.

CHAPTER X

SUMMARY SESSION

Chairman: Dennis E. Miller, Johnson Controls, Inc.

1.0 INTRODUCTION - Dennis E. Miller

What we would like to do this morning is to conclude our discussion of the workshop. For the first hour we will have the session chairman present the results from their sessions. What we would like for you to concentrate on, given the final objective of the workshop, is to fill in the blanks or to fill in the slots of the activities necessary to follow through on the application of dynamics to HVAC systems. Limit your discussion, as you present your results, to the specific tasks as you see them for the areas that you were concerned with. As you do make these presentations, I would ask you to come up to the microphone so that we can record your discussion of your tasks. During the remainder of the time after the chairman's presentation, we are going to further discuss the synthesis of these activities into a coordinated plan for the application of dynamics to HVAC systems.

2.0 CHAIRMAN'S SUMMARY

2.1 Equipment: David A. Didion

I'll give Bill Chapman a chance to be an "I told you so" since I asked what we would do if we finished early. The fact of the matter is that we didn't even finish. I think it is important to realize that after some discussion, we made a distinction, from the equipment point of view, between off-peak steady state conditions and true dynamic response. We said that there was, first, an off-peak steady state condition that we were concerned with because as of right now you look at equipment as on-peak or full-load steady state. The second level of dynamics then was a true dynamic condition, a cyclic or a variation transitory period going from one level to another. As a result of the discussions we have broken our list of recommendations into two general categories. The first category is one which includes items that are generic to all equipment needs. The second category lists the specific type of equipment and the particular problems we saw necessary for the particular equipment. We focused, in general, on what should be done in the public sector. In order to maintain the competition we will place comments here and there in the report as to what we feel is being done in the private sector. In other words, all things don't need to be known in text books. The companies have to have a certain amount of proprietary information to compete.

Under our first category of common to all equipment we have three (3) major needs. The first one is to establish a representative use cycle or a load cycle that the equipment sees for heating and cooling. Equipment manufacturers feel that they don't have adequate knowledge of how the equipment is being loaded in the field. These cycles can be annual cycles, diurnal cycles and so forth. We see this being done probably by the use of simulation programs. Load programs that include both the building load and the HVAC systems such as Ross Meriwether's program, or something like that.

The second topic is an off design system optimization, that is, energy savings if equipment is to be sized according to average load rather than maximum load. We left the term "average load" sort of wide open. It has to be defined. It's certainly not average use as Al pointed out, that could be zero on an annual basis, but it is something, maybe average daily temperature instead of maximum temperature. What we are saying is we have to evaluate whether or not there is significant energy savings using some "average load". We all feel there is, but that has to be studied.

The third one, like the second one, is to take the next step and evaluate the typical equipment dynamics. That is the controlled caused ripples that happen to equipment for the magnitude of potential energy savings. So what we are saying is that in the second step we want to evaluate the energy savings that are available by considering off-peak steady state operation and then in the third step we want to evaluate energy savings if you consider true equipment dynamics, - these little ripples that go on. We think the second step is very important and will show significant energy savings. The third step is dubious in our mind as to whether there is true energy savings there.

This takes us into the second category where we listed specific equipment.

1. Boilers

The first equipment was boilers. We see the need for the development of performance simulation model for modulating boilers to aid product designers in understanding boiler dynamics. This particular aspect of boiler manufacturers is far behind in sophistication of design of the refrigeration side. They don't, to my knowledge, and we've looked into it in detail, have any such analytical tools to assist them in considering off-peak considerations. Also, under boilers we saw that we should determine the barriers to high seasonal performance efficiencies. This should include economics and environmental effects. In the residential area in particular, a lot of developments are going on which might get into condensate boilers, that sort of thing. We have to find out why they are not coming on more or faster. What are their barriers?

2. Positive Displacement Compressors

Then we went to positive displacement compressor and compressor systems. This included reciprocating, rotary and screw compressors. We saw the need for dynamic model for unitary equipment, not for fuel directed, but for unitary only. That work is under way, but in the public sector. That is about all. The competitiveness in this field is such that it seems to be healthy. There has been a great deal of stimulus put forth by the government and other agencies already. We saw no more need to do other public sector work in this area. There is a great deal of work going on in the private sector already.

3. Electric Motors

This led us to the off-shoot of electric motors. So, our third category is electric motors and we saw the need here to conduct a feasibility study, which will evaluate energy inpact, design options and economics for new motor designs which have improved performance over the entire load range. There seems to be little question in people's minds that you can have them, it is technologically possible, but there might be some darn good economic reasons why not. They should be looked at again in the light of the new economics of today's energy.

4. Centrifugal Compressor

The next category was centrifugal compressors and compressor systems. Here we saw a different need, although the product designers are in national competition which keep development going. There is a need to develop generic documentation, which would enable system designers to select chiller systems on an off-peak design criteria basis to obtain seasonal energy efficient performance. In other words, the manufacturers data is generally presented to enable the designer to pick a chiller system on a full load steady state basis performance. It is possible that manufacturers already have the information needed for off-peak design criteria and it could be reconstructed and put in as a part in the ASHRAE Handbook. This would give a procedure based on optimum seasonal performance, by which you would now pick your chiller system. There are various options that you could do about peak times. You could use natural storage in the building or artificial storage. Like power plants, you could have booster systems for peak loads or you could live with discomfort. We saw the options interfacing with other things that were not under our jurisdiction. We just thought that since those things were coming along, this is something that should be considered more seriously.

5. Others

We have other categories which we didn't finish. We have them in rough notes. I don't have them in statement form. We considered absorption systems, heat exchangers and cooling towers. We spent a good deal of time on cooling towers. There is a particular need for additional design criteria and develpment of cooling towers. None of us are part of the cooling tower industry (one had worked in the cooling tower industry several years ago). We felt that we were going to have to contact them, their trade associations and the TC's in ASHRAE and see what can be done. We know there is great potential there, but we didn't feel we had the expertise to develop that area.

2.2 Controls: George Schade

The first and foremost thing that the controls group felt was absolutely necessary in order to make progress in the conservation of energy was to develop a computer program, available to the general public, which could be used for evaluating the energy impact of various control strategies. Now, the feeling was that this program probably would not have to involve the specific details of individual controls, but that it be able to evaluate the energy consumption aspects of the currently used control systems, and possibly future control strategies. Given this program, it would be possible to answer other questions and to carry out the other recommendations that the controls group felt should be undertaken. The other recommendations should be carried out as parallel projects while this computer program is being written. Specifically, the other recommendations are for research topics that could be addressed in laboratory situations.

First of all, there is the need to establish the magnitude of the excess energy consumption due to unstable operation of existing control systems. One specific example cited was control valves operating at small openings. There was a feeling that systems performance standards should be studied if not established.

The concept of establishing standards on system performance should be studied. In conjunction with that, there was a recommendation to study the possibility of establishing standards on individual components of the systems.

There was a feeling that optimal control theory should be used to reduce energy consumption, taking into account the complete building and physiological makeup of the occupants. Currently there is a request for proposals involving a study of optimal control of a building, the scope of this RFP could be expanded, or the work in this request for proprosals could be continued to include physiological aspects. This would give the opportunity for more leeway in what could be done to optimally control the building with respect to energy consumption.

There was a recommendation to determine the energy consumption effects of the controller characteristics such as linearity of controllers, histeresis, repeatability, offset, and resolution.

There was a recommendation to study the possibility of establishing formal testing and rating procedures for control equipment.

There was a recommendation to study the effects of part-load, off design operation of environmental control systems to determine the energy effects.

In general the feeling of most committee members was that the systems that are in the field are not really well understood with respect to their dynamic interactions. Better tools are needed for use by engineers in the field to optimize existing systems. More knowledge of the dynamic response of the system elements and the dynamic interactions of the elements in the systems is necessary so that better systems can be created in the future.

2.3 Structures: Ross F. Meriwether

Our approach to the discussion of the structure as an element in the dynamic behavior of the total system was to list a series of questions that needed to be addressed for each of several subelements of the structure. The questions range from determining whether or not we knew enough about the behavior of the particular subelement on a steady state basis, going on into what were the differences and consequences of steady state behavior vs dynamic behavior of the particular subelement, continuing on to what were the research areas or types of additional data that need to be developed to have an adequate handle on the dynamic behavior of the subelement and finally looking at what were the interactions between that particular subelement and other elements in the total system. Each of those particular questions were addressed to the individual subelements into which we subdivided the building. The subelements were:

(1) the opaque surfaces of the structure,

(2) the fenestration of the structure,

(3) air leakage in the structure,

(4) moisture movement into and out of the conditioned space,

(5) sensible heat storage within the structure (meaning natural storage just from the mass of the building, not from artificial storage),

(6) the latent heat storage in the structure,

(7) the internal gain patterns,

(8) the overall heat balance of the structure.

In the first area, opaque surfaces, we felt that most of the steady state behavior was adequately defined, and we probably had usable information.

The one area that was felt to be most deficient was the interaction between the structure and the ground. That interface was probably the least well defined, and in some instances it was felt to be of significance. Since there is Canadian activity directed in this particular area, our recommendation was that we would await the results of some of that research to see whether or not that supplied what was felt to be the missing data.

The information on the behavior of the insulation, particularly the air movement within the insulation, was felt to be deficient. There are a number of programs that are underway at the present time that address the whole subject of the behavior of insulation. These programs probably will address that particular question adequately. A correlary of the deficiency that existed in the general interface between the structure and the ground was the slab on grade with respect to the cooling impact. It was felt that almost all of the information that had ever been developed on the interface between the building and the ground was concerned primarily with heat loss from the standpoint of increasing the heating load of the structure and not with respect to decreasing the cooling load of the structure. It was felt that information was needed to see what the impact of the interface was or could be on cooling loads.

Regarding the response factors that are published in the ASHRAE guide for the 92 types of wall construction, it was felt that additional work was needed that would develop and validate the response factors for a number of complex wall materials; walls that are not a series of homogeneous layers.

On the next subject - fenestration - it was felt once again, that for the steady state, most of the information now available for transmission and solar heat gain through the fenestration seem to be adequate. The one area that was identified as being inadequate was information on glass sections that have film added after installation or by others than the glass manufacturers. ASHRAE's TC4.5 is already addressing the question of that deficiency. It is expected that they will either try to find ways to fill in that missing information or develop the work statements that would lead toward research projects to supply the needed information. An organization was identified that is concerned with trying to develop integrated information for the fenestration as a whole. The National Fenestration Council might be a source of good information for us since they will take into account not just the glass as a separate element, but all of the elements that make up the composite fenestration.

It was felt that the dynamic behavior of the interior shading devices was probably one of the most deficient areas for the overall fenestration and that new test procedures were needed to evaluate shading, shuttering, and draping as the effect the dynamic conversion of the heat gain in the space to the cooling load. By the same token, the cooling load weighting factors for solar conversion are needed for a wider variety of construction types. While the cooling load weighting factors for the conversion of solar gain into cooling load were specifically addressed here, all of the cooling load weighting factors for the conversion of any of the heat gains need to be expanded in scope and experimentally verified.

The next question addressed on fenestration was the growing trend toward the use of windows for natural ventilation, and whether or not we have the ability to adequately evaluate that impact on energy consumption. It was the feeling of the group that the ASHRAE guide certainly doesn't provide adequate information for the dynamic behavior of infiltration resulting from changing window settings. Enough data has been generated by European countries on the subject that ASHRAE should collect and evaluate that information to see whether or not it can be extracted and included in the ASHRAE guide.

The next subject was infiltration. It was felt that the information that is available for steady state evaluation of infiltration is shaky, let alone the dynamic interaction of infiltration with the other elements in the building. Consequently, many research needs were identified; particularly, regarding the trend toward the use of the delta P approach instead of the more classic methods previously given in the ASHRAE Handbook. Two elements that need to be further identified for proper use of the new calculation techniques are: (1) flow coefficients for a variety of wall-unit behavior. Not just walls per se, but the whole outside area of the structure considered simultaneously, with particular attention paid trying to identify and quantify the sources of air leakage into and out of the structure, and (2) the so-called A_0 term. That is the air leakage that occurs regardless of whether or not there is a delta P or delta T across the wall section. Various research programs that are presently under way were identified. These programs may fill in some of the missing information. We tried to identify other areas that would need to be attacked if we are going to fill in all the needs.

An area closely related to infiltration is the moisture movement into and out of the space. The paths of air leakage are significant in trying to identify moisture movement into and out of space. In looking at the moisture question, it was felt that almost all of the massive amounts of information available on moisture movement is directed toward consideration of condensation in the insulated space from the standpoint of potential problems with the insulation material or the structure itself. That is, it was from the standpoint of structural integrity that the information has been developed, not from the standpoint of energy impact. Consequently, it was felt that information needed to be developed would identify the energy impact of moisture movement into and out of the space. It was agreed in the group that the primary source of that moisture movement was air leakage. Any attention that has been paid to permeable materials in the past was probably primarily because of the possibility of condensation on various surfaces or within the insulation. Moisture migration through permeable materials was not expected to be of significance energy-wise.

In the storage areas we talked about whether or not we have adequate information for the dynamic evaluation of what happens to the heat gains and losses in the space during periods of non-operation, when that heat gain is transferred into the mass of the building, the passive element of storage. It was generally concluded that the methodology that we have for calculating passive storage is adequate, but that the coefficients that are available to describe the process need re-examination and expanding since the coefficients and the behavior by which storage takes place has a strong impact on energy consumption as well as the design (sizing) of equipment. This tied in with what was talked about earlier on the need for general improvement in the available weighting factors.

The discussion of moisture storage was brief. We concluded that there is virtually nothing known about any sort of behavior of moisture storage within the space. It was indicated that we obviously need a research project to establish absorption and release rates under a variety of dynamic conditions for various interior materials, including the building materials themselves (floors, walls), as well as the furnishings within the building.

In discussing internal gains, it appeared that the handling of the entire question of cooling load resulting from lights might need additional information. Since Kansas State University already has a project to address that question, it was felt that we didn't need to identify specific research that was required at this time.

The only other area that we addressed on internal gains was a need for better information on the dynamic or transient characteristics of internal gain from various types of office equipment, such as copying machines. The manner in which those gains should be translated into cooling loads is not well known. We also talked about the crossover between handling internal gains and fenestration resulting from the utilization of natural daylighting. We're not sure whether or not a deficiency exists in that area since the major problem is identification of the techniques that will be utilized for controlling artificial lighting in the face of natural lighting. Until some of those techniques are defined, we don't really know whether or not our calculation procedures at present can handle them. There are a number of programs, incidentally, in this area that we will suggest in our report be monitored for possible inclusion in the guide.

Our final subject was the overall building response. Kusuda introduced a concept of trying to evaluate the dynamic response of the building as a whole by evaluating the dynamic response characteristic of all of the individual elements. He presented an interesting concept of how we need to evaluate the frequency response characteristics of the various elements in order to identify that type of frequency response evaluation is required from other related elements to be integrated into the behavior pattern of the building as a whole. A written summary of Kusuda's concepts is included in Chapter IV.

2.4 Human Factors: Ralph F. Goldman

In terms of human factors, it seems to us that we know very little about buildings and building design requirements, but we don't feel guilty because it appears to us that you know equally little about the human body. We will start with the human body and what we think we have to do about it for comfort. There are four factors we need from you - the air temperature (T_A - i.e., dry bulb temperature), the wet bulb temperature from which vapor pressure (P_A) can be determined, the air velocity and the mean radiant temperature (MRT). You have to specify values for these four factors within the occupied space for us. We have to specify for you, what the metabolic heat production (M) is and also three clothing parameters: 1) the insulation, 2) the moisture vapor permeability and 3) how these change with air or wearer movement. Thereafter, comfort is a very simple thing.

In a comfort state, the metabolic heat production (M) is about equal to the heat losses (L). These heat exchange losses are made up of some readily defined components: convective heat loss (Q_C) which is a function of the dry bulb temperature, air velocity and the clothing insulation; radiant heat exchange (Q_R) as controlled by mean radiant temperature and clothing insulation; respiratory heat losses (Qres); diffusional losses through the skin (Qdiff); required sweat regulatory losses (E_r) which are a function of the per cent relative humidity and the saturated vapor pressure, the air velocity and the permeability of the clothing. Basically, we get in the comfort zone at a "predicted mean comfort vote" (PMV) of zero (which corresponds to a vote of 4 on the standard comfort ballot scale which ranges from 1 to 7). We can predict mean vote in the steady state quite reasonably as a constant times an exponential coefficient of body heat production (i.e., metabolism) plus a constant, all times the difference between the heat production and the loss of heat from the body, both expressed per square meter of body surface area. (See Table 1). It turns out that when the absolute value of the predicted mean comfort vote (PMV) is 0, about 5% of the people will still be predictably dissatisfied (PPD) even at that "optimal" condition. If the absolute value of the vote is ± .5 about 10% of the people will be dissatisfied, and so on down the line. (See Table 1).

On the hot side, the required sweat evaporation becomes more of a problem. It represents the balance between metabolic heat production (M) plus or minus heat exchanges by radiation and by convention evaporation, etc. If heat production is greater than the maximum heat losses, then the extra heat must be stored in the body, with a storage of 25 to 80 kcal noticeably uncomfortable (See Table 1). The trick for comfort on the hot side is to keep the ratio of the required to maximum evaporation less than 20%; thus, the sweat wetted skin area will be less than 20%, there will be no heat storage problem and it will be a comfortable condition. On the cold side, the skin temperature at equilibrium can be estimated as the air temperature plus 0.18 times the circulatory heat input to the skin, times the clo insulation. The best you can do for a finger in terms of insulation is about 0.3 clo extrinsic of still air layer unless you start wearing gloves and that gets us into a manual dexterity problem. If you keep the man warm (i.e., you keep his heat balance reasonably good) he'll put about 72 Calories per square meter per hour into his finger; if you look at the math (72 times 0.3 x 0.18 ≈ 3.9), it appears you can keep a finger about 4°C above the air temperature if the air is still. The trick is to keep the finger above 10°C; if you get the man cold, the circulation heat input is going to drop down to 7 instead of 72 kcal/m^2.hr. Now you've only got a finger about 0.4°C above air temperature. So in a very simple way, those are the parameters we need to tell you, and that is why we need you to tell us those 4 values for the environment.

When we look at the dynamic factors there are 3 things we can talk about - a basal temperature, the amplitude (i.e., what width the air temperature is going to swing) and the rate of change, both up and down. This has been studied in 3 ways so far by our people in different projects: 1) by discrete steps around a basal temperature 2) by cyclic excursions around a basal temperature, and 3) using ramps, where we might talk about night set-back or just simply temperature drift. The state-of-the-art right now is pretty much discrete step and cyclical studies data, where we take our base temperature, and we talk about an amplitude/time function. The ramp is probably a degenerate or abbreviated form of a cycle and the available data base will, we think, work reasonably well. So now we can talk about working off a base temperature and chasing up a ramp (or up a cycle) until we reach a warm discomfort or a cool discomfort. Again, 1) the 20% sweat wetted skin on the heat side, and 2) the uncomfortably cold feet or toes or 3) a skin with problems of uneven temperature distribution in the cold, will be the limiting features of comfort; although these three problems will not occur at the same air temperature independently of rate of change (i.e., there is a rate dependency) we would have to say that the longer it takes you, probably, the less you are going to be able to go up on the hot side and STET you are going to have to stay on the cold side. Our ramp information to date, which comes from some limited studies that look pretty good and seems to be consistent with what we were hearing yesterday from you, is that at 5/10 of a clo intrinsic insulation the comfort temperature is about 76.8°F; at 7/10 of a clo the base comfort temperature is 75.5°F and at 9/10 of a clo intrinsic insulation the base comfort temperature is about 74.3°F. It turns out that, at a rate of change of 1°F per hour, you can swing around these bases by + or - 3°F. This seems to correspond to what Bob Tamblyn was talking about yesterday; if you've got 9/10 of a clo (which is winter clothing) at a average base of 74.3°F you can get down to about 71°F and up to about 77°F and when you start getting outside that you start getting screams.

We can now talk about research needs. We started our considerations with the "off design point" problems. First of all, we feel there was a need to validate the steady state models within and outside ASHRAE Standard 55-74 when we are operating off design. In other words, at higher work rates than 55-74 covered; with different clothing (55-74 specifies 0.6 clo); with different mean radiant temperatures and air temperature adjustments, not just assuming that the adjusted dry bulb temperature will carry us. One of the other things we need to do, independently of looking at dynamics, is look at the value of improved insulation on the cold side. We know, for example that wearing 0.6 clo of insulation our comfort temperature is about 74°F for office work; for every tenth of a clo change, we expect we can get about a 1°F adjustment of the air temperature. So we can go to 60°F if we can get the office work force to wear two clo of insulation. In theory, because we can't get down much below socially accepted clothing levels, we can only go up to 77°F by reduction of clothing back to about 0.3 clo. Some other points should be raised though. We'd like to know what the adjustment for air temperature could be simply by improving the footwear, because that is the first onset of cold discomfort. Is the adjustment 1/10 of a clo of footwear per degree°F? I doubt very much that it is and I'll bet we can do a lot better with warmer footwear. We need to study the effects of altered clothing in general; particularly females with skirts, get them to wear slacks, get them to wear a little heavier clothing. In the comfort zone it doesn't matter; it is not critical and they can wear almost anything they want (within a wide latitude), but as you approach the boundaries on your swings, as you approach the boundaries on the comfort zone, what they are wearing (the clo insulation) becomes more critical. Also, we want to look at the value of a warm hat because as it gets colder you can lose tremendous amounts of your heat through your head because it's blood supply doesn't constrict as most of the rest of the skin blood flow does. Along the same line, we should look at what is the minimum air temperature for manual dexterity. In other words if you go to 2 clo at 60°F or you go to 2.2 clo at 55°, will the hand still stay functional? A simple, discrete question, but it ought to be answered because that is what is going to set the absolute lowest limit for office temperature assuming you could solve all the problems of insulating the body. We also ought to look at alterations in the permeability of clothing; should we go to reduced permeability, e.g., "wind shirts", "Gortex shirts", something like that? Normally, you lose about 12% of the heat you produce by diffusion of moisture and its evaporation from your skin. We can trap that with reduced permeability clothing and save about 10 or 15 watts, or 12% of the body's heat productions. We see little promise, on the hot side, of getting clothing that is going to be more permeable; that doesn't seem to work, though there are some long range suggestions. We feel that if we are going to push our thermostats, or our environments to the lower boundaries of hot or cold discomfort, we certainly have to consider acclimatization. Quite probably the operating standards for the beginning of the heating season or the beginning of the cooling season will have to be different than what they could be at the end of these seasons if you get out to the boundaries of comfort. The body, and the mind both have the ability to do quite a bit of adjustment. The adjustments won't be there at the beginning of the season, but at the end of the winter (or at the end of the summer) there will be different conditions for comfort up near the threshold; again, in the mid-zone of comfort, acclimatization doesn't matter. We also should look at sudden transients and short term occupancy; that hasn't been done in terms of night set back or walking in from the outside to an over cooled or over heated room and then letting the temperature drift. We also see promise in such approaches as the "Predicted Indoor Habitability Index" (PIHI) which is basically what we are after to develop a juxtaposition of the building, the conditioned air sources, the controls, their cycling and the resultant environment of the occupied spaces and their habitability by the occupant. That has been started; we feel it should be pursued for both dynamic or steady state. Also the ASHRAE ADPI is a promising modelling approach for the effects of altered ventilation, air infiltration or air motion.

Before we get to approaches in which dynamics is totally involved, we would also like to look at local auxiliary heating and overall auxiliary heating; what can you do with a spot heater just over the typewriter, what can you do with a panel convector or a panel radiator just at the work space, or instead of simply ducting the conditioned air into the whole space, duct the treated air down over the work site? There is some energy saving there we are sure.

Finally, when we get to the dynamics approaches, we need to know the applicability of the steady state models to slow drift responses, particularly the ramps. We think the models will work but we don't know, and we need to know the applicability of the dynamic model, which is a cyclic one, to ramps. We need to validate the dynamic model. We are a few years ahead in the dynamics research question, but we haven't done 10 years of research in the last three. Finally, at the dynamically reached bounds to comfort we ought to explore adjustments; i.e., if we drift up or down a temperature ramp, when we get to the bounds of comfort-discomfort (where the man or woman at the work site is at the end of his acceptance), instead of running down the ramp, can we simply take off or add clothing and then let the environmental conditions drift up or down a bit more? Can we do something about air motion; turn on or off a local fan? Can we adjust the local relative humidity or the overall relative humidity? i.e., can we ramp up in temperature and then, instead of changing temperature, ramp down in humidity by dehumidification? Can we do something with mean radiant temperature, kicking on a radiant panel at the work site when your air temperature has drifted down to the lowest acceptable level during the day? Can we achieve economies by locally adjusting the mean radiant temperature? Then of course there are some simple things like simply giving hot or cold drinks when you get to the bound; letting the people leave the work space and go to a recovery room which may be warmer or cooler; we even talked about simply shifting the work force from the perimeter of the building into the core, and the core work force out into the parimeter; i.e., crossover work shifts. We need to know more about recovery times.

TABLE 1. Human Thermal Balance and Its Relation to Comfort and Discomfort

HUMAN THERMAL BALANCE

$$M \pm L \simeq 0$$

$$M = 1 \text{ to } 17 \text{ MET (N.B. 1 MET} = 50 \text{ kcal}\cdot m^2\cdot \text{hr)}$$

$$L = (Q_R \pm Q_C - Q_{res} - Q_{diff} - E_r - W)$$

$Q_R = A_D f_{eff} f_{clo} (T_{cl}^4 - T_r^4)$

$Q_C = A_D f_{cl} h_c (T_{cl} - T_a)$

$Q_{res} = RMV(h_{ex} - h_a)$

$Q_{diff} = 3.1\ A_D(\bar{P}_s - P_A)$

$W = M$

$E_r = 0$ to 600 kcal/hr sustainable maximum

COMFORT: IF $M \simeq (L)$

$$PMV = (0.303e^{-0.036M/A_D} + 0.276)(M-L)$$

if:	$\lvert PMV \rvert$ 0	$\pm .5$	± 1.0	± 1.5	± 2.0
then:	PPD 5%	10%	25%	50%	75%

<u>COLD</u>: IF $M<L^*$

by: 25 to 80 kcal-uncomfortable

80 to 150 kcal-intolerable

> 150 kcal-danger of hypothermia

*cold injuries to skin can occur with M>L

<u>HEAT</u>: IF M>L

by: 25 to 80 kcal-uncomfortable

80 to 120 kcal-intolerable

120 to 160 kcal-risk of heat exhaustion

160 to 240 kcal-probable heat exhaustion

2.5 Circulation/Distribution: Herman F. Behls

Air and/or hydronic systems tie together the major components of HVAC systems. The air systems link the conditioned spaces with the heating/cooling coils, while the hydronic systems transfer heating and/or cooling mediums between components. Overlayed on the many possible types of systems and system layouts, each of which has its own dynamic characterisitcs, are the response characteristics of control systems. The Circulation/ Distribution Task Group, which included Mr. Harold E. Straub of Environmental Systems Corporation, Dallas, and Mr. J. Richard Wagner of The Poole & Kent Company, Baltimore, discussed the state-of-art of air distribution system design, space air diffusion, hydronic system design, and the characteristics of circulation/distribution components such as terminal control units, fans, coils, and pumps. Also, taken under discussion was the effect of mass and insulation on the response of a system to the loads imposed thereon. Although this task group treated system components individually, each HVAC system, including controls, needs to be evaluated as a complete package.

It is the consensus of opinion by the task group that duct systems are designed for steady state, design-load conditions, and frequently receive too little attention by Consulting Engineers. One reason is that, in spite of recently renewed efforts by ASHRAE, the design data on duct fittings which is available to designers is still rather limited. Other reasons are that the calculations are tedious and time consuming. Presently, there is consideration towards standardized duct fittings by ASHRAE Technical Committee 5.2, AIR DUCT DESIGN & CONSTRUCTION, to ensure energy efficient duct system design. To assist designers in the design of supply and return air systems, I, as a member of Technical Committee 5.2, am recommending through Technical Committee 5.2 that ASHRAE prepare and publish a comprehensive duct design manual similar to the ASHRAE Cooling and Heating Load Calculation Manual (GRP 158) prepared by Dr. Rudoy of the University of Pittsburgh. To design energy efficient duct systems, particularly variable volume systems, the use of computer programs is more than likely necessary. These programs should include standard fittings for which loss coefficient data have been validated.

The design and performance of constant and variable volume terminal control units was discussed in depth. Advances in the design of variable volume boxes has made the performance of single and dual duct, both constant and variable volume, air systems more reliable. Further sophistication of these control boxes will be rapidly forthcoming, and each will have its own response characteristics. The task group agreed studies are necessary to determine the response of each style of terminal control unit and that the studies need to include the control of air handling system pressures and flow beyond that controlled by the terminal unit.

Fans and their performance is another important factor in understanding the dynamic behavior of air systems. In variable volume systems, the performance characteristics of fans need to be known over the entire range of varying system conditions. In varying system dynamics the method of fan capacity control is of major importance, yet most data is very generalized. To dynamically analyze systems there is a need for a complete understanding of fan volume control for any of the methods devised, such as discharge dampers, variable inlet vanes, and speed variation. Many fans operate beyond the range recommended by fan manufacturers with apparent success, thus fan dynamic studies need to be extended to include off-optimum operation. Poor fan inlet and outlet connections can severely affect the performance of a fan and thus result in significant energy waste. To aid in the layout of fans/systems, the 'system effect factors' in AMCA's (Air Movement and Control Association) need to be more comprehensive and inclusive. Data is particularly needed for centrifugal fan outlets and vaneaxial fan inlets and outlets. The system effect factors for centrifugal fan inlet connections seem to be adequate. The Circulation/Distribution Task Group is of the opinion that the proper application and selection of fans is not as well understood by system designers as it should be. To assure efficient fan selection, training aids or other techniques, such as performance type specifications, is encouraged.

The theory of room air diffusion is not complete, but considerable knowledge supported by experimental studies is available for the steady-state design of air supply and return air systems. The Air Diffusion Performance Index, which is based on constant flow and cooling conditions, attempts to bridge the gap between the dynamics of airflow from diffusers and the dynamics of airflow in a space. A procedure of this type needs to be expanded to include heating as well as low and minimum airflow. Furthermore, it appears that the Human Factors Task Group intends to allow space design conditions to float from a fixed setpoint temperature; therefore, airflow patterns need to be studied in terms of varying psychometric conditions. Since the heating and cooling loads are not instantaneous, the space air diffusion studies need to be extended to include the response time necessary to pick-up loads, including the occupants, imposed on an all-air system, an all-water system, or a combination air/water system.

Many of the considerations for the layout and design of air handling systems also apply to piping systems. Pumps in water systems are analogous to fans in air systems except that the application and selection of pumps is better understood by system designers. Except for cavitation problems, pumps are generally less affected by adverse installation conditions. Water systems differ from air systems in that various water circuiting arrangements are possible, such as primary/secondary pumping. However, the basic system concepts are similar with regard to constant or variable flows and temperatures. Thermal time lag is normally more pronounced in water systems than air due to system mass. Mass includes not only the circulated medium, but also the materials of construction including insulation. Studies are necessary to determine the incremental magnitude of energy conservation as a function of system design, circuit layout, temperature control, and system operation. System shutdown, or on-off control, may have different characteristics than systems operated continuously.

So far we have covered air distribution systems, space air diffusion, and piping systems. To complete an analysis of these systems one must have extensive data correlation on coils, the link between air and water networks. A coil literature search needs to be conducted, the studies analyzed, and additional research identified. Workshop members have indicated extensive data and reports can be found in the literature.

To dynamically analyze HVAC mechanical systems with the purpose of efficiently utilizing energy the following needs to be studied.

1. Effectiveness of all-air systems, air-and-water systems, all water systems.

2. Effect of mass and insulation on air and water systems.

3. Duct design techniques, including layout and system mass.

4. Piping design techniques, including layout and system mass.

5. Response characteristics of HVAC system components; such as terminal control units, fans, coils, pumps.

6. Dynamics of airflow from diffusers and the dynamics of space air diffusion, including variable design comfort conditions.

7. Load pick-up factors for transferring load sources, including occupants, to the air systems.

8. Response of controls to any variation of system parameters; such as HVAC system selection, component selection and system design layout.

9. Effect of duct leakage and air stratification within ducts to system performance, including controls.

These are the major classifications identified by the Distribution/Circulation Task Group over the past few days. As research continues, many variations of these generic classifications will surface. Each concept will require a sensitivity analysis so as to eliminate as many variables as possible and thus keep the scope as defined by this workshop manageable. To assure the design, installation, and operation of energy efficient HVAC systems, specialized HANDBOOKS and WORKSHOPS will be necessary.

2.6 Design, Operation, & Use Patterns and Managements and Codes: Alfred Greenberg

As a continuation of what my predecessor discussed he sort of tried to tie together what went on before and I guess I feel the same way. I'm even going to tie in what he did and tie it up a little tighter. Maybe the one after me will really tighten the noose.

We discussed, basically, two separate areas: one is the area of Management and Codes, and the other Design, Operation & Use Patterns. The management and codes aspect really concerns itself with establishing the pecking order of all the parties involved in the process of building construction from the conception to the operation. You start off with the owner, then you add your design team. The utilities, the government regulatory agencies, the code makers, the financial institutions, etc. are all involved at various times. After that you've got the contractors who build the required work, then you have the operators of the facilities and the users of the spaces. The needs, the desires, the requirements and the role of each of these elements varies from job to job, area to area. Let's dispense with the contractors quickly. I don't mean to belittle contractors or the benefits they sometimes add to a project, but to me a contractor's only function is to translate what the designer has done into an end product; a product that matches the designer's intent. Contractors, many of them would be insulted by this. They seem to feel that they have a unique function to serve. They feel that they have experience, capability and ingenuity and should offer input. That is not at all what a contractor is supposed to do. Most contractors' input is aimed at reducing the cost and quality of the project in order to enhance their own profits. That takes care of contractors.

The owner is the one who wants the facility to begin with. He usually is concerned only with getting the optimum results at the minimum costs - first cost, usually. Our subcommittee finds that there is very little you can do to directly control an owner. We talked about incentives, disincentives, taxes, maintenance, all kinds of things. Realistically, these things don't work with many owners unless you really do something extremely radical, and we are not a radical society. We do things in very slow ramps.

Utilities are another area we can't really control.

The regulatory agencies go by the book with a few twists added. The code makers really just sit back and do whatever they are told. They don't initiate anything so they don't really enter into this dynamic response process. There is nothing dynamic about codes unless they refuse to accept your design.

The financial institutions usually go along with the owners, often they are owners themselves. They sometimes set standards for the owners but strictly from a financial point of view. They seldom really get involved in the dynamics of how a building is operated as long as they are certain they are going to get their money. That's all they really care about.

In this whole process everything really seems to point to two elements where you may be able to develop a degree of control. If you can exercise that control, it will radiate out and eventually affect the owners and the way in which they do things - and the government and regulatory agencies in the way they do things. Space users don't usually have much to say about or know what goes on. The design team and the operators are the areas on which we must concentrate. First of all, they are the weakest link in this whole building process. They are the areas where ASHRAE can potentially do something about changing the way in which they operate and hope to improve the total situation. Right now the design team's role is primarily to prepare plans and specifications. I am not talking about the unusual situations. They prepare the plans and specifications for bid by contractors. Their role in the construction process is generally quite minimal. They check shop drawings; they may go out into the field, pick up a few items, make a final punch list and that is it. We feel strongly that emphasis must be placed on developing procedures through ASHRAE statements, directives, guidelines or standards as to what the true role of a consultant should be. The consultant is the developer of the design and it is on the consultant that the owner leans in order to get something that the owner feels that he can live with or that the space users will live with. The consultant really has no control over the process if all he does is put designs down on paper and then is eased out of the picture and has no control over what happened. We believe that the consultant, since he developed the design, is the only one who can really interpret the design during construction; therefore, he has got to be more actively involved in construction supervision process. He must make sure that changes are not made that affect the operating or energy benefits of the project or the dynamic response of the results that are anticipated. The consultant is the only one who really knows what results are expected. I don't see the logic of outside companies coming in and testing and balancing the system and certifying the results based on their interpretation of the design concept. That means a third hand party who has been hired as a low bidder by a contractor, also a low bidder, and who is not beholden to the consultant coming in to interpret and measure what the results should be. Really, the consultant can do that best and yet very few consultants do testing and balancing. Then, after the job is built the operators are brought into the picture. Oftentimes no one knows who is going to operate the buildings until after the job is built. Therefore, the operator has no input into the design aspects nor the construction aspects. The consultants seldom ever give the operator real input as to how the building is supposed to function. Therefore, the designer, to really do his job properly for the owner and to insure the proper results of the building, must develop good operating and maintenance manuals - not just a package of manufacturers' literature. That usually means that from the inception of the design, that a true design involvement in a job will last through the design, through the construction and probably two to three years into the operation of the building in order to insure that the building is operated as intended and that the owner is getting optimum results.

I believe that ASHRAE can set up some effective guidelines as to what the involvement of the consulting team should be in order to properly establish and maintain the dynamic characteristics of a building. If the government tried to do it, forget it. ASHRAE can suggest, but at least somebody's got to do it. Nobody's doing it right now - certainly not NSPE, the consulting engineers councils or the AIA.

Talking about dynamic response, there is no point talking about things that should be if we can't control the processes that attempt to develop the end result. Operators are in worse shape than engineers. Most of them don't know much about operation of a building. Many of the people that operate buildings are insufficiently trained. There is really no place to train them. Too many are nothing more than the glorified janitors that used to operate the brown stones or the six story walk-up apartment houses. The good ones come from the marine field. I've always felt that building operations was a good place for consultants to retire to. I understand they would make more money, though, operating a noodle shop. We've got to do something about up-grading operations in buildings. Otherwise the best layed plans and standards that we are talking about are going to be meaningless. We've got to set up schools with proper courses and continuing education for operators. It all starts with proper operating and maintenance manuals that the engineers will develop. The manuals are based on the assumption that the engineers know how the buildings are supposed to be operated. Except for setting up minimum effective standards I believe that between the trade unions, the building operators, the building owners and ASHRAE, we can set up the mechanism for the proper training of operators. ASHRAE can help. I think we have the expertise to establish the curriculum and personnel for these courses. If we can get these other groups to participate so that they input their knowledge and support then we can get an effective program moving. In effect, what I am saying is that right now all I am talking about is education and although I think many people don't consider education as being very dynamic, we are at that point in time where to go on from here we better know what we are talking about or we are just turning wheels.

That takes care of management and codes.

ASHRAE must set up an energy audit standard. The 100 P series being worked on now in ASHRAE is a complete and utter fiasco. I don't mean to impune the well intentioned efforts that have gone into it; a great deal of effort has gone into the development of the 100 series. Some of you here may have been involved in it. I wrote a letter when it started 2-1/2 years ago strongly suggesting that they silently fold their tents and go home and that something really good be done. It is not that what they've got is so bad, it does not help someone know where to start, it is unenforcible and it is not for all building types. The one thing that is common about all building types is the procedure for doing an audit on existing buildings. Yet, that is the one thing that is missing from all these 6 standards that are being discussed. We've got to set up a uniform standard for audit procedures. ASHRAE can do that and it has been discussed as to whether or not it shouldn't be a 7th group on top of the 6 groups that have already been established, but apparently they are not planning on doing it. We strongly recommend that this be done. This is an area for immediate research and action.

We also believe that one of the things that has to be studied in buildings from the Design, Operators and Use Patterns' viewpoint is the development of operating codes which accept the premise that buildings do not operate at steady state much of the time and that means for reducing lighting levels, outside air requirements, etc. should be modulated to meet actual demands, if that can be measured. For example, outside air is one of the biggest energy wasters. Codes set up minimum outside air quantities based on the peak occupancy of the building. How often do you have design occupancy in a building? So why can't we set up a criteria for establishing whether and how we can minimize or vary outside air based on the actual occupancy of the building. We should also make sure that the outside air is where you want it, which is where the people are. There is no point in setting up 5cfm per person if all the air is going to be dumped in one spot and all the people are everyplace else in the building. In many buildings this is what happens. For example, if you put the air in the corridor and you have minimum air to begin with and the people are not in the corridor, then you need more outside air for comfort. To get the outside air more evenly distributed and as needed is an area where we've got to do some research so that it will eventually end up in the code areas.

We talked about licensing and certification of operators. We believe this is necessary. The utilities enter into the building process because a lot of utilities don't permit sub metering or check-metering or informational metering or whatever. If you are going to put in means for measuring the dynamic characteristics of a building then we've got to also provide the means for at least getting the information so that it may be analyzed and acted upon.

Ultimately, every building has got to have some type of energy management system. A system which records and analyzes sufficient information to enable operators to understand what is happening. In general, people cannot measure most dynamic characteristics or operate buildings effectively based on dynamic characteristics that vary in ways which are difficult for them to interpret into proper actions. Proper instrumentation can do the job. Yet, we can't even get these relatively simple systems that are installed now to work. There is a lot of work to be done in the control applications area. Not in the theory of control, but how do you take these complex fabulous machines and make them work? Again, education, liaison, coordination, cooperation. We got more human problems than technical problems, going even beyond the physiology.

Another area for ASHRAE research is that enough buildings have these complex, wonderful computer systems that don't work and are sitting around idle, that ASHRAE may select some of these buildings and get research projects going to make them work. The information obtained may help us set standards or guidelines for things like energy budgets and minimum automation requirements for various building types. Of additional interest are the energy budgets for the sub-systems in the building so as to establish what percentage of the major energy using areas of the building are a part of the total. Building operators could then find out accurately and intelligently where to spend their major efforts on improving the quality of the building and getting it down to the energy budgets that are going to become law and are going to become the way in which we talk about buildings.

2.7 Energy Storage: Calvin D. MacCracken

On Energy Storage we came up with the following points. The first point that we looked at was the energy consumption of duct systems. We were very impressed with the seasonal losses in heating and air conditioning that may be incurred as well as the loss of response from unwanted storage of heat or cooling in ducts and perhaps a lesser extent in pipes. Lower mass of ducts or internal insulation may secure a large savings. We urge that a research study be made of the actual, seasonal energy consumption of a low mass all-fiberglas duct system as compared with the conventional. We suspect that this savings is far larger than might be expected.

The second point was that all new construction with central heating or cooling be designed with distribution systems that can deliver full load at 105°F. This allows for operation and use of storage for heat pumps and for solar energy on an efficient basis.

The third point - we recommend a research project on means of retrofitting a low mass, low temperature, hydronic radiant space heating and cooling system and to building it in a cost effective manner.

Our next recommendation is the study of radiant room cooling with the use of a non-ducted dehumidifier.

We also recommend the use of dryness in storage and buildings so that a space, its envelope, its contents can be brought down to low relative humidity at night and thus, daytime cooling loads could be lower.

We also recommend the study of off-peak heat pumps which store both cooling and heating and pick up heat from low cost unglazed or unspaced glazing solar collectors and from the ground as well as from the ambient air and that this be implemented as an ASHRAE Task Group on multi-mode heat pumps. The TG has already been unofficially formed.

We recommend that chilled water storage systems for large buildings be broadly encouraged and engineers educated as to its cost effectiveness and energy and cost savings. That both small storage (24 hour chillers) and large storage (100% off-peak chillers) be explained. We recommended that bulk tank eutectic salt thermal storage systems be studied in light of the latest developments. We recommend that rock bed studies be made to improve analysis and experiment with different designs and materials.

3.0 SUMMARY: William P. Chapman

First of all, let me take this opportunity to thank you for your participation, for the contributions that you've made and, really, for the enthusiastic response, dynamic or otherwise, that you've given us. I was apprehensive when we started, it was a tough task and I realized taking 2 1/2 days of your time was asking a tremendous contribution from you. Now it does seem that the workshop has generated something that will be very worthwhile. I think we can look upon this workshop as one of the milestones in ASHRAE's effort to advance technology. I do believe we are going to be able to come up with a long range research plan that we set as our objective.

The task group will meet on May 11th in Chicago to further discuss this plan. Except for Cal McCracken, the Workshop Session Chairmen are members of the Task Group, so by inviting Cal, we will have to review the results of this workshop.

In these few remaining minutes I think we should attempt to discuss how the various research requirements can be synthesized. One means might be to develop a simulation model. We are not able to do so at the moment, and we do not want to re-invent the wheel, but I do believe we could develop a generalized model that will permit us to create special and separate models later. For example, we might consider one model for equipment selection in order to compare design alternatives for operating strategies to optimize energy utilization. I would like each of you to think of the research needs that you've discussed today and developed during this workshop so that you might comment on the practicality of developing a simulation model.

David Didion, in the equipment session, stated that there was a need to develop some dynamic response characteristics of equipment, but also he said our data on transport lags; that same point was brought up in the distribution session. I think it was pointed out in the storage session that there is a considerable amount of energy that is contained in the conduit system, (in the duct work, in the pipe work) all of which relates to the distribution session. Considering these comments, how might we integrate these needs? Further than that, if we get this information, how might we use it, how might it be put together? I believe that the best way to integrate the programs is to generate a simulation model. True, it is going to be abstract at first; it will require education; and it will have to be disseminated to our users on the assumption that they use computers. Nonetheless, if these are characteristics that each of you have described that in turn will effect the proper utilization of equipment, then they have to be considered in one synthesized or integrated whole system. The Human Factors Session pointed out that we can tolerate some temperature deviations of $\pm$ 3°F providing the rate of change isn't too great. But how might we predict this rate of change if we don't know the dynamic characteristics of the equipment and the structure, itself? Conversely, knowing this, we should be able to generate operating procedures and strategies that will allow us these excursions without reducing the quality of performance and control that we have demanded of our past systems.

The task group will meet on May 11th and try at that time to take these various statements and describe somewhat more fully this one research plan. It can very easily become too vast, too great to be considered. We have to be careful of that. It can also appear that we are going to redo what a lot of people have attempted to do in the past. We have to be careful of that, but if we are introducing this new concept, that we are leaving the steady state thermal equilibrium assumptions, I think we have to make the suggestion that what we have done in the past has to be extended. I am not as concerned about the charge that we will be reinventing the wheel, as I am concerned about our ability to take these factors that you have described today and put them into one totally integrated system. No doubt about it, that's going to be quite a task. The Task Group will prepare an overview statement, and make the proceedings of this workshop available to all of the participants. We will have a symposium in Los Angeles to advise the Society of our findings. That is our goal, we obviously cannot accomplish it in time for Detroit. I would invite each of you that participated in this workshop and all other interested people to attend the symposium in Los Angeles. I would ask that all people take these proceedings, review them critically, submit any comments that they feel are pertinent so that speakers at that symposium will have advance notice of comments. With this type of conversation and this type of communication, I think we will be in a good position in the early part of 1980 to make a presentation to the Department of Energy, and I would think with the credentials of this group, that such a recommendation will have a tremendous impact on research planning at the government level.

Getting back to what Paul Achenbach said 2 1/2 days ago, it is incumbent upon us to take this plan, get the work done, carry it forth to the design stage then to the construction stage and thereby put it into being. If we stop at the research description, then of course, it will have gone to naught. We see, therefore, that a great deal of continuing effort is required, starting with the task group, armed with these statements, approaching the TCs. Most, but not all the TCs that will be incorporated in this program, are represented here today. That will give us a head start. At the TC meetings in Detroit, and again at Los Angeles, I would ask you to carry this message to them; alert them to the fact that these proceedings are going to be available and are going to be discussed. Advise them that the task group has started its effort to consider dynamic response.

I am sorry that today we won't have the time to do much more than take comments from the floor. We are not going to be able to prepare a statement today that can be used as an overview statement, but I do think we have time, on the basis of what we have heard this morning, to make some comments regarding the practicality of a model, regarding the soft spots and difficulties of a model, etc.

Comments by Alfred Greenberg

I think I would like to suggest another point of view to what you said about what the results of this should be. You talk about designing a few things and developing a simulation model for conduits and distribution systems, etc. As an alternate I suggest a different approach. I suggest that instead of getting all these efforts into universities and laboratories of manufacturers that we strongly consider the use of the existing buildings as the laboratories. Use the technical expertise and other resources of the manufacturers. Don't make everybody wait until the researchers have come up with what they think is the right thing while everyone else sits back and does nothing until they come up with the right answer. Get something done NOW. Produce a methodology, a procedure. If one building does it and it works and he has followed a methodology which is reproducable, verifiable, and transferable others will follow. If you just do it "inhouse" then nobody would get anything done. We need results. So actually the approach is not to produce research projects to existing buildings. Let's get all kinds of information but lets not wait until we get to the point where we are sure it is going to work, where we are not going to have anyone yell at us. That takes too long and is inadaptable and you still have the field problems. Right now you've got the buildings, let's use them.

Response by William Chapman

Well, Al, I certainly think we will have to use the existing buildings to validate the work we are going to do. I believe what we were talking about here today (applying dynamic characteristics to building operations), though, is an approach that is not available for immediate application. We have nothing to take out today to get the job done, other than to tighten up possibly, as you have pointed out, the construction techniques, energy audits, these types of things. They aren't quite germane, however, to the subject of dynamic response. If we are going to utilize dynamic response to prove operating strategies, then certainly we need the research requirements that have been set forth by these other sessions. That is going to take time, several years of time. In the meantime there can be improvements in our present techniques, yes. I hope that the TCs will pick that up.

Comments by David Didion

I think you will find out an obvious thing. We in equipment group not only understood what Tomami Kusuda was trying to say, we came up independently with the same things. Our third problem of the first category was an attempt to state what was needed. If you are going to take a dynamic approach to the whole building you must look at, for want of a better word, the time constant of the building shell vs circulating system vs the equipment, etc. Try on a dynamic basis to identify the magnitude of the potential energy savings of these different systems. I think this actually is what Tom is suggesting, the forerunner to the model. It tells you what characteristics are more important on what elements of the building system are more important and, therefore, should be modelled in detail. It might be possible, for instance, that equipment response characteristics are very short relative to the others, for example the circulation system, and will, therefore, as you are implying may not be significantly effected by true dynamic response. Otherwise, if you don't do this type of overall study, I'm almost certain the model will become unyielding. It is too big, too complex, so you have to drop out the compliments which are less significant. I think what Tom is suggesting and what we've talked about is just this; there is a preliminary study of what is important for dynamic modeling of the building.

Response by William Chapman

Yes, I think it is appropriate to say that we are going to have to creep before we walk and this, may indeed be reflected if we have oversimplified the model and thereby have made it useless. On the other hand, we can bog down in a morass of detail.

Comments by Raymond Cohen

You have just heard Dr. Didion warn that a building simulation program can be so large that "we can bog down in a morass of detail". I'd like to add that it is extremely difficult to develop a large scale computer model which is able to solve all problems for everyone. It makes much more sense to me to approach the problem with a "two prong approach". The first part is the development of models using energy savings as a criteria which can predict the dynamic characteristics of the components in the system. The second part is the use of these models in an overall system model.

For some time, we have been involved, as have others, in the development of computer simulation models for components such as compressors, heat exchangers and throttling devices. Even individually, those which can predict dynamic response are very complex. It might seem appropriate to assemble these complex models of the components into one big model for the entire system, but that takes a considerable amount of time and energy to develop the program, and cost for computer running time to use it. Instead, we should use the complex simulation models of the components to determine a characterization of the dynamic behavior of these components so, for example, that a single, or a few linear differential equations (a time-constant approach) can be used for the model of the entire system. In this way, we will not have to carry over the mass of detail of the component models into the system model, but still carry over enough information so that the system model adequately shows accurate system dynamic behavior. This approach would be very efficient with the big advantage that the system simulation model may have a short computer run time - short enough to consider using it as the criterion function of a computerized optimum design search routine.

Unfortunately, we neither have all the component models nor do we know how many time constants will be needed to adequately characterize the dynamic behavior of each component. The "two prong approach" I suggest is to attack these two problems simultaneously; that is, to develop and test both component models and the system model simultaneouly. Thus, use of the individual complex component models would provide behavior patterns on which to base time constant assumptions. Use of the overall system model using assumed time constants for components would determine sensitivity to the number and magnitudes of the time constants. These two parts of the approach, when executed simultaneously, constitute a synthesizing process which will lead to appropriate simplifying assumptions showing which elements have greater importance for energy conservation than others and ultimately leading to a manageable system model capable of an "optimum design" procedure.

Response by William Chapman

That is probably what would be unique; that would be the contribution, this synthesizing. If we can work with simpler assumptions, and it is probably true that the importance of some of the elements will so out-weigh the importance of others that great simplifications can be made. The trick, I suppose, will be to make a pretty accurate estimate of the major and the minor factors. It is that kind of comment that I welcome at this time.

I see that Dennis Miller is dutifully taking notes and is going to help us pull this overview statement together.

Comments by George Schade

I would just like to say that I don't think simplification is the right word. I think that very soon you'd realize reduction to manageability is the correct thinking. Simplification has kind of a bad connotation to it and it seems like you are throwing something away, while to try in great detail to simulate a building, it may be unmanageable.

William Chapman - So, instead of simplifications reduction to manageability.

George Schade - Right, reduction to manageability is something that can be done.

William Chapman - Alright. That is a good point.

One question that comes to my mind is the source that we might consider, or sources that we might consider, as the developer of such a simulation model. Where might we turn to have such a development done? I think that whoever does it will have to draw on the TCs for expertise. The judgement, through experience of what is apt to be important, of what is apt to be major compared to what might be considered as minor, would seem to be found in the TCs. The first order of approximation that might be considered practical probably would be suggested by our own normal sources, usually the TCs, but where might we turn for the developer? Who might take the lead in attempting this simulation model? Are there any suggestions along those lines?

Comments by Alfred Greenberg

Yes, very definitely. Again we seem to be avoiding the fundamental issue, which is, that you've got all these existing buildings. What we should first try to do is see how energy is used in those buildings. We can play all kinds of games with new designs, but you won't play games with new designs until after they are built, and you find out what they really do. The first order of business is to reduce energy. First you need to develop an acceptable audit procedure. An audit procedure that will determine in sufficient detail what a building is now doing, so that you understand it and you break it down into its major important components. If a building is grossing, based on the meters you now have, 150,000 Btu per square foot you develop the procedure by means of some computer program that will allow you to find out how much the elevators use, the lighting, the people, the air conditioning. You break it down in zones, the domestic hot water, computers, etc. Once you have the building broken down into components or zones then you can start determining other factors such as: what is the frequency of use, how do the various envelope reaction, etc? Can you determine this information from existing instrumentation in the building or do we have to get additional instrumentation? Once you have this information you can start to design ways of saving energy, but you must start with existing buildings.

Comments by David Didion

Bill, maybe it isn't clear that the model that is being discussed, I believe, is an operational model. One that simulates existing building operations and not one to design new buildings with. I don't know if we said that at the beginning or not.

Response by William Chapman

Yes, Dave, I meant to bring that out. In fact, in our cross-area session yesterday, it was stated that we do need separate models. One would be the operating model, call it a control model. The design, is a load calculation program. We are not attempting to utilize that program or to modify it for design alternatives; however, another use of an overall model might be to compare design alternatives. At this time we don't have an easy means of comparing alternatives.

Now, I see that we are going to have to start packing up to catch the first bus. Again, gentlemen, thank you so much for your participation, it has meant an awful lot to me. Thank you.

APPENDIX A

WORKSHOP ON THE DYNAMIC RESPONSE OF ENVIRONMENTAL CONTROL PROCESSES IN BUILDINGS

Prepared by the Workshop Subcommittee
Task Group on Dynamic Response
January 24, 1979

INTRODUCTION

On March 13, 14 and 15, 1979, a workshop will be held at Purdue University, West Lafayette, Indiana, for the purpose of evaluating the dynamic characteristics affecting the energy used by the environmental control systems of buildings. These characteristics result from (a) building structures, (b) HVAC systems (distribution, equipment and control), (c) the physiological response of occupants to interior conditions and (d) the use of the buildings and their spaces. Specific areas of discussion will include the following with respect to dynamic characteristics: (a) the present level of understanding, (b) the potential impact of complete understanding, and (c) the research required to gain the level of understanding necessary for application to design and operation.

The workshop is being organized by the Task Group on Dynamic Response as an ASHRAE research effort. The Department of Energy is providing the funding for the workshop.

The information obtained from the workshop, which is to be summarized in published proceedings, will be used by the Task Group on Dynamic Response to develop long range research plans which will lead to the consideration of dynamic characteristics in order to optimize the energy used to maintain acceptable comfort levels in buildings. It is expected that other ASHRAE task groups and technical committees as well as government, university and industry organizations will also make use of the results of the workshop.

The objective of this paper is to present (a) background information on the need for the workshop, (b) the development of the workshop approach, (c) the procedures for the workshop and (d) the responsibility of those attending the workshop.

BACKGROUND

Most design and analysis of buildings and their environmental systems has been, and in general still is, based on steady state considerations only. The dynamic characteristics and interactions of the building system have not been considered of sufficient importance to warrant detailed investigation. The same emphasis on steady state has been reflected in the determination of occupant comfort conditions. Primarily because of the present and expected future cost of the energy used by building environmental control systems, it is necessary to understand the dynamic response of these systems and the dynamic requirements for occupant comfort. Although the complete benefits of considering dynamics of the design and operation of buildings and their HVAC systems are not at this time known, there are many indications that there are indeed benefits in terms of energy use as well as initial building and system costs and equipment operating costs.

Energy use and the need for dynamic response consideration can be examined from the point of view of analysis and actual system operation. Nearly all building and environmental control system analysis for design or general study is based on the assumption of steady state conditions over one hour or longer periods of time. Such analysis has been shown through validation and comparison tests to provide an effective tool with which to comparatively evaluate building structures and HVAC system designs as well as some general operating methods. Specific validation tests, such as those carried out at Ohio State, have shown that the use of hourly based calculations and the assumption of essentially steady state operation can result in good agreement between calculated and actual energy use over long periods, such as one month or a full year. However, agreement over relatively short periods, such as hours or days, has not been found to be nearly as good as long term results.

It has been found that energy use can be reduced by a number of techniques which reflect HVAC system dynamics and dynamic interactions. The control of the time a system is started in the morning or shut down in the evening; the control of supply systems (cooling and heating) to the specific level needed to meet loads; the cycling of HVAC equipment for electric demand limiting or average energy use reduction - all of these are presently in use and produce system changes which act over periods of minutes to a few hours. Physiological research indicates that the interior environment does not have to be maintained at constant conditions, but rather can be varied beyond traditional comfort conditions for short periods--minutes or hours--without significant adverse effects. The effective use of storage to support both heating and cooling as well as some heat recovery techniques requires system evaluation in minutes or, at the longest, hours. Thus, it is seen that the accurate evaluation of many present and future means of reducing energy use must consider time periods not well covered by existing building analysis methods. What is required are techniques which can represent component and control dynamics as well as dynamic interactions. Such techniques are not available in ASHRAE literature and have been developed to only a limited extent by the industry in general.

The ultimate objective of the knowledge of dynamic response is not analysis of what might be, but rather to produce operating methods which optimize energy use; design procedures which may reduce building costs and HVAC equipment monitoring and control techniques which maximize long term performance. It is expected that through the knowledge of dynamic characteristics and interactions of the building structure, environmental control system and occupant comfort requirements, operating strategies will emerge which will optimize the use of energy. Such knowledge will also lead to design techniques which take into account dynamic operating requirements and can thus result in HVAC system and equipment selection to exactly meet the needs of the structure and interior environment specification. Finally, through a knowledge of HVAC system and equipment characteristics, the ability of the building operator to maintain peak performance of the environmental control system will be enhanced.

Each of the major factors of the building system - the structure, the interior ventilation processes, the primary heat transfer equipment, the control processes for ventilation and heat transfer equipment, the required interior conditions and the occupant comfort requirements are specifically considered by one or more ASHRAE technical committees or task groups. The scope of no single TC or TG extends across all of these. As developed in the previous paragraphs, all of these factors must be encompassed if the limits to the use of energy in a building system are to be evaluated and, more important, achieved in actual practice. The Task Group on Dynamic Response was established in order that the gaps between the areas covered by the TC's and TG's can be filled. Each member of the TG is now or has been actively involved in one or more technical committees, thus establishing on the TG a wide cross section of interests.

DEVELOPMENT OF THE WORKSHOP

It was determined by the members of the Task Group on Dynamic Response that a major obstacle to the consideration of the dynamic characteristics of buildings and their interactions is that there is no single point at which the problem can be attacked. Thus, a single technical committee, even if interested in this area of study, can develop research projects which only produce information on one part of the total. This information, considered separately,, may well not lead to any significant conclusion relative to the overall impact of dynamic characteristics on building operation and energy use. With the view across many aspects of building environmental control systems represented by the task group, the general research efforts necessary to achieve mutually supporting results can be identified. By identifying these research efforts, organizing them into a coordinated plan and then presenting this plan to the technical organizations within ASHRAE, the task group can best fulfill the objectives for which it has been formed as well as maintain the function of a task group as defined by ASHRAE.

The primary activity of the Task Group on Dynamic Response is then to determine the research activities which are necessary to achieve an understanding of the inter-relationships between dynamics of buildings, building occupants and building systems and the effect upon energy utilization. There are two specific objectives to this activity.

A. The first objective is to identify the research activities which will lead to:

    1. The understanding of the dynamic characteristics affecting the environmental control systems of buildings which result from (a) building structures, (b) HVAC systems, (c) the equipment used in HVAC systems, (d) the interior conditions required for occupant comfort, and (e) the use of the buildings and their spaces.

    2. The capability to utilize the dynamic characteristics and their interactions for the development of (a) operating strategies for the optimization of energy use, (b) improved design procedures for buildings, their environmental control systems and environmental control equipment and (c) improved methods of maintaining HVAC equipment performance.

B. The second objective is to combine the identified research efforts into a research plan which will result in an orderly development of the understanding of the dynamic response characteristics and interactions and the application of dynamic response considerations to the design and operation of building environmental control systems.

The detailed knowledge necessary to effectively achieve these objectives goes beyond that readily av.ilable to the task group. It was concluded that a workshop, made up of individuals knowledgable in the major areas of interest as identified by the task group, would be the best approach to developing the information necessary for the research plan. Therefore, the workshop described in the following two sections was requested.

WORKSHOP PROCEDURE

The workshop developed by the task group will be held on March 13, 14 and 15, 1979 at Purdue University, West Lafayette, Indiana. The general characteristics of the workshop are to be as follows:

1. As presently planned, there will be eight areas specifically addressed by the workshop, these areas, the number of invited participants and the chairmen responsible for the workshop session corresponding to each area are:

   a. Equipment - 4 - Dr. David Didion, NBS
   b. Controls - 3 - Dr. James Tobias, Honeywell, Inc.
   c. Structure - 4 - Mr. Ross Meriwether, Ross F. Meriwether Associates
   d. Human Factors - 2 - Dr. Ralph Goldman, U.S. Army Research, Environmental Medicine
   e. Circulation/Distribution - 5 - Mr. George Coultas, Kahoe Air Balancing Company
   f. Design, Operation, Use Pattern - 3 - Mr. Alfred Greenberg, Alfred Greenberg Associates
   g. Management and Codes - 3 - To be announced.
   h. Energy Storage - 3 - Mr. Calvin McCracken, Calmac Manufacturing Corporation

   Each of these is discussed further in later paragraphs.

2. The discussion on each area will be carried out in concurrent working sessions and will be led by the session chairman designated above.

3. In order to gain the specific expertise needed, each session chairman will invite the number of persons noted above to participate in the workshop (hereafter referred to as invited participants).

4. At some time during the workshop, persons representing different areas of expertise will combine in "across area" working sessions in order to have a more general exchange of ideas.

5. A preliminary time schedule for the workshop is as follows:

   Tuesday, March 13

   8:00 - 8:30 - Registration
   8:30 - 10:30 - First general session
   10:30 - 12:00 - First working session
   1:00 - 5:00 - Second working session

   Wednesday, March 14

   8:30 - 11:00 - Third working session
   11:00 - 12:00 - Second general session
   1:00 - 3:30 - "Across Area" working session
   3:30 - 5:30 - Fourth working session

   Thursday, March 15

   8:30 - 9:30 - Fifth working session
   9:30 - 11:30 - Third general session and conclusion

6. Based on the funding provided by DOE through ASHRAE, the session chairmen, invited participants, and workshop organizers will be reimbursed for the expenses incurred in attending the workshop. This includes travel, food, lodging and registration fee.

7. The workshop is open to all interested persons. However, prior registration is required and attendance will be limited to 90 persons in order to maintain the intended "working" environment. Persons not included under item 6 will not be reimbursed for expenses and their participation in the working sessions will be limited to written comments submitted to the session chairmen.

8. No formal presentations of papers are specifically planned. Informal presentations may be requested of the participants by the session chairmen or workshop organizers.

9. The discussions during the working sessions will be summarized, as appropriate, under the direction of the session chairman. These summaries will be the primary ingredient of the published proceedings.

10. Purdue University, as workshop contractor, will be responsible for facilities arrangements, registration, publications and financial control.

The workshop sessions are discussed in more detail in the following paragraphs.

The three general sessions will include all workshop attendees and will be prepared by the workshop organizers. At the first general session, the background of the workshop will be presented; the objectives and procedures described and the administrative procedures discussed. The second general session will be used to discuss briefly the progress of the first day; to consider procedural problems if any and to set up the "across area" working sessions which will follow. The third general session concludes the workshop. Summary reports will be presented by each session chairman. The general results of the workshop will be discussed and any final adminstrative details considered.

The working sessions are the basic feature of the workshop. The results of these sessions, which are run concurrently for each of the eight planned areas, are the results which will be reported for the workshop. The specific format for the working sessions is the responsibility of the session chairman; however, the general format will be as follows:

1. First session - outline of procedures, introductions, objectives and comments from participants.

2. Second and third sessions - develop the details of dynamic characteristics, impact and understanding in respective areas. Consider research goals, level of effort represented by the goals and impact of results.

3. Fourth session - begin summary of discussion, review results for completeness, cover open areas of discussion.

4. Fifth session - finalize the results of the previous sessions and finalize presentation at the following general session.

As presently planned, eight areas are to be covered by working sessions during the workshop. The scope of each of these areas and the rationale for their selection are discussed as follows:

1. Human Factors - the ultimate product of the environmental control system in buildings is, in most cases, to maintain an acceptable level of comfort. Historically, comfort levels have been based on steady state environmental conditions. Recent research indicates other approaches, considering dynamic conditions, may result in more flexible environmental requirements. This flexibility may well lead to lower system operating costs.

2. Structure - the heat and mass transfer through the shell of buildings and within the interior has long been considered only with respect to steady state extremes. The use of hourly based analysis programs improve the ability to predict heat transfer through the shell on a more real time basis. However, the dynamic characteristics of other factors such as radiation, water vapor transport and infiltration, all of which impact comfort and energy use, are not well defined. In addition, the dynamic nature of the properties of the materials, when used together in buildings, with respect to temperature and water content, are not well understood or applied to design or analysis.

3. Equipment - given a number of units of energy intensive equipment (chillers, boilers, fans, pumps) and a steady state load, there is a set of operating conditions which result in minimum energy use. Some work to identify this set of conditions has been done. However, steady state loads exist only a portion of the actual operating hours in a building. Thus, the more general problem is one of maintaining the equipment at an optimal state in the face of dynamic loads. A further consideration of dynamics with respect to equipment is the effect on maintenance and operating life.

4. Circulation - the process of moving the air and water through a building is dynamic in nature although again normally considered as steady state in design. Not only does the distribution process consume energy through fans and pumps, but also the process affects the performance of the equipment through the time required to meet the loads. Air and water balancing are both significantly affected by the dynamic nature of the loads imposed on the HVAC system.

5. Controls - fans, pumps, chillers, boilers and the conditions of the building interior must be controlled. Design and analysis practice has been to generally consider conditions fixed at the values specified. This only approximately represents real control characteristics. Offset, oscillation and response time affect energy use and comfort. Further, if the building's energy using systems are to be maintained at an energy optimal state in the face of dynamic loads and non-linear characteristics, forms of control are necessary which utilize time varying conditions to determine and maintain the proper set points.

6. Energy Storage - the use of energy storage techniques is becoming much more common in buildings. This storage, associated not only with solar heat augmented HVAC systems, but also with systems using conventional hardware, is a dynamic process of availability and transfer. For storage to be as effective as possible, the dynamics of its use must be known and entered into the design and operation of the HVAC system.

7. Management and Codes - almost all specifications of building operating conditions whether by managers or code writers, are based on steady state conditions. If it is assumed that future buildings can be and are operated based on dynamic criteria for comfort and the HVAC systems, in order to optimize energy costs, what is the impact on present specifications, management practices and codes?

8. Design, Operation and Use Patterns - the evaluation of the benefits and feasibility of the application of dynamic considerations to the operation of buildings is dependent on the dynamics of the loads imposed on the HVAC systems by the type of environmental control system employed and the use patterns and operation of the building. Effective analysis and projection of cost benefits requires representative data on these factors. The understanding of the dynamics of the building, comfort conditions, equipment and control must ultimately relate to a coordination of the initial design of the building (through system selection, equipment sizing, hardware specifications, material selection, and the method of building operation). This approach will represent a significant change from present practice.

When the impact and/or application of dynamic characteristics are understood in these areas, it is expected that the benefits of the consideration of dynamics in building environmental systems will be realizable.

The "across area" working sessions are to mix people and their ideas in order to help insure that the summary statements of each area reflect the overall theme of dynamics with respect to the total HVAC system. The invited participants will be split into eight groups with each session chairman leading the discussion of the group assigned to him. During this session, each participant may summarize the considerations in his area.

RESPONSIBILITY OF WORKSHOP ATTENDEES AND CONTRACTOR

The workshop will be a success through the efforts of those attending it. To achieve success, each attendee - organizers, session chairmen and invited participants - have a responsibility to the workshop and ASHRAE. Some of these responsibilities are discussed in this section.

The workshop organizers in cooperation with the workshop contractor, Purdue University, are responsible for providing an environment conducive to the accomplishment of the workshop's goals. The three general sessions will be set up and administered by the workshop organizers. Specific speakers and the presentation of necessary information are their responsibility. Following the workshop, it will be the organizers' responsibilities to insure that publication and financial arrangements are carried out by the workshop contractor.

The success of each of the planned eight sessions is dependent on the session chairmen. This success will result both from the people selected for the session and the leadership of the six working sessions. The session chairmen are responsible for selecting and inviting participants for the sessions. If specific participants are to prepare information or make informal presentations during the working sessions, the chairman must notify them. The development of the summary of results of each area of discussion and the presentation of the summary at the final session is the responsibility of the respective session chairmen. Purdue University will type and grammatically edit the working session summaries referred to in Item 9, under WORKSHOP PROCEDURES. The respective session chairmen will be responsible for reviewing the typed copy to insure that the results of the working sessions are accurately represented.

The persons invited to participate in the workshop will be selected based on their ability, demonstrated through prior work, to contribute to the subject of the session. Although formal presentations by the participants are not expected, it will be expected that they be prepared to discuss, in depth, their particular area of expertise. In order to do this, references to related literature, research or applicable activities as well as appropriate personal activities and industry information should be compiled. This information, while not necessarily used verbatim, will become a valuable contribution to the published proceedings of the workshop.

Purdue University, as represented by the R. W. Herrick Laboratories and the Division of Conferences and Continuing Education, is the workshop contractor. The contractor is responsible for attendee registration, facilities, financial arrangements and control, and proceedings publication. With respect to the latter, Purdue will transcribe and generally edit the summary recordings of the working sessions as previously noted and the recordings of selected portions of the general sessions. Final content editing will be done under the direction of the workshop subcommittee and the session chairmen.

APPENDIX B

CONFERENCE ROSTER

Paul R. Achenbach, National Bureau of Standards, Washington, D.C. 20234
Herman Behls, Sargent & Lundy, 55 E. Monroe St., Chicago, IL 60603
Larry Berglund, J.B. Pierce Found. Lab., 290 Congress Ave., New Haven, CT, 06519
Michael Bitterice, PPG Industries, One Gateway Center, Pittsburgh, PA 15222
William Chapman, Johnson Controls, 8260 N. Gray Log Lane. Milwaukee, WI 53217
John Clark, Univ. of Michigan, 2214 Avalon Place, Ann Arbor, MI 48104
William Clark, Carrier Aircondition Co., Carrier Parkway, P.O. Box 4808, Syracuse, NY 13221
Raymond Cohen, School of Mechanical Engineering, Ray W. Herrick Laboratories, Purdue University, West Lafayette, IN 47907
Joseph F. Cuba, ASHRAE, 345 E. 47th St., New York, NY 10017
David Didion, National Bureau of Standards, Bldg. 226, Rm. B126, Washington, D.C. 20234
Wayne Ellis, H.B. Fuller Co., P.O. Box 625, Spring House, PA 19477
Richard A. Erth, York Div. Borg Warner, P.O. Box 1592, York, PA 17405
James Ford, Government of Canada, Dept. Public Works, Riverside Dr., Ottawa, Ont.,Canada
Ralph Goldman, U.S. Army Research Institute, Env. Med., Natick, MA 01701
Alfred Greenberg, GEO-Energy Ltd., Rd. 2, Box 235, Port Jervis, NY 12771
James F. Hamilton, School of Mechanical Engineering, Purdue University, West Lafayette, IN 47907
Floyd Hayes, The Trane Co., Building 12G, La Crosse, WI 54601
Walter D. Houle, IBM, P.O. Box 2150, Atlanta, GA 30301
Greg Johnson, Ray W. Herrick Laboratories, Purdue University, West Lafayette, IN 47907
Thomas Kinman, Univ of Cincinnati, Service Bldg., Cincinnati, OH 45221
Tamami Kusuda, National Bureau of Standards, Washington, D.C. 20234
Peter Lambert, York University, 4700 Keele St., Downsview, Ont. Canada
Jerry E. Lawson, TPI Corp., 135 Wesley Dr., Johnson, TN 37601
Wolfgang Leidenfrost, School of Mechanical Engineering, Purdue University, West Lafayette, IN 47907
Ted Lundy, Oak Ridge National Laboratory, Union Carbide Corp., P.O. Box P, Oak Ridge, TN 37830
Calvin MacCracken, CalMac Mfg. Corp., 150 So. Van Brunt St., Englewood, NJ 07631
Merle McBride, Owens/Corning Fiberglas, Granville, OH 43023
Joan McGlothlin, Ray W. Herrick Laboratories, Purdue University, West Lafayette, IN 47907
Ross Meriwether, Ross F. Meriwether & Assoc., 1600 NE Loop 410, # 241, San Antonio, TX 78209
Dennis Miller, Johnson Control, P.O. Box 423, Milwaukee, WI 53201
G.P. Mitalas, National Research, Council of Canada, Ottawa, Ontario, Canada
Frederick Morse, Purdue University, West Lafayette, IN 47907
Clayton, Mote, Consumers Power Co., 212 W. Michigan, Jackson, MI 49201
William Murphy, Ray W. Herrick Laboratories, Purdue University, West Lafayette, IN 47907
Alwin Newton, 136 Shelbourne Dr., York, PA 17403
Daniel Nobbe, Univ. of Michigan, 1408 Arborview, Ann Arbor, MI 48103
Joseph Pearson, School of Mechanical Engineering, Purdue University, West Lafayette, IN 47907
Frederick Rohles, Kansas State University, 700 Harris Ave., Manhattan, KS 66502
George Schade, Honeywell Plaza, MN 12-4240, Minneapolis, MN 55408
Jim Shih, National Bureau of Standards, Bldg. 226, Rm. B126, Washington, D.C. 20234
Robert Tamblyn, Engineering Interface Lts., Ste. 200, 2 Sheppard Ave. E., Willowdale, Ont. Canada
Steven Thomas, Ray W. Herrick Laboratories, Purdue University, West Lafayette, IN, 47907
Garth Thompson, Kansas State University, Dept. of Mechanical Engineering, Manhattan, KS 66506
James Tobias, Honeywell Corp. Tech. Center, 10701 Lyndale Ave. So., Bloomington, MN, 55420
David R. Tree, School of Mechanical Engineering, Purdue University, West Lafayett, IN 47907
Rod Vidal, Port Authority of NY, One WTC 58S, New York, NY 10048
Richard J. Wagner, The Poole & Kent Co., 4530 Hollins Ferry Rd., Baltimore, MD 21227
Richard Walker, Purdue University, West Lafayette, IN 47907
Donald Weast, Purdue University, West Lafayette, IN 47907
Theodore J. Williams, Purdue University, West Lafayette, IN 47907