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Research and Innovation in the Building Regulatory Process

Linda Beavers

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[2]Some divisions within the center are located at Boulder, CO 80303.
[3]Located at Boulder, CO, with some elements at Gaithersburg, MD.

Research and Innovation in the Building Regulatory Process

Proceedings of the Sixth
NBS/NCSBCS Joint Conference

Technical Seminar on Streamlined Administrative Procedures,
Computers in Construction, and Fire Safety Technology

Held in Denver, Colorado
on September 11, 1984

Linda Beavers, Editor

Center for Building Technology
National Engineering Laboratory
National Bureau of Standards
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PREFACE

This document contains the Proceedings of the Sixth NBS/NCSBCS Joint Conference on Research and Innovation in the Building Regulatory Process, held on September 11, 1984, in Denver, CO. This conference addressed streamlined administrative procedures, computers in construction, and fire safety technology. These Proceedings contain the 10 papers selected for presentation at the conference.

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The editor expresses appreciation to the authors for their input to this publication. In addition, although their remarks are not published, appreciation is expressed to the Welcome Speaker and Session Moderators for their participation in the conference.

Welcome	Mr. Richard E. Wolfe Director Office of Manufactured Housing 1645 West Jefferson Phoenix, AZ 85007
Session on Streamlined Administration and Computer Applications	Mr. Rick A. Howell, Moderator Executive Manager Division of General Services 300 Gervais Street Columbia, SC 29201
Session on Developments in Fire Safety Research and Technology	Mr. Arthur E. Cote, Moderator Systems Vice President Engineering & Technical Services National Fire Protection Association Batterymarch Park Quincy, MA 02269

ABSTRACT

The Proceedings of the Sixth NBS/NCSBCS Joint Conference on Steamlined Administrative Procedures, Computers in Construction, and Fire Safety Technology contain 10 technical papers:

- Common Format for the Model Building Codes: An Application of Advanced Techniques for Standards Analysis, Synthesis and Expression
- Structural Safety Assessment During the Construction Phase
- Automation of the Building Code Compliance
- Microcomputer Design Tool to Aid Construction Professionals to Comply with the Florida Model Energy Efficiency Code
- Automated Checking of Simply-Supported Prismatic Reinforced Concrete Beams for Compliance With Code Requirements
- Emerging Engineering Methods Applied to Regulatory Fire Safety Needs
- Survey of the State of the Art of Mathematical Fire Modeling
- A Second Look at Fire Protection Code Criteria
- Non-Evacuation in Compartmented Fire Resistive Buildings Can Save Lives and It Makes Sense
- Telephone Connected Early Warning and Communication System

Key Words: building codes; building research; code administration; computers; fire; regulatory needs; structural safety

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*Paper not presented at the Conference.

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INTRODUCTION

James G. Gross
Deputy Director
Center for Building Technology
National Bureau of Standards
Gaithersburg, MD

I am pleased to introduce this Sixth Conference on Research and Innovation in the Building Regulatory Process, sponsored by the National Conference of States on Building Codes and Standards and the National Bureau of Standards. In addition to these six conferences, we have jointly held two specialty conferences addressing building rehabilitation issues. The proceedings of these eight conferences have been published and are available.

The purpose of this conference is threefold: (1) to share information on new developments and research results which can improve the building regulatory process; (2) to provide a record of these developments by publishing the proceedings and making them available to building officials, building designers, contractors, and the public; and (3) to encourage further building related research and the development of innovative practices for building regulation.

This year we selected three subjects for discussion: (1) streamlined administrative procedures, (2) computers in construction, and (3) fire safety technology. These subjects are particularly timely because of major developments in each of these areas. Many jurisdictions are reviewing, reorganizing, and simplifying the administrative procedures for building regulation. An example is the development and implementation of the one-stop permitting process. There is rapid development in computer capability, increased capacity, reduced cost, and improved ease of use with the development of a large variety of user-friendly software. These developments have greatly facilitated the use of computers by the entire building community. In order to take advantage of this increased capability, there is need for research to fill great gaps in knowledge. This is particularly true as it relates to the incompatibility and difficulty in interfacing various programs by different developers and the many computers of different manufacturers. The ability to handle, transfer, and use information is going to change our lives dramatically in the near future. The fact that all of this sophisticated software and hardware cannot be effectively integrated is a major problem; but it is being worked on, and we will learn about some of this progress today.

Rapid advancements in the understanding of fire growth and smoke promulgation permitting the mathematical modeling of these phenomena have many building regulatory implications. It is these advancements in understanding the scientific fundamentals that will change the way fire protection is practiced today. This afternoon's session on developments in fire safety research and technology will excite your imagination as you see potential regulatory application of these developments to provide more flexibility in meeting life safety requirements at reduced costs.

Unfortunately, two of our speakers will not be with us today. Stephen Jaeger, from the University of Texas, experienced travel problems and Wendell Smith is in the hospital. Fortunately, we have one addition, Jim Noland, an engineer from Colorado, has offered to present a paper this afternoon entitled "Automation of the Building Code Compliance." So we will be short one speaker but not two.

Now, I would like to introduce Rick Howell, who will be our moderator this morning. He is the NCSBCS Delegate from South Carolina. He has an Associate Degree in Fire and Safety Engineering from Rowan Technical College in Salisbury, North Carolina. He serves as the Executive Manager of the South Carolina Division of General Services. He has many important responsibilities in this position. They include the South Carolina Building Code Council, the South Carolina Barrier Free Design Board, the South Carolina Manufactured Housing Board, the South Carolina Pyrotechnic Board, the Office of the State Engineer, the Office of Construction Planning and Building Services, the Office of Materials Management, Property and Planning Division, and the Insurance Division. So Rick is a busy man. Thank you for being with us -- Rick Howell.

Common Format for the Model Building Codes: An Application of Advanced Techniques for Standards Analysis, Synthesis and Expression

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ABSTRACT

Current research at the NBS Center for Building Technology (CBT) supports development of a common format for the model building codes. This study demonstrates an application of advanced techniques for standards analysis, synthesis and expression (SASE) to code format development. Specifically. the SASE techniques allow model code provisions to be stored in specialized databases, classified for easy access, and displayed in conjunction with any candidate code format. By "mapping" the technical contents of existing model codes onto various candidate formats, each candidate may be evaluated as to the extent to which it adquately contains and provides access to code provisions. Moreover, the mapping technique permits analysts to determine whether or not the provisions of any individual code have been properly or logically classified. Results of CBT's research will facilitate the more rational development of a common format for model building codes.

1. INTRODUCTION

1.1 Problem and Overview

The three principal model building codes (*) are being adopted by code governing bodies in various jurisdictions with increasing frequency. This has resulted in more up-to-date building regulations, improved technical content of regulations, and more uniform definitions and building type and occupancy classifications. However, different formats presently exist among the model building codes. Such differences potentially:

(1) increase costs and risks for designers, builders,

(*) The BASIC BUILDING CODE, 1981 Edition [1], the STANDARD BUILDING CODE. 1982 Edition [2], and the UNIFORM BUILDING CODE, 1982 Edition [3].

and manufacturers working in multiple code jurisdictions,

(2) increase regulatory barriers to the introduction of new technology,

(3) increase costs and risks of losses for building owners,

(4) make comparisons of technical requirements in the model codes difficult, and

(5) provide barriers to the reconciliation of differences in the model codes.

Moreover, imperfections in the format of each individual code make it difficult to find provisions applicable to specific technical situations. As a result, the user is often unsure as to whether all applicable provisions have been located, and interpreted correctly.

To date, neither the model code organizations nor the building industry at large have been able to agree on a common format. To a large extent, they have lacked a rational technical basis for selecting an appropriate common format, the financial resources needed to define and achieve agreement on a format, and the representation and support of the entire building community. However, the environment may now be more favorable for achieving a common and better format for the model building codes. In particular, the President's Commission on Housing has urged "the model code organizations to accelerate their efforts to reconcile their provisions, and especially to use a common format so their provisions can readily be compared." Moreover, rational techniques for standards analysis, synthesis and expression (SASE) now are available as a result of research at the NBS Center for Building Technology (CBT).

Under the sponsorship of the U.S. Federal Trade Commission, CBT is applying advanced techniques for standards analysis, synthesis and expression to formulate and assess candidate common formats for model building codes. The study proceeds from the premise that a common format for model codes is a desirable goal. However, no preconceptions regarding any particular formats are assumed. Rather, the study develops a rigorous method by which candidate formats can be formulated and analyzed, and demonstrates the utility of this method in relation to three such candidates. No judgments are rendered regarding either the existing model code formats, or about the clarity, correctness and consistency of individual provisions of any code.

1.2 Technical Barriers to Achieving a Common Format for Building Codes

The organization, or format of a building code determines whether provisions can be found easily and reliably by the user. Format deals with both the scope and arrangement of a model code. To investigate the utility of some candidate format fruitfully, tools for rationally analyzing scope and arrangement are required. Through rational analysis:

(1) a format can be shown to contain and express the desired scope of the document adequately,

(2) a format can be shown to provide logical and useful channels for accessing code provisions relevant to some query, and

(3) individual code provisions can be shown to be properly classified, so that a given query will return all relevant provisions.

Analysis of a candidate format according to these criteria presents a number of complex technical problems. The analyst must test the efficacy of the format's classification system, and study all applicable provisions and relationships among provisions, as well. A model building code contains, on the average, some 1,000 individual requirements (*), and hundreds of other definitions and determinations (**). In addition, a scheme to access information contained within a model code may contain well over 1,000 classifier titles.

Advanced techniques embodying concepts from classification theory, logic and operations research have been developed [4] to efficiently search, sort and merge such large volumes of data. Pioneering work by Fenves [5] on the modeling of standards has led to the concepts that: (1) individual provisions of a standard could be explicitly modeled by decision logic tables which reveal rules linking conditions with actions, and which suggest tests for completeness and consistency, and (2) decision tables and their ingredients could be linked through a network which models specific relationships among the standard's provisions. More recently, this approach has been expanded by Harris and Wright [6] to consider the complex organizational aspects of standards documents. This latter work is

---

(*) A requirement is a provision which precisely stipulates the qualities to be possessed by some product or process, and is a statement which can be evaluated as either "satisfied" or "violated" when checking a given design decision. (**) A determination provides information needed to evaluate a requirement. Examples include analytical formulas, and other procedures or rules which govern design under a particular set of conditions.

particularly important to the present study of model code format. Until quite recently, however, these concepts could not be conveniently applied by building code analysts.

1.3 New Tools

During the last several years, CBT researchers, collaborating with other workers, have developed a set of computer based techniques for standards analysis, synthesis and expression. The SASE software system contains:

(1) tools for modeling both the substantive content and the physical organization of a code or standard document,

(2) techniques for evaluating the clarity and completeness of provisions as well as the logic of an organizational structure, and

(3) facilities for database establishment and management.

Nearing completion as a production system, the SASE software package is intended to support various needs of the standards writing community. These include the maintenance of codes and standards, the rigorous analysis of provisions and relationships among provisions, and the formulation and evaluation of alternative formats. A summary of the SASE system is provided in reference [7].

2. GENERAL METHODOLOGY

2.1 Conceptual Framework for Organizing Codes and Standards

Scope and arrangement, introduced earlier as the bases for a building code's format, may now be explored in more detail. Scope defines the products and/or processes, together with their required qualities, covered by a code or standard. A clear statement of scope tells a user what can--and cannot--be found within the document. Arrangement deals with the means of access to provisions pertinent to a user's inquiry, and is expressed most visibly by the hierarchically ordered headings forming a table of contents.

The conceptual model for organizing a standard can be illustrated briefly as it applies to performance requirements. The scope is initially defined by listing classifier terms which name the products and processes ("entities") to be covered, and also their required qualities ("attributes"). Once listed, these classifiers may be combined into trees expressing any logical or convenient information structure. Figure 1a illustrates a tree of entity classifiers for the structural portion of a performance standard for residential buildings. Figure 1b shows the related tree of attribute

(a) ENTITY TREE

```
                    BUILDING
                       /\
                      /  \
                     /    \
                    /      \
                   /        \
                  /          \
                 /            \
         STRUCTURAL      INTERIOR
           SYSTEM        SURFACES
                            /\
                           /  \
                          /    \
                         /      \
                        /        \
                     WALL      FLOOR
```

(b) ATTRIBUTE TREE

```
                         PERFORMANCE
                          /       \
                         /         \
                        /           \
                       /             \
                      /               \
               SAFETY                SERVICEABILITY
               /     \                   /     \
              /       \                 /       \
             /         \               /         \
            /           \             /           \
           /             \           /             \
  FORCE LOADS   OTHER AGENTS   FORCE LOADS    OTHER AGENTS
  max/min vals  max/min vals   max/min vals   max/min vals
```

Figure 1. Example Classifier Trees

classifiers. The trees follow the logical criteria for classification of being exhaustive over the desired scope, and mutually exclusive. Candidate formats to organize the substantive information of the standard (i.e., the requirements) are now developed by systematically combining the entity and attribute classifier trees. This is illustrated in Figure 2.

Assuming that all relevant requirements have been correctly classified with respect to their characteristic entities and attributes, then they can be mapped onto the candidate format, as shown in Figure 2. Following this general methodology, a building code analyst may construct any permutation of entity and attribute classifiers which satisfies prevailing criteria for scope and arrangement, and then map available requirements onto the resulting format.

2.2 Conceptual Framework for Modeling the Substantive Content of Codes and Standard: A Brief Diversion

Although this paper deals with the analysis of a code's organization rather than with its individual provisions, concepts for modeling organization should be viewed within the proper context. The overall organization of a code will be influenced by the document's substantive content, as well as by its scope. Moreover, organization will be affected by interrelationships among individual code provisions. In this brief digression, concepts for modeling provisions and their interrelationships are introduced.

2.2.1 Modeling individual requirements

A code requirement is defined here as a statement stipulating that a product or process shall have or be assigned some quality. Recent work [6] provides guidance on expressing requirements. Code writers should express requirements as simple sentences in the active voice, for example, and should make explicit the performance attribute of the provision. Often, however, the logic of a provision is too complex to express in a simple declarative sentence. In these instances, a decision table can be used to model the requirement.

Consider an example drawn from the BBC, concerning height and area limitations for buildings used for storing and handling combustible dusts and grain (Section 610.2). Table 1 shows the text of the requirement, along with its decision table representation. The decision table form permits analyses of clarity and completeness. For clarity, the analyst checks for both redundancy (two or more identical rules, or vertical columns) and contradiction (rules with identical condition entries, but different action values). For completeness, the analyst must ascertain that no possible combination of condition entries lacks an explicit action value. These analyses may be aided significantly by developing a decision tree based on the table. An example of this extension can be found in reference [7].

BUILDING

STRUCTURAL SYSTEM

SAFETY

FORCE LOADS ...... list of applicable requirements
OTHER AGENTS ...... list of applicable requirements

SERVICEABILITY

FORCE LOADS ...... list of applicable requirements
OTHER AGENTS ...... list of applicable requirements

INTERIOR SURFACES

WALLS

SERVICEABILITY .... list of applicable requirements

FLOORS

SAFETY .... list of applicable requirements
SERVICEABILITY .... list of applicable requirements

Figure 2. An Example Format for a Portion of a Performance Standard

Table 1. Original Text and Decision Table Representation of BBC (1981) 610.2: Height and Area Limitations for Buildings Used for Storing and handling Combustible Dusts and Grain.

610.2 BUILDINGS. All such buildings and other occupied structures shall be of Type 1 or Type 2 or of laminated planks or lumber sizes qualified for Type 3A construction, within the height and area limits of Table 505 for Use Group H; except that when erected of Type 1 or Type 2 construction, the height and area of grain elevators and similar structures shall be unlimited, and when of Type 3A construction, the structure may be erected to a height of 65 feet and and except further that, in isolated areas, the height of Type 3A structures may be increased to 85 feet.

Condition Entries	Rules 1	2	3	4	5	ELSE
1. Building is Type 1 or Type 2 construction	T	-	-	T	-	
2. Planks or lumber qualifying for Type 3A construction	-	T	T	-	F	
3. Building is a grain elevator or similar structure	T	T	T	F	F	
4. Location of building = isolated	.	T	F	.	.	
5. Height </= 65 feet	.	.	T	-	-	
6. Height </= 85 feet	.	T	-	-	-	
7. Within height and area limits of Table 505 for Use Group H	.	.	.	T	T	
Action Entries						
1. Requirement 610.2 is SATISFIED	X	X	X	X	X	
2. Requirement 610.2 is VIOLATED						X

Legend: T = true
F = false
. = immaterial
+ = implied true
- = implied false

2.2.2 Modeling relationships among requirements and other provisions

A standard consists of a system of interrelated provisions. These interrelationships can be modeled using an information network, in which each node represents a single requirement or determination. Consider a requirement from the American Concrete Institute's Building Code for Reinforced Concrete (ACI 318-1977), stipulating that the water-cement ratio of laboratory trial batches (LTB) yields some specified average test strength (*). To evaluate strength for a given value of LTB water-cement ratio requires that certain ingredient data be available, including:

- average test strength as determined by field experience; and
- strength corresponding to LTB water-cement ratio.

Evaluation of these components, in turn, requires that certain additional ingredient data be available, as illustrated in Figure 3. Because information networks explicate precedence relationships among provisions of a standard, they are useful analytical tools. In particular, they may reveal such flaws as circular logic which result whenever any datum is found to be its own ingredient. An example of this use of the information network is shown in reference [7].

2.3 Software Implementation of Concepts for Standards Analysis, Synthesis and Expression: Principal Features

The SASE software system (SASE/SS) now under development implements the concepts for modeling the organization and contents of codes and standards. The system aids the building code analyst by permitting the contents of a code document to be stored in a computer-usable form, to be reconfigured, and to be tested for clarity, consistency and correctness. The software is oriented towards interactive use. Thus, its use during the course of codes and standards committee meetings and working sessions is possible on a real-time basis.

The power of SASE/SS as an analytical tool derives from a number of built in processors. Candidate building formats are constructed, displayed and stored using the ORGANIZATION processor. Code provisions are mapped onto a given format by invoking the OUTLINE processor. The INDEX processor permits a code analyst to alphabetically organize classifier expressions, and then map code provisions onto this organization. The NETWORK processor generates information networks from user-supplied precedence data, and provides capabilities for checking a network's logic. The analyst builds and maintains decision table and function representations for individual code

---

(*) Based on ACI 318-1977, Section 4.4. "Proportioning by Laboratory Trial Batches."

```
(R1) REQUIREMENT THAT LTB W-C RATIO YIELDS AVG TEST STRENGTH
:    AS SHOWN IN D1
:
:....(D1) DETERMINATION OF REQ'D AVG TEST STR BY FIELD EXPERIENCE
:    :
:    :....(D2) DETERMINATION OF STD DEV OF STRENGTH TEST DATA
:         :
:         :....(I1) BACKGROUND MATERIALS AND PROPERTIES
:         :
:         :....(I2) REPORT OF STRENGTH TEST DATA
:         :
:         :....(I3) PREVIOUSLY SPECIFIED f'c
:
:....(D3) DETERMINATION OF STRENGTH CORRESPONDING TO LTB
     :    WATER-CEMENT RATIO
     :
     :....(I4) LTB AIR CONTENT
     :
     :....(I5) PREPARATION OF LTB SPECIMENS
     :
     :....(I6) LTB SLUMP
     :
     :....(I7) DETERMINATION OF REQ'D AVG TEST STRENGTH BY FIELD
     :         EXPERIENCE
     :
     :....(I8) LTB TEST PROCEDURE
```

```
Legend:  (R ) = requirment datum
         (D ) = determination datum
         (I ) = input data, i.e., information required from the
                  design or field
         :... = pointer to ingredient requirements, determinations,
                  and/or input data
```

Figure 3. Information Network for a Concrete Quality Requirement

provisions using the TABLE and FUNCTION processors. The TREE processor develops decision trees from tables, providing capabilities for checking a provision's completeness and clarity.

Functional use of SASE/SS is based on the system's command language. Four types of commands are available allowing the user to create, modify, display, or remove building code data. There are three primary data categories:

(1) standard, version and chapter identifiers;
(2) decision tables and functions representing individual provisions; and
(3) classifiers which allow provisions to be outlined, indexed and accessed.

Networks, organizations and outlines all are generated from these basic data types. Other aspects of SASE/SS are treated in reference [7].

3. A COMMON FORMAT FOR THE MODEL BUILDING CODES: A STUDY IN THE APPLICATION OF ADVANCED CONCEPTS FOR STANDARDS ANALYSIS, SYNTHESIS AND EXPRESSION

3.1 Objectives of the Study

Pursuit of a common format for the model building codes provides a unique opportunity to examine SASE concepts in practice, and to apply the prototype SASE software tools. To fulfill its own objective that a common code format be achieved, the Federal Trade Commission established a cooperative study involving participation by both CBT and the National Institute of Building Sciences (NIBS). Central to the success of the effort is SASE.

The overall objective of the CBT project is to provide technical guidance which could, eventually, lead to industry consideration of a common code format. Of immediate concern, CBT's objectives are to: (1) provide concepts, methods, and data with which candidate formats could be developed and objectively evaluated, and (2) document three such candidates, noting the strengths and shortcomings of each.

The objectives of NIBS are to: (1) provide to CBT advice regarding desirable attributes of a common format; (2) review databases and candidate formats developed by CBT; and (3) report to the Federal Trade Commission overall findings and recommendations regarding a common building code format. To achieve these goals, NIBS engaged a codes community committee representing knowledgeable and affected interests of the building industry.

3.2 Technical Approach

Three interrelated tasks characterize CBT's technical approach. These are to establish model code databases, develop candidate model code formats, and evaluate the candidate formats.

3.2.1 Establishing model code databases

The SASE methodology bases format analysis on sound documentation of a code's substantive technical content (i.e.. individual provisions). Strictly speaking, this requires rigorous content analysis of an entire code. During the analysis all requirements and deteminations are identified, all applicable decision tables are formulated, and all precedence relationships among provisions are specified. Moreover, individual provisions are classified as to the specific entities and attributes with which they deal. Once a complete classifier list has been been established, classifiers may be drawn from the list and used as headings in a candidate format. Applicable provisions then can be mapped onto the headings as an aid to evaluating the format.

The current study utilizes an abridged form of SASE database. In particular, since the study is not directly concerned with analyses of individual provisions or of relationships among provisions, tables, functions and precedence data are not developed. For the purposes of this study, principal elements of a model code database are:

REQUIREMENTS: "one line" titles which capture the essential meaning of requirement provisions couched within the text of a building code (*);

CLASSIFIERS: words or short phrases which name the entities and attributes dealt with by REQUIREMENTS.

Sample database entries drawn from each model code, denoting requirement titles and related classifiers, are illustrated in Figure 4. Requirement data for each model code are stored in a code requirements database, and classifier data are maintained in a classifier database. The relationship between the various databases is illustrated in Figure 5.

Finally, model code databases established for this study are abridged further by excluding descriptions of any provisions that are not requirements, *per se*. It is felt that the exclusion of definitions, other determinations and input datum items does not jeopardize the analysis of format, since the user primarily seeks *requirements* when using a code. Moreover, all ingredient

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(*) Within a building code, requirement provisions are bounded text units which specify that some entity (product or process) shall possess some attribute, e.g., "All structures of reinforced concrete...shall be designed and constructed in accordance with ACI 318" (BBC-1981. section 1216.1).

BBC

NUMBER	REQUIREMENT TITLE			SEC	PAGE
8185	LOCATION REQ FOR INTERIOR DOORWAYS LEADING TO AN EXIT			812	159
	CLASSIFIERS:	1034	EXITS		
		1052	DOORWAYS		
		5009	MEANS OF EGRESS REQUIREMENTS, MINIMUM		
		5113	ARRANGEMENT AND LOCATION, ACCEPTABLE		
10550	PROVISION FOR OVERLOADING PILES IN COMPRESSION			1014	219
	CLASSIFIERS:	1591	FOOTINGS, PILE		
		5191	COMPRESSIVE STRENGTH, MINIMUM		

SBC

NUMBER	REQUIREMENT TITLE			SEC	PAGE
5175	REQS FOR AUTOMATIC SUPPRESS SYS IN COVERED MALL BLDGS			507	516
	CLASSIFIERS:	1040	BUILDINGS, COVERED MALL		
		1816	SPRINKLERS, SUPERVISED		
		5525	PER NFPA 72A-72E		
		5708	PER NFPA 13		
7065	PROHIBITION OF ELEVATORS & STAIRWAYS IN COMMON SHAFT			701	72
	CLASSIFIERS:	1057	STAIRS		
		1072	ELEVATORS		
		5305	LOCATION OR POSITIONING, PROHIBITED		

UBC

NUMBER	REQUIREMENT TITLE			SEC	PAGE
5015	HEIGHT LIMITS FOR PARTS OF MULTIOCC BLDGS			503	51
	CLASSIFIERS:	1010	BUILDINGS, MIXED-USE		
		5609	HEIGHT, MAXIMUM		
23015	DESIGN REQS FOR LATERAL FORCE DISTRIBUTION			2303	124
	CLASSIFIERS:	1068	ELEMENTS, STRUCTURAL		
		1611	LOAD, LATERAL		
		5602	LOAD DISTRIBUTION, ADEQUATE		

Figure 4. Sample Requirement Database Entries for each Model Code

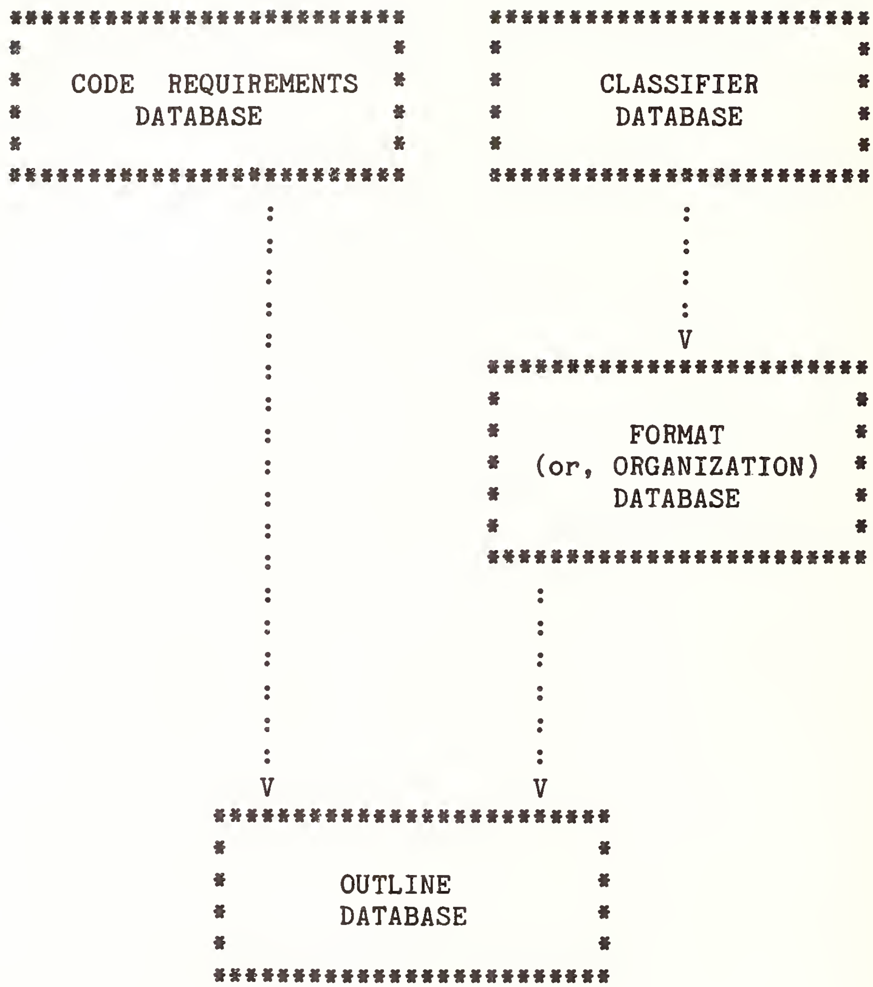

Figure 5. SASE Databases

determinations and input data may, secondarily, be accessed through their root requirements.

3.2.2 Developing candidate formats

A code format is a logical arrangement of hierarchically structured headings, and is analogous to a code's table of contents. In principle, headings used to construct a candidate format are drawn directly from a classifier database. In practice, however, the classifier terms and phrases may have to be reworded--without changing their intended meaning--to ensure smooth transitions among headings composing the format. For example, the heading FORCE LOADS in the format illustrated in Figure 2 may actually appear as LOADS, FORCE in the original classifier database.

Headings used to construct candidate formats for this study are drawn from a single, reconciled classifier database. Construction of this database began with the BBC content analysis. That is, as BBC requirements were identified and recorded, new classifiers were added to the classifier database. As the SBC and UBC were analyzed, new classifiers were continually added to the database where no existing classifier was satisfactory. The resulting classifier database contains virtually no redundant classifiers, even though the three model codes are extremely similar in scope.

One difficulty encountered while building the common classifier database concerns the fact that a significant number of classifiers are highly specific to the individual codes. For example, an attribute classifier specifying the quality of being "in conformance with BBC Table 505" is irrelevant to the SBC and UBC. Moreover, this classifier is redundant to ones specifying the qualities of being "in conformance with SBC Table 400" and "in conformance with UBC Tables 5-C and 5-D". This redundancy is reconciled by establishing the single generic attribute classifier: "in conformance with height and area tables". Thus, actual classifiers used as headings within candidate formats are drawn from a final, reconciled classifier database.

Construction of individual formats follows the principles for organization summarized in section 2.1 above. A set of candidate formats constitutes a format database (see Figure 5). It cannot be overemphasized that the SASE software tools facilitate only the maintenance, manipulation and presentation of classifiers, headings and formats. Decisions affecting a format's content and structure must be made by skilled building code analysts. The SASE organization concepts and software tools are significant aids in making such decisions.

3.2.3 Evaluating the candidates

Once candidate formats have been constructed and stored using the SASE/SS ORGANIZATION processor, software tools are available which aid the analyst in examining--and ultimately evaluating--these candidates. The principal tool for studying formats is the OUTLINE processor. Invoking this processor causes SASE/SS to merge the requirements contained in a code requirements database with the headings (classifiers) arranged in some particular candidate format. The function of OUTLINE is illustrated by reference to a hypothetical "new edition" of one of the model codes. This new edition contains precisely the same requirements as did the "old" edition, however, they are arranged differently. Indeed, the new arrangement is dictated by a (candidate) format of the analysts choice. The OUTLINE processor, then, resequences the display of code requirements to reflect any desired format.

Given a set of requirement-format mappings, or simply outlines, the analyst may apply certain criteria in order to rank order the outlines or to make qualitative statements about them. The general objectives that an organizational scheme defines the desired scope of a building code, and that it provides reliable and quick access to its provisions, governs all decisions regarding format. Access is of paramount concern to the user of code, and is affected by such factors as the logical organization of the format, the format's relevance to the user's needs, the relevance and uniqueness of headings, and the proximity of related provisions within the code's text. The quality of available cross referencing devices, including the index, also influences a user's access to specific material within a code.

Thus, at least on a qualitative level, an information accessibility criterion may be employed when evaluating or comparing candidate formats. For example, the analyst can judge the degree to which headings composing a format concisely express their scope, unambiguously impart to the reader their intended meaning, and present a regular gradation in levels of scope [6].

Quantitative measures of candidate formats also may be compared. For example, the analyst can determine whether the headings composing a format are mutually exclusive (ensuring that each individual provision will appear in only one location in the outline) and collectively exhaustive (ensuring that all provisions contained in a code requirement database are mapped onto the format). In practice, however, the mutual exclusivity criterion can be difficult to satisfy and even misleading. This occurs because the analyst often chooses to link multiple entities and/or attributes when formulating a single requirement datum, and as a result, such requirements may map onto more than a single format branch. When multiple mappings are found, the analyst must determine whether they are appropriate, or if some should be deleted from the outline. Alternatively, the analyst may determine that the best course is to disaggregate the original compound requirement.

The present study demonstrates the usefulness of this approach in selecting a common building code format from among a number of candidates. To do this, the requirement databases for each model code must be individually mapped onto each candidate format. The analyst can conduct an initial check to determine which candidates most fully contain the complete scopes (i.e., the complete requirement databases) of all three model building codes. Candidates passing this criterion may then be evaluated employing the various qualitative criteria for accessibility, relevance, etc. Even if only one candidate passes the scope criterion, its structure and the language of its headings may require adjustment if the format is to score well against the additional criteria. Figure 6 illustrates the concept of mapping the three model codes onto three candidate formats.

3.3 Preliminary Technical Work Toward a Common Format for the Model Building Codes

Specific procedures for establishing model code databases were derived from the SASE concepts and general methodology outlined earlier. Practical considerations and time constraints permitted CBT staff to develop only the BBC database. Both the SBC and UBC databases were established for CBT by private sector contractors.

In preparation for the BBC task, CBT staff developed data collection and recording procedures during trial studies of other standards. One such trial involved an exhaustive content analysis of ACI 318-1977, Chapter 4 (Concrete Quality). Because each of the three model code databases was developed by separate organizations and at different times, the maintenance of consistency across the data is of paramount concern. Thus, once CBT completed a draft BBC database and awarded the SBC contract, the contractor proceeded under the guidance of a skilled CBT monitor. Lessons learned during the SBC task resulted in corrections and improvements to the earlier BBC database. These procedures reflect development of the UBC database, as well.

During the database establishment phase of the project, a number of candidate common formats were hypothesized. Examples include organization by building systems and components, by compliance and checking procedure, and by aspect of public health and safety. These examples are illustrated, in general terms, in Figures 7 through 9, respectively. Detailed development of these candidates is in progress.

Strictly speaking, organization of a code by building type also is a plausible--and possibly desirable-- candidate format. The LIFE SAFETY CODE (NFPA 101) is an example of this kind of organization. However, only a small proportion of BBC, SBC and UBC requirements is specific to any building type. A comparative mapping exercise based on such a format would not pick up all code requirements (only all those requirements that are explicitly relevant to some building type). Since an important criterion for evaluating a candidate format is that the organization contains the complete scope of the existing model codes, it would not be possible to evaluate an outline properly based on organization by building type. Thus, consideration of this candidate lies outside the scope of this study.

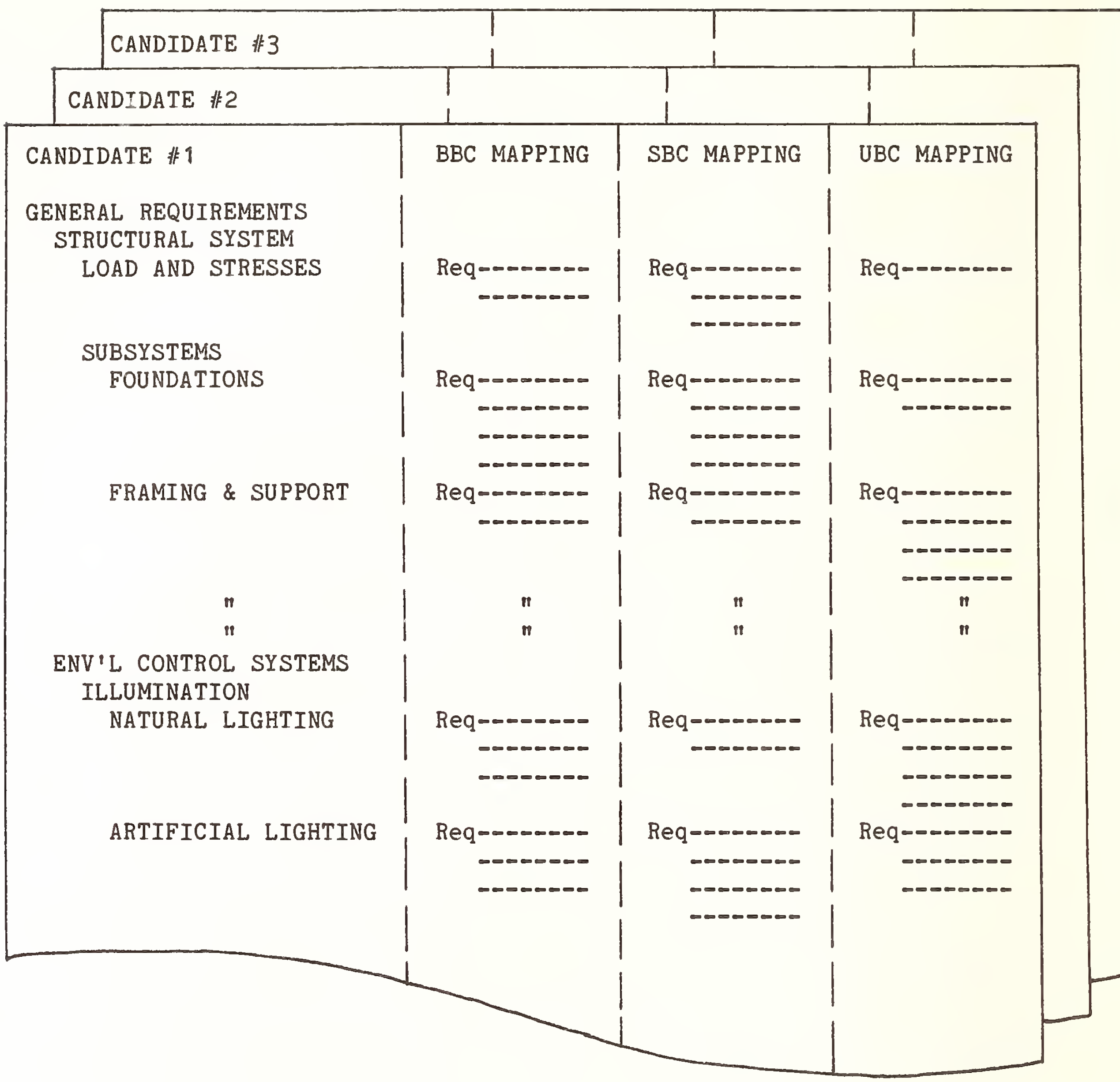

Figure 6. Summary of Mapping Concept

GENERAL REQUIREMENTS FOR BUILDING DESIGN AND CONSTRUCTION

- STRUCTURAL SYSTEM
    - LOADS AND STRESSES
    - SUBSYSTEMS
        - FOUNDATIONS
        - FRAMING AND SUPPORT
        - PREFABRICATED ASSEMBLIES
        - FLOOR-CEILING ASSEMBLIES
        - ROOFS
        - LIGHT-TRANSMITTING PLASTIC ASSEMBLIES
    - MATERIALS AND TESTS
- ENCLOSURE SYSTEM
    - WALLS
    - FLOORS
    - CEILINGS
    - ROOFS
- LIFE SAFETY SYSTEMS
    - FIRE LIMIT REQUIREMENTS
    - FIRE SEPARATION
    - FIRE RESISTANCE
    - FIRE PROTECTION
    - ALARM AND COMMUNICATIONS
    - MEANS OF EGRESS
    - ELECTRIC WIRING
    - SPECIAL CONSIDERATIONS FOR HAZARDOUS AREAS
- ENVIRONMENTAL CONTROL SYSTEMS
    - ILLUMINATION
        - NATURAL LIGHTING
        - ARTIFICIAL LIGHTING
    - VENTILATION AND AIR QUALITY
        - NATURAL VENTILATION
        - MECHANICAL VENTILATION
        - HVAC SYSTEMS
    - ENERGY CONSERVATION
    - SOUND TRANSMISSION AND CONTROL
    - SANITATION
- CONVEYANCE SYSTEMS
    - ELEVATORS AND OTHER PASSENGER CONVEYORS
    - NONPASSENGER CONVEYORS
    - OTHER MECHANICAL EQUIPMENT

SPECIAL REQUIREMENTS FOR INDIVIDUAL OCCUPANCIES

- STRUCTURAL SYSTEM
- ENCLOSURE SYSTEM
- LIFE SAFETY SYSTEM
- ENVIRONMENTAL CONTROL SYSTEM
- CONVEYANCE SYSTEM

SPECIAL REQUIREMENTS FOR ELDERLY AND HANDICAPPED OCCUPANTS

SPECIAL REQUIREMENTS FOR CONSTRUCTION OPERATIONS AND SAFETY

Figure 7. Example Organization by Building Systems and Components

DETERMINATION OF BUILDING CLASSIFICATION

- OCCUPANCY GROUP
- TYPE OF CONSTRUCTION
- LOCATION ON PROPERTY
- AREA AND HEIGHT LIMITATIONS

DETAILED REQUIREMENTS FOR INDIVIDUAL OCCUPANCIES

DETAILED DESIGN, FABRICATION, INSTALLATION AND CONSTRUCTION REQUIREMENTS

- STRUCTURAL SYSTEM
  - LOADS AND STRESSES
  - STRUCTURAL SUBSYSTEM REQUIREMENTS
  - MATERIALS AND TESTS
- ENCLOSURE SYSTEM
- ENVIRONMENTAL CONTROL SYSTEM
- CONVEYANCE SYSTEM

DETAILED LIFE SAFETY REQUIREMENTS

- FIRE LIMIT REQUIREMENTS
- FIRE SEPARATION
- FIRE RESISTANCE
- FIRE PROTECTION
- ALARM AND COMMUNICATION
- MEANS OF EGRESS
- ELECTRIC WIRING
- SPECIAL CONSIDERATIONS FOR HAZARDOUS AREAS

REQUIREMENTS FOR ELDERLY AND HANDICAPPED OCCUPANTS

REQUIREMENTS FOR CONSTRUCTION OPERATIONS AND SAFETY

Figure 8. Example Organization by Compliance and Checking Procedure (based on SBC and UBC compliance verification recommended procedures)

BUILDING FUNCTION

- GENERAL BUILDING LIMITATIONS
- SPECIAL USER REQUIREMENTS
- SPECIAL OCCUPANCY REQUIREMENTS

BUILDING CONFIGURATION

- HEIGHT AND AREA CONSIDERATIONS
- SITE CONSIDERATIONS

FIRE HAZARD MITIGATION

- FIRE LIMIT REQUIREMENTS
- FIRE SEPARATION
- FIRE RESISTANCE
- FIRE PROTECTION SYSTEMS
- ALARM AND COMMUNICATIONS
- MEANS OF EGRESS
- ELECTRIC WIRING
- SPECIAL CONSIDERATIONS FOR HAZARDOUS AREAS

STRUCTURAL INTEGRITY

- LOADS AND STRESSES
- STRUCTURAL SYSTEMS
  - FOUNDATIONS
  - FRAMING AND SUPPORT
  - ENCLOSURE
  - MISCELLANEOUS (SIGNS, ETC.)
- MATERIALS AND TESTS
- PREFABRICATED CONSTRUCTION
- LIGHT-TRANSMITTING PLASTIC CONSTRUCTION

MECHANICAL INTEGRITY

- ELEVATORS AND OTHER PASSENGER CONVEYORS
- NONPASSENGER CONVEYORS
- OTHER MECHANICAL EQUIPMENT

ENVIRONMENTAL QUALITY

- ILLUMINATION
- AIR QUALITY
- SOUND TRANSMISSION AND CONTROL
- SANITATION

ENERGY CONSERVATION

CONSTRUCTION OPERATIONS AND SAFETY

Figure 9. Example Organization by Aspect of Public Health and Safety

Once detailed candidate formats have been completed and stored in a SASE/SS format database, it will be possible to evaluate the formats using criteria described in section 3.2.3. Evaluations shall include qualitative statements about information accessibility for each of the candidates, as well as quantitative measures of scope. In addition to certain caveats mentioned in section 3.2.3, actual evaluations will be complicated further by any inconsistencies which exist among the databases created from the model codes. For example, when mapping requirements from all three codes onto a particular candidate format, two codes may yield relevant provisions under a given heading, while the third does not. This could mean that the third code does not, in fact, possess relevant provisions, or alternatively, that the analyst classified relevant provisions of the third code in a nonstandard way (causing the provisions in questions to appear elsewhere in the mapping). The scope of the present study prohibits exhaustive analyses of such inconsistencies, and as a result, the final evaluation report should be construed only as suggested of the method's power and potential, and not conclusive regarding the quality of specific candidates investigated.

4. CONCLUDING REMARKS

4.1 Practical Constraints and Recommended Practices

In the current study, advanced techniques for standards analysis, synthesis and expression are used to develop and evaluate candidate common formats for the model building codes. These techniques are based upon certain concepts for rationally modeling individual code requirements, relationships among requirements, and overall document organization. The concepts themselves are rooted in classification theory, operations research methodology, and fundamental logical principals. As with most any application of a complex methodology, practical constraints often arise which influence the conduct--and results--of the study at hand.

4.1.1 Database establishment

Such constraints have been encountered in connection with database establishment. For example, SASE concepts suggest a cyclical procedure during which the code requirement and classifier databases (and even formats) are developed and refined concurrently. That is, as requirements are classified (according to their referenced entities and attributes), it may be found that the requirement itself requires editing or modification. If it is noted a particular requirement classifies with respect to "too many" entities and/or attributes, the analyst may wish to split the original compound requirement into two or more simpler ones. Moreover, the formulation or classification of a requirement may suggest modifications to other requirements taken earlier from previous code sections or chapters. Where building code content analyses are subject to time and other resource contraints, the databases may not benefit from adequate cycling and editing.

Important benefits of cycling may derive from the introduction of various expert viewpoints at different levels of editing. But when sufficient cycling is not possible, the resulting databases are best construed as "drafts". For these reasons, planning adequate resources for database drafting, editing and verification (across differing expert views) is highly recommended.

The SASE concepts also suggest that a classification strategy should be reasonably well formulated prior to classifying any requirements. For example, the analyst may stipulate, a priori, that each requirement shall be classified as to its referenced (or implied) occupancy classification and/or building subsystem, as well as to its more fundamental entity (product or process) and attribute (required quality). According to this example, any requirement could be accessed not only by product or quality name, but by occupancy classification or building subsystem name as well. When a consistent classification strategy is not employed, then a user query based on some particular classifier(s) is not likely to return all relevant requirements. Studies have suggested that a useful and relevant classification strategy for a particular code or standard may not emerge until after several cycles have elapsed, during which a number of candidate classification schemes have been tried [6]. Convergence to a consistent classification scheme (within resource constraints) is highly recommended, since this lays the foundation for information access in the code or standard.

The quality, consistency and utility of model code databases also may be influenced by the analysts themselves. In the current study, for example, each model code was content analyzed by different individuals from different organizations. One database was established by researchers at CBT (an R&D laboratory); the others were developed by private sector engineering consultants. Whenever a single body of knowledge (i.e., the collective knowledge of building technology, as contained within the model building codes) is abstracted and classified by different analysts, the potential for inconsistency may be substantial. Draft model code databases developed or obtained by CBT were, in fact, found to differ in several respects. For example, one analyst tended to construct compound requirement data items, each consisting of multiple entities and/or attributes. Others tended to construct simplier requirements. All interpreted the technical meaning of the codes correctly. However, each approach yields different levels of information accessibility. In the case of the database consisting of many compound requirements, a user query may yield one-line requirement titles which mask much of the information actually contained in the referenced code text.

Where it is necessary to employ several analysts working independently, the work of each must be carefully coordinated. The project manager should be careful to stipulate data collection standards and norms as early as possible. However, as previously noted, such norms often do not emerge until well into the study, and perhaps not until one complete cycle has been completed and evaluated. Perhaps the single most significant recommendation deriving from the CBT study is that all code requirement database work be undertaken by a single team which develops standards and norms, and reconciles problems, as the database develops.

4.1.2 Format development

While the formulation and expression of building code organizations or formats also are governed by SASE concepts, practical considerations may influence actual format development. When assembling a candidate format, the analyst draws classifier words and phrases from the classifier database, and then constructs hierarchical information structures. The organization is completed by joining several such structures to form an arrangement which is both logical and relevant to the standard's intended use. Once the format has been specified and stored in the format database, the classifiers from which it was constructed are thought of as <u>headings</u> under which technical information (i.e., code requirements) will be logically presented.

However, it is not always true that a phrase used as a classifier is appropriate for use as a heading. For example, the code analyst may construct classifiers in a way which aids information access during a user query, as in the case of AREA, ALLOWABLE. Organizational headings found either in a table of contents or as bold-face type within a code's text would not appear this way. When drawing classifiers to construct a candidate format, therefore, it is important that the analyst carefully consider the use of terms. Terms and phrases best suited to information access via user query (as through a code's index) are not necessarily the most useful phrases for highlighting information within the body of the text (as through bold-face headings).

The analyst also must consider the need to combine several classifiers into a single format heading, to ensure that all relevant code requirements will map onto the format. For example, the classifiers AREA, ALLOWABLE; AREA, MAXIMUM; and AREA, MAXIMUM AGGREGATE (useful for querying very specific kinds of information) might be combined under the single heading ALLOWABLE AREA in a format.

Additionally, it is extremely important that the analyst approach the format development task with some ideas regarding the nature of the desired format(s). The SASE concepts provide useful guidelines for logically structuring code contents. The SASE/SS software tools enable the analyst to create, maintain, and manipulate important data defining a code. Neither, however, can generate candidate formats which suit particular user needs within a given context. Responsibility for this rests solely with the analyst.

4.1.3 Format Evaluation

Finally, practical considerations may influence the conduct and results of format evaluation tasks. Perhaps the most critical factor concerns the sheer amount of information which must be integrated and evaluated by the analyst. In the CBT study, each of the three code requirement databases contain (on the average) some 1.000 individual requirements. The classifier database contains more than 1,700 classifiers, and a typical format may contain some 400-600 headings. When the three code requirement databases are mapped onto the three candidate formats, nine extremely lengthy outlines are produced. These must be studied in great detail, and compared with one another.

Of course, certain analyses and comparisons can be quickly accomplished by the computer. For example, the computer can determine and report how many--and precisely which--requirements in a given requirement database failed to map onto a particular candidate format. This provides an important quantitative measure of a candidate's ability to contain a code's complete scope.

The more qualitative comparisons, however, are more difficult with large outlines. To determine how the candidates compare on the matter of information access, for example, it might be necessary to test each outline in building design or code review simulations. Such trials fall outside the scope of the current CBT study.

4.2 Summary

Current CBT research to support development of a common format for the model building codes has been discussed, and preliminary work demonstrating the application of advanced techniques for standards analysis, synthesis and expression has been presented. The SASE techniques allow model code provisions to be stored in specialized databases, classified for easy access, and displayed in conjunction with candidate building code formats. By mapping the technical contents (specifically requirements) of existing model codes onto various candidate formats, each candidate may be evaluated as to the extent to which it adequately contains and expresses code provisions.

A conceptual framework for modeling the content and organization of building codes was described in relation to model code format development. The structure and application of prototype software tools based on these concepts also were discussed in detail. Finally, practical constraints of the current study were enumerated, and recommended practices to guide future work were offered.

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Structural Safety Assessment During the Construction Phase

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ABSTRACT

In recent years, building failures during construction have attracted much attention, such as the Harbour Cay Condominium collapse in Cocoa Beach, Florida. This failure and other related failures illustrate the need to monitor the structural integrity of the building during construction.

A technique is proposed which can be used with reasonable accuracy to determine the effects construction loads have on the structure capacity of a reinforced concrete building. The technique accounts for different types of slab construction, variations in concrete strength throughout the structure, and the nature of different shoring and reshoring systems. The technique uses the equivalent frame method to determine moments and shear forces produced in the structure by the imposed construction loads, and compares these resultants to the shear and moment capacity of the structure at various stages of construction.

The technique is formulated for implementation on a micro-computer. As an example, a case study of the Harbour Cay Condominium is presented.

INTRODUCTION

Major building failures during construction attract much attention. Two noted construction failures of reinforced concrete building are the Skyline Plaza collapse in Fairfax County, Virginia,(1) and the Harbour Cay Condominium collapse in Cocoa Beach, Florida(2). These catastrophic failures have drawn attention to the many problems associated with construction safety.

One of the problems was the behavior of concrete at early ages. Research has been conducted on the development of non-destructive techniques of estimating the concrete tensile and compressive strength at early ages. This would permit the determination of the varying concrete strengths within the structure during the construction phase. However, knowing the concrete strength does not guarantee safety. To determine the margin of safety against failure, one needs to perform a structural analysis that accounts for the magnitude and location of construction loads, including the effects of shoring and reshoring as well as knowing the concrete strength at various stages of construction. It would be time consuming and costly to perform this analysis each time a new floor is placed or when the reshores are removed.

The National Institute for Occupational Safety and Health (NIOSH), Division of Safety Research, developed a method of determining the effects of construction loads on a structure under the author's guidance. The approach accounts for different types of slab construction, concrete strengths which vary with time and throughout the structure, different shoring and reshore systems (temporary supports used after forms and shoring is removed), and ease of employment in the field. This approach employs the well known equivalent frame method,(3) (a technique that models the building as a series of frames, where the floor slabs are represented by the beams in the frame) together with equivalent distributed floor loads resulting from shoring and reshoring to determine the magnitude and distribution of the shear, moments and direct column loads on the structure. These forces are compared to the shear moment capacities of the structure using the ACI code nominal values in order to determine possible overload conditions.

METHOD OF ANALYSIS

The equivalent frame method is employed to determine bending moments in slabs and columns resulting from the structures dead loads and construction loadings. This approach was adopted because of its familiarity to structural engineers through its inclusion in the ACI Building Code, ACI 318 and commentary,(3,4) as well as its treatment in other contemporary sources(5,6). The equivalent frame method is capable of analyzing different reinforced concrete building designs; such as flat slab, slab with drop panels or column capitals, slab with spandrel beams, and slab and beam construction. With this method, reinforced concrete buildings can be analyzed by floor and column row which permits the use of a micro-computer with only 48K RAM capacity. Structural data (building, column and beam dimensions) are first stored by floor and column row. Next reinforcing data (bar size, and spacing) are stored in the same manner.

A structural analysis is performed on each floor that supports shoring or reshores. In the analysis, the following are considered live loads: shoring, reshoring, and the loads transmitted by the shoring and reshoring, such as the construction loads and the weight of the fresh concrete. The self weight of the mature concrete floors is considered as a dead load.

Since the magnitude of the live loads are dependent upon the type of shoring scheme in use, the effects of different shoring schemes need to be analyzed(2,7,8,9). The results of the shoring analysis is conveniently expressed as equivalent uniformly distributed floor loads which can be used with other floor loads in the equivalent frame method.

To perform the analysis, using a micro-computer, the slab and concrete strengths are first entered by column row and floor and the corresponding structure data is read from storage. Next the results of the analysis, that is the slab and column moments and shears, are stored for later reference. Then the reinforcing bar data is retrieved and the shears and moments capacities are computed using the ACI Code nomimal values. Calculations for the moment capacity of the slab or slab-beam system are made at the slab-column joint and midway along the column lines. The effective depth of the slab is assumed to be the slab depth less cover and bar diameter. In slab-beam construction it is assumed that the beam carries the moment and shear loads. For the slab with spandrel beams, the moment capacity is obtained by summing the slab and beam capacities. Also, it is assumed that the spandrel beam carries the shear load, see Park and Gamble(5).

Two sets of shear calculations are made: the punching shear resistance and shear produced by unbalanced moment effects. The punching shear resistance of the slab is calculated at each column. In the case of beams or spandrel beams, the slab shear resistance is replaced by the beam shear capacity. The shear produced by any unbalanced moment is only considered for flat plate or slab and spandrel beam construction as recommended by ACI(3). For the slab and spandrel beam system, the unbalanced moment is reduced by the torsional resistance of the spandrel beam. Also, for these cases, the spandrel beam is checked for shear and torsion capacity using the ACI Code provisions. If the moments and shears determined in the structural analysis exceed the ACI Code shear and moment capabilities, the structure is said to be in a failure mode.

HARBOUR CAY CONDOMINIUM-A CASE STUDY:

To illustrate this approach, the Harbour Cay Condominium was analyzed for the conditions prior to its collapse. The structural information and concrete strengths were obtained from the NBS Report; "Investigation of Construction Failure of Harbour Cay Condominium in Cocoa Beach, Florida"(2). The following live loads were assumed:

shoring 10% of supporting floors dead weight

reshores 5% of supporting floors dead weight

Loads transmitted by shoring and reshoring to supporting floor

1. 25%* of construction live load--50 psf (a typical value which meets the ANSI code provisions)
2. 25% of the weight of the fresh concrete.

*The 25% was determined from the shoring analysis for one floor of shoring and three floors of reshores. This percentage will vary for different shoring systems.

The analysis was limited to the column row two or the second row of columns parallel to the front of the structure. This column row was chosen for it is the most critically loaded column row in the structure. The structure was loaded as if all ten bays of the roof had been poured, where in reality, the workers had not poured the last two bays at the time of collapse! This was done in order to obtain the worst loading case when analyzing the building for possible failure conditions. The Harbour Cay collapse is only used to illustrate the approach presented, not to draw any conclusions about the collapse.

DISCUSSION OF RESULTS

Figure 1 compares the moments produced by the live and dead loads to the ACI nominal moments in the floor slabs. In figure 2, the punching shear forces are compared to the ACI nominal shear force and the shear stresses produced by the unbalanced moments at the columns are compared to the allowable stress in figure 3.

As can be concluded from figure 1, the floor slabs had ample moment capacity to carry the imposed loads. However, a review of figure 2 reveals that the fifth floor punching shear force around the columns exceeded the ACI allowable shear force by 9 to 21% of the allowable. Also, the shear stressed produced by the unbalanced moment transfer to the fifth floor columns exceed the allowable stress by 11 to 26% of the allowable. Therefore, it is concluded that the structure is overloaded, since there is not enough strength at column connections to carry the imposed loads. This is similar to the conclusions drawn in the NBS report for the possible cause of the collapse.

DISCUSSION AND CONCLUSION

The equivalent frame safety analysis presented is designed to monitor a concrete structure under construction for possible building failure conditions. By calculating the moments and shear forces within the structure and comparing them to the ACI Code shear and moment capacities of the structure, one can estimate the margin of safety against failure.

The safety analysis presented has some advantages over existing field practices.

> In America the general building contractor is responsible for the design, erection and removal of formwork. The method presented analyzes the structure for varying concrete strengths, based upon field conditions, in column rows, floors and beams making it particularly adaptable to micro-computers. Thus, it should appeal to building contractors wishing to monitor the construction cycle in reinforced concrete structures.
>
> The method can determine the points where overload would occur before the placement of the concrete. If the structure is overstressed, appropriate

precautions can be taken to prevent injury to workers or damage to the structure.

The method allows the field engineer, by monitoring the structure for possible failure conditions, to proceed at an optimum construction rate. This would be achieved by taking advantage of early concrete strength, and preventing unnecessary damage to the structure by overloads.

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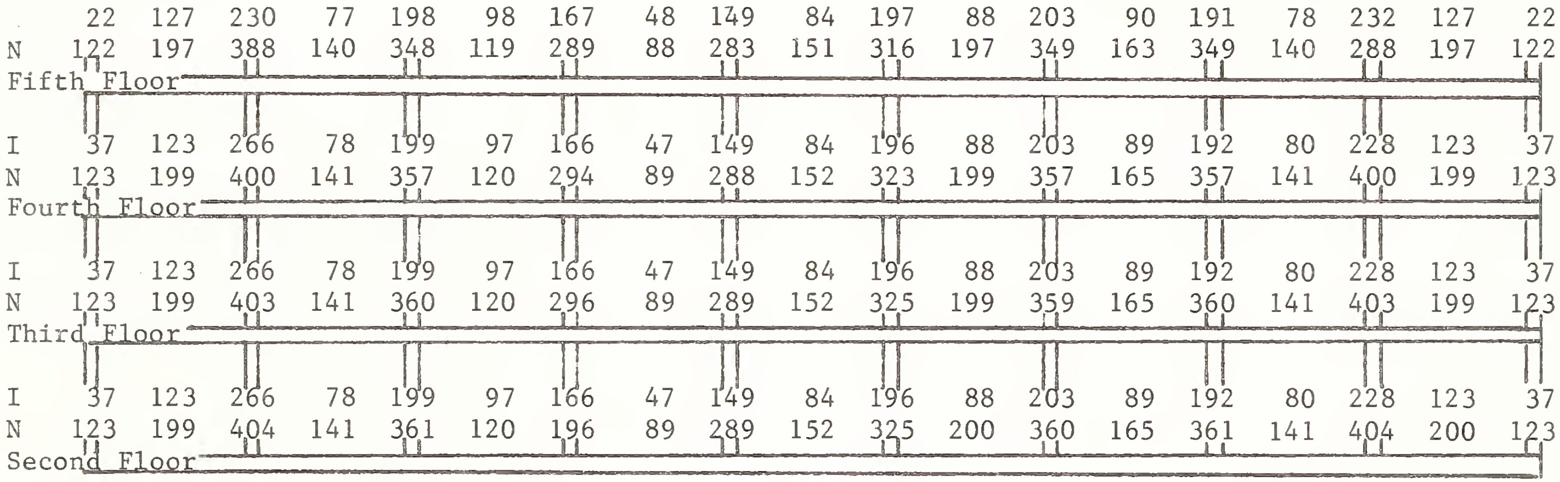

Fig.1 - Imposed and Nominal Bending Moments in floor slab along column row two, foot-kips

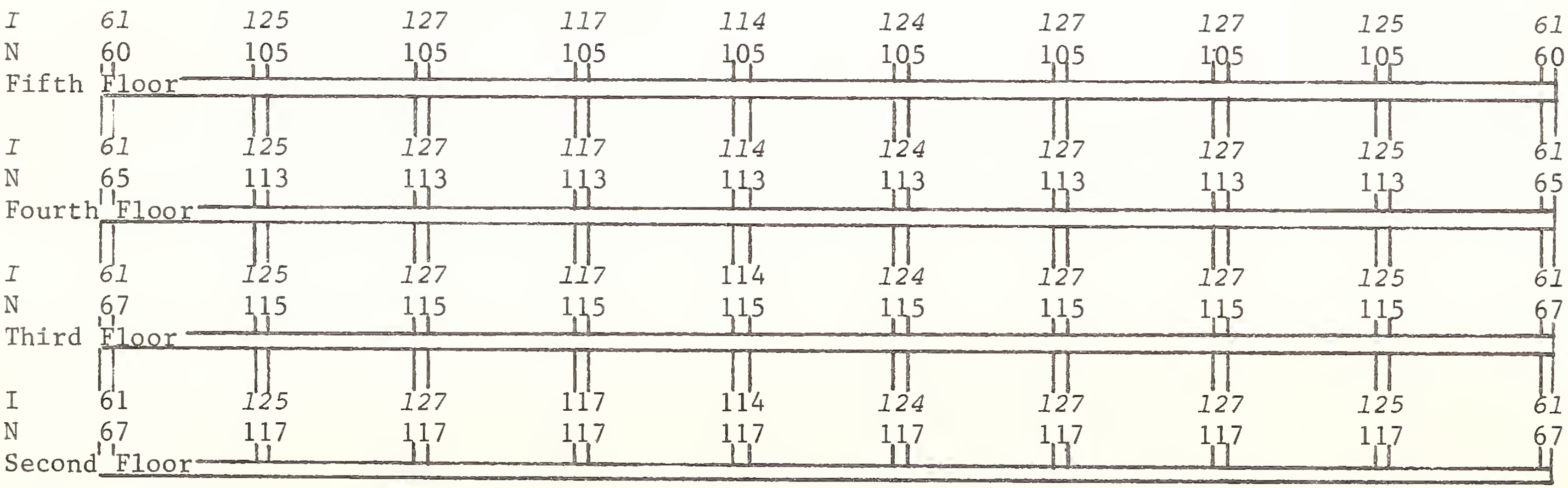

Fig. 2 - Imposed and Nominal Punching Shear Forces around columns, along column row two, kips

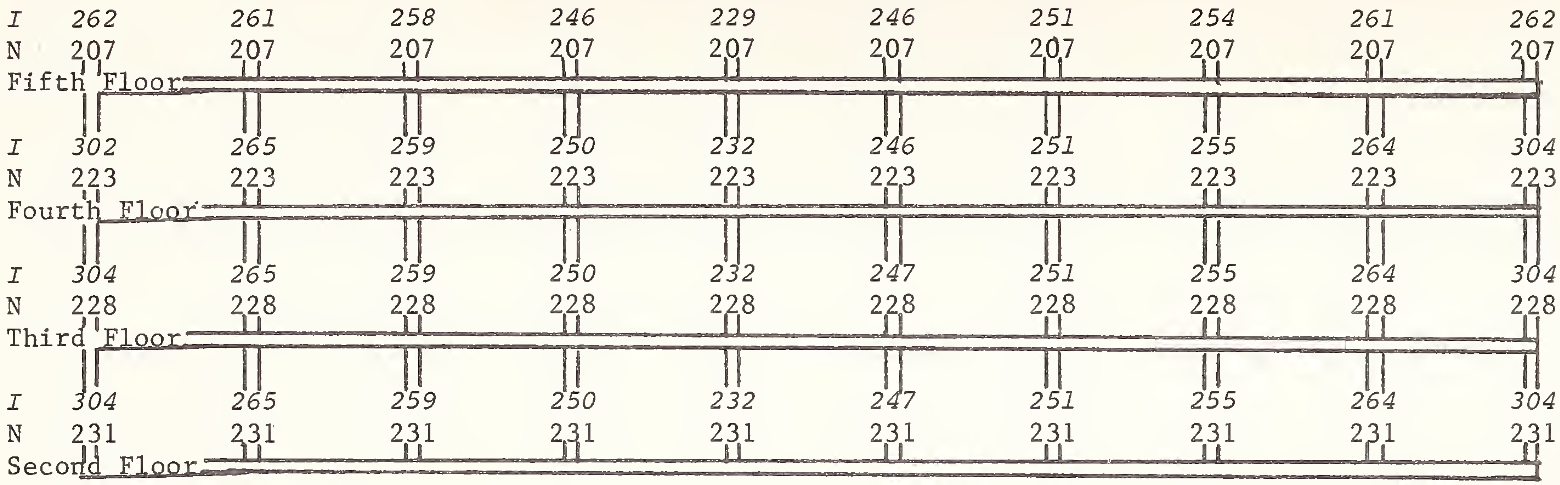

Fig. 3-Imposed and Nominal Shear Stresses around columns in column row two, psi

Automation of the Building Code Compliance

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Using microcomputers to check building code compliance started a year ago when 120 architecture students at The University of Texas at Austin needed to check their proposed building designs with the energy conservation code and the exit section of the Uniform Building Code. This project was unsupported until a member of the building inspection department of the local government authority saw the usefulness in the procedure, and a microcomputer company donated some hardware and software to test the concept. This is a software development project using microcomputers to check a proposed building project's compliance with the building codes. The codes chosen for project are the Uniform Building Code and ASHRAE* Standard 90A-1980, "Energy Conservation in New Building Design." The computer program is structured to ask a series of questions on the building project in an easy-to-respond menu format, then the program compares the proposed design with the code provisions for energy conservation and exiting. Future versions of this program will use graphic diagrams with the questions presented to help people using the program. The present program version will be used for site testing in building inspection departments and architects' during 1984 and 1985. The authors of these programs envision more programs being developed in the future, one on mechanical building code and one on electric code.

Plan review and permit procedures in metropolitan building inspection departments are encumbered with a number of problems. Among these are the logistics of processing the increasingly complex construction projects and processing them in a reliable, replicable and consistent manner. This program provides the means toward those ends.

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*ASHRAE--American Society of Heating, Refrigeration and Air Conditioning

Plan-Check-90 and Plan-Chek-Exit were developed first as a teaching aid for classroom use and later expanded because some building code professionals felt that they would be useful to both the architect and the plan reviewer in the code compliance review of a project. The programs allow the architect or engineer to test alternatives, and provide the building inspection department with a method for checking the building design quickly and in greater detail. By automating the building energy conservation code and exiting provisions of the Uniform Building Code, it frees the architect and design engineer to develop more innovative solutions by providing an easier method to check ideas. After testing these programs will be available to organizations such as building inspection departments and architecture firms.

The automation of the building code process does have some disadvantages in addition to the obvious advantage of help in reducing the time spent checking code compliance. These advantages and the disadvantages of the building codes are shown, as can be seen, there are some very important reasons for developing the programs.

ADVANTAGES

1. It's estimated that the code review proceeds 3 to 4 times faster.

2. The architect can compare alternative design solutions and get a response quickly to a design concept.

3. The interpretation of the code is predictable and repeatable.

4. A report is available that compares the building design to the code requirements and shows the designer code deviations.

5. An inspection report is developed for the building inspector on critical parts of the design.

6. The building design is recorded in an updated format for fire department use and future additions or changes to the building.

7. The adjustments to the code for local needs is easily accomplished by resetting program constraints.

DISADVANTAGES

There are some problems that need to be addressed to use computers to check building codes. These concerns are:

1. Equipment cost is approximately $4000 to $5000 per plan reviewer in a building inspection department for the computer and software and an equivalent cost for the architectural firm as they're needed.

2. Training appears to be needed for confident use of the computer.

3. Since program bugs are a fact-of-life with any computer software, an experienced plan reviewer or architect is needed to recognize these problems. A computer program is not a tool for a novice; it just allows them to make errors faster.

4. New administrative procedures are needed to incorporate microcomputers in an existing organization of a building inspection department.

When this project started, the program developers were concerned with who would use the program and how it would be used. The goal was to design a program for the architect, the engineer, the facilities manager, and the plan reviewer of the building inspection department. The concern was how to make the programs most useful for the building professionals. To achieve this goal, the authors looked at how the different professionals might use the computer methods to select the critical features of the software.

Architects--preliminary review of schematic design, testing of alternative designs. The need to be able to easily change the designs. Time spent with codes--10%.

Engineers--checking energy designs of the building project, reviewing fire safety requirements. Need to provide alternatives. Time spent with codes--10%.

Facilities Managers--reviewing construction plans, reviewing building modifications and uses. Need to keep a history of the project. Time spent--5%.

Building Plan Reviewers--preliminary consulting with architect and engineers and review of the building design. The program needs to be able to be customized. Time spent with the code--75%.

Others--developers, energy consultants, general contractors, subcontractors, manufacturers of building products. The program must be self-explanatory enough that individuals unfamiliar with the program can use it; this is a goal that has not yet been achieved.

Building inspection departments clearly use the building code most often and their primary need is an aid to help speed the task of building plan review and keep a record of the results. Other building industry professionals, architects, engineers and facilities managers, only use the building code a few hours per week, which explains why they are generally not well versed in the code. These professionals would find helpful some aid in using the building code to check all the proposed design. A computer program should help them through the code checking process with the opportunity to temporarily stop the procedure and revise the building design when needed. The last question that was encountered by the program designers is what type of reports should be provided? For example, the authors considered the following:

1. The design does or does not comply with the code provisions.

2. Suggestions to the architect on changes to bring the building design in line with the code.*

3. Provide suggested improvements over and above the minimum requirements.*

4. Provide an inspection list for the construction inspector; for check for critical features.

5. Provide an owner's report that compares the design with other buildings.

6. A contractor's report which show the contractor the critical features of construction.*

7. The building inspection department report, that records the type of construction with the code provisions that were referenced.

*Not in the Building Inspection Department domain.

The two computer programs are developed to give the architect a report on a comparison of his design with the building code; and a report for the building inspector of items to check on the construction site.

It was necessary to make some judgments on the building code implantation in a computer program, such as in the energy code on air leakage on buildings it states, that window and door frames shall be caulked. As this requirement may not be specified on the construction drawings, the inspection report that goes to the construction inspector would include note that says; check for window caulking. The energy code was straightforward to use evaluating a proposed design, but with the exit provisions of the Uniform Building Code, the problem is more complicated. The exiting requirements depend on many factors such as on how the building is used, on the height, floor size, construction materials, and occupants of the building. Because of these conditional features, the evaluation of the building for exiting required a computer program that branches through building code sections. This means the program is complex and involved, having a large number of routines when during the plan checking the program control moves between the routines in a manner similar to a plan reviewer using the Uniform Building Code.

The programs are at the present time being tested where they will be used by architecture students, and selected building plan reviewers and architects. The results from the testing with the students and plan reviewers, will be used to improve the programs before they are made available. The present schedule for testing the programs will last approximately one year as shown:

Phase 1 — Locate errors and user problems. Check that the programs give the same results as experienced plan reviewers. Tested by students and a selected building inspection department. September 1984 to March 1985.

Phase 2 — Further testing for errors and improving the user interaction. The goal is to make the program self evident. Tested by selected architects and building inspection departments. March 1985 to October 1985.

Phase 3 — Evaluation of the documentation and public release of the program. August 1985 to November 1985.

The testing of the programs will be directed toward the common faults of computer programs; such as unclear and excessive documentation, extra unnecessary data input, unclear error messages, unnecessary program reports and poor checking of user input. It is the authors' goals that the users of the programs should not need to know anything about computers or computer programs other than how to turn the equipment on.

PLAN-CHEK-EXIT

Specifically, the program provides a menu-driven interactive comparison of required specifications for the current project with the measured or proposed specifications of the project. The requirements are based upon the Uniform Building Code 1982 edition, but may be modified to respond to other model or local codes.

Plan-Chek-Exit parallels the organization, format and content of chapter 33 of the Uniform Building Code in order to reduce the possible misapplication or misinterpretation of the building code. The program proceeds as follows: (1) Program prompts requesting project information, such as occupancy use, floor area, number of floors and other building factors. (2) The menu provides user options for specific code sections or comparisons of required specifications. The menu also provides for a selection of output alternatives such as, required features in the building or options given the known input information. (3) A written record of the plan review is available as a procedural tool for the reviewer. (4) Example of questions include:

A. Is there fixed seating in the space? Yes or No ______

B. If yes, select the type of seating from the following (choose 1, 2 or 3):

1. Individual seats.
2. Benches or pews.
3. Booths

C. If 1, what is the number of individual seats? ______

D. If 2, what is the total length of benches or pews? ______

E. If 3, what is the total length of booths? ______

G. Is there an area within the space (other than aisles required for the fixed seating) where there is no fixed seating? Yes or No ______

H. If yes, what is the area in sq. ft.? ______

I. What is the use category of the area? (Table 33-A appears on screen, user selects category.)

The total occupant load of the space is ______.

PLAN-CHEK-90

This program compares the building design with the ASHRAE standard. The program will be updated when the ASHRAE standard 90A-1985 is adopted as a building energy conservation code. This ASHRAE standard is an energy conservation standard for new construction that has been adopted or is being considered by many communities in the country. These communities now have the task of implementing this energy conservation code, and Plan-Chek-90 was developed to help them compare the proposed building design with the energy conservation standards. The features that make this program useful for implication of an energy code are specifically a menu input and the ability to alter energy conservation code provisions to meet local needs, to make them more stringent or lenient to adapt the local building custom. A sample of the input menu questions that the plan reviewer or architect sees is the following.

```
Select a menu please
     1.  Envelope test
     2.  HVAC system
     3.  HVAC equipment
     4.  Service hot water
     5.  Energy distribution system
     6.  Lighting power budget
     _______?

Envelope menu
     Walls     Number of types of walls _______?
               Type 1 U-Value _______?  Area _______?
                       Weight _______?
               Type n U-Value _______?  Area _______?
                       Weight _______?
     Roof             U-Value _______?  Area _______?
                       Weight _______?  Thickness _______?
                        Specific Heat _______?
     Slab      Resistance _______?
     Windows   Area _______? U-Value _______?
               Shading Coefficient _______?
     Infiltration        Rate _______?  Method Used _______?
```

The menus for HVAC systems, hot water service and lighting are similar in structure and use to the envelope menu shown. The program checks each user input for errors of misunderstanding by comparing the input with a range of acceptable values. After the architect or plan reviewer inputs a design a record is made of all the input so a simple change in building parameters at some future time results in an easy input change and not reinterpretation of the entire project. When all the required information has been input to the program a comparison is made of the building with the standards the required output reports printed: the reviewer's report, the architect's report, the inspector's report and the summary for the building inspection department.

It is felt that these programs will help the building design process by the architect, the plan review and the building inspection department by providing timely and accurate information on the proposed building design. The architect should find the information helpful during the preliminary design phase of a building project when many basic decisions are made. The plan reviewer will appreciate the ordered procedure to compare the building design with the building code and the ability to keep a record of the project and plan review. One of the possible future benefits of this procedure is that important useful building information is in computer files of the Plan Chek programs that can be used by architects in future building renovations. In addition, building managers or fire marshals can easily check the building's approved use and check proposed renovations. These programs serve a present need in the building code compliance process and offer future improvements on how code compliance is managed.

REFERENCES

1. Uniform Building Code, International Conference of Building Officials, 1982, Whittier, California.

2. ASHRAE Standard 90-80, Energy Conservation in New Building Design, American Society of Heating, Refrigeration and Air Conditioning Engineers, 1980, Atlanta, Georgia.

3. Model Energy Code, Council of American Building Officials, Falls Church, Virginia, 1983.

Microcomputer Design Tool to Aid Construction Professionals to Comply with the Florida Model Energy Efficiency Code

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This paper will discuss the development and use of an Apple II+ compatible computer program that calculates the residential Energy Performance Index (EPI) under Section 9 of the Florida Model Energy Efficiency Code. The program was developed as a design tool for builders, engineers, architects, and others in the construction field desiring to achieve cost effective and superior residential energy performances under the code.

Many states now have energy performance building codes responding to the Federal requirement of the Energy Policy and Conservation Act (Public Law 94-163). Florida law originally referenced minimum standards for construction to meet or exceed national standards such as those of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE 90-75). However, these standards were designed primarily for climates where heating is more important than cooling. Consequently, the Florida Model Energy Efficiency Code for Building Construction was developed to be climate-specific for Florida and to address other Florida problems such as growth rate, energy costs, and energy availability. Before discussing application of the computer program, a brief background and description of the FMEEC is in order.

BACKGROUND OF THE FLORIDA MODEL ENERGY EFFICIENCY CODE (FMEEC)

The United States still imports about 30 percent of its energy requirements from foreign countries. A lack of fossil fuel resources make Florida's dependence much greater. There still lurks the threat of oil embargos, blockades, or a Middle East crisis that could cut off energy supplies and cause shortages such as experienced in 1973-74 and the summer of 1981.

There is a limit to the amount of oil resources available. Oil has other uses besides energy. Petroleum, as feedstock, is used to manufacture fabrics, plastics, and many other items we now take for granted. These resources must be protected for future generations.

Let us not forget the environment. The less energy we burn in the power plants, the less pollution of air and water. For every Btu equivalent of electricity that is saved through conservation in buildings, we save three from being burned in the power plant. Electric power plants are only about 30 percent efficient in producing electricity from coal or oil.

Self-sufficiency, preservation of resources, the environment -- all motherhood and apple pie. Rising energy costs get attention and action faster. Due to Florida's growth rate (residential construction rates currently at 250,000 units/year), electrical demand in Florida will become a real problem. The tremendous capital investment needed to construct new power plants has caused electrical rates to rise faster than the general rate of inflation. This is predicted to continue.

In the last three years gasoline prices decreased, but in some areas of Florida, electric rates have increased more than 40 percent. There are cases where some people are paying more for electricity to operate their home than they pay for mortgage payments.

Residences in Florida consume 24 percent of the energy used for all purposes in the State. Furthermore, 11 percent of all the energy used in Florida is consumed in homes as oil (oil used to produce electricity). The average residence in Florida consumes enough energy that, if converted to oil, a person could drive a 15 mile per gallon automobile about 40,000 miles per year.

To address these issues, a comprehensive Energy Code was developed. The Florida Model Energy Efficiency Code provides a statewide uniform standard for energy efficiency in the thermal design and operation of most buildings. This code may be made neither more stringent nor more lenient by local government. The Florida Department of Community Affairs has the responsibility to administer, modify, revise, update, and maintain this energy code. According to the Department of Community Affairs, an intelligent, long-range program of code implementation may save an estimated 700 million gallons of oil during the next ten years without sacrificing the standard of living.

DESCRIPTION OF SECTION 9 OF THE FLORIDA MODEL ENERGY EFFICIENCY CODE

Section 9 is a point system for ascertaining whether a residential building complies with the Code. This performance based on standard allows flexibility in the design of the building as opposed to a strict prescriptive compliance method as delineated under Section 10 of the Code which is another option.

Under Section 9 a point method is used to indicate how much energy the residence will use for air-conditioning, water heating, and space heating. A certain number of points have been assigned to each energy consuming feature of a residence. When the points are added up and divided by a factor determined by floor area, a total number of EPI points are calculated.

Each residence is assigned a base EPI between 80 and 120 depending on size*. A home with an EPI of 50 points is expected to use only 50 percent of the energy required for air-conditioning, heating, and water heating as a home of the same size having an EPI of 100. The lower points, the better the residential energy performance and the less energy consumed. A comparison can be drawn between the EPA mileage ratings for automobiles and the residential EPI. Actual mileage is affected by individual driving habits. Likewise, residential energy performance is affected by the family's lifestyle.

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* Effective June 30, 1984, the Code was modified by a size and performance adjustment multiplier so that the base EPI points for all residences is 100.

This EPI is affected by many factors including:

- floor plan geometry
- compass orientation (north, south)
- window size, type, function
- manmade shading or overhangs
- insulation and construction materials
- water heating method
- characteristics and efficiency of air-conditioning and heating units
- door selection
- use of fans
- location of washer and dryer

Florida, in general, has a hot, humid climate, but because of Florida's long 6° north-south peninsula there is a relatively wide divergence of climate within the State. South Florida has less than 200 heating degree days while some areas of North Florida have more than 1500. Appropriately, Florida is broken into three climate zones. A separate color coded reporting Form 902 was developed for each zone with different multipliers or points assigned to energy conservation measures appropriate to their influence on overall energy savings. This Form 902 is submitted to the responsible building code inspector for approval (Appendix A).

CALCULATIONS REQUIRED UNDER SECTION 9 TO DETERMINE THE EPI

Table 9A is used to determine the maximum EPI allowed. (See Appendix A.)

Determine Gross Winter Points (GWP) by multiplying the area of each component of the envelope by the corresponding winter points multiplier for the amount of insulation to be added to that component.

Determine Gross Summer Points (GSP) by multiplying the area of each component of the envelope by the corresponding summer points multiplier for the amount of insulation to be added to that component.

The glass component requires consideration of several factors to select the proper multipliers, orientation, overhang, single or double glazing, and shaded coefficient. For shading coefficients other than 0.83, the following formula may be used and is used in the computer program:

GSP = Area x STP x SOF   where STP = (SPM-CI) x SC + CI and

SPM = Summer Points Multiplier for single pane of double pane clear glass from the 902 Form.

SOF = Summer Overhang Factor from Table 9F.

SC = Shading Coefficient of Glass from Manufacturer's specifications.

STP = Summer Tint Points.

CI = Conduction-Infiltration factor show below.

Conduction/Infiltration Factors	Climate Zones 1,2,3	4,5,6	7,8,9
Single pane	13	19	41
Double pane	6	10	21

To determine the final Winter Points (WP), multiply the Total Gross Winter Points (GWP) by the Duct Multiplier (DM) and the Heating System Multiplier (HSM) and divide by the Floor Area (FA). Table 9G is used to find the appropriate Heating System Multiplier (HSM) corresponding to the type of heating system to be used. Gas and oil-fired systems use a multiplier of 1.0 (Credit for gas and oil heating systems is given in Table 9D).

To determine the final Summer Points (SP), multiply the total Gross Summer Points (GSP) by the Duct Multiplier (DM) and the Cooling System Multiplier (CSM) and divide by the Floor Area (FA). Refer to Table 9H for the appropriate Cooling System Multiplier (CSM) corresponding to the type of cooling system to be used.

Hot water credit points (HWCP) are found in Table 9I.

Table 9C lists design practices for which points may be subtracted. If the dwelling qualifies for special design credit points, a maximum credit of 12 points can be used. Table 9E lists design features requiring penalty points to be added.

To test for code compliance, determine the Total Winter Points (WP), Total Summer Points (SP), Duct Multiplier (DM), Heating System Multiplier (HSM), Cooling System Multiplier (CSM), Floor Area (FA), Hot Water Credit Points (HWP), Special Design Credit Points (CP), Heating System Credit Points (CP), and Penalty Points (PP). The find:

a. The Energy Performance Index (EPI), using the formula:

$$EPI = (WP) + (SP) - (HWP) - (CP) + (PP)$$

Where $(WP) = \frac{(GWP) \times (DM) \times (HSM)}{(FA)}$

And $(SP) = \frac{(GWP) \times (DM) \times (CSM)}{(FA)}$

b. If the EPI is less than or equal to the maximum EPI allowed in Table 9A then the building is in compliance.

While the Form 902 is fairly straightforward, the large number of conservation elements addressed, each with multipliers or points, made it a prime candidate for computer adaptation. With that background and description of Section 9 of the FMEEC, a discussion of the computer program and its use as a design tool is in order.

COMPUTER PROGRAM FEATURES

The computer program will perform all the calculations on Form 902, but more importantly, it serves as a "Design Tool" for architects, engineers, builders, and others in the construction field who desire to achieve the lowest and most cost effective Energy Performance Index (EPI) under the Florida Model Energy Efficiency Code (FMEEC). This program was developed by the author in his role as Energy Extension Service Specialist for the School of Building Construction, and is offered as a public service by the Institute of Food and Agricultural Sciences and the Energy Extension Service at the University of Florida.

1. It allows you to enter the data on a residential design and store the results for future review or modification. Storage may be accomplished on the back of the program disk or on a separate disk.

2. It allows entry of a wide variety of construction parameters, i.e., windows with different shading coefficients, overhangs, single and/or double glass on any or all nine orientations; combinations of concrete, frame, and common wall construction; and a variety of roof and floor designs all in one structure.

3. Will automatically interpolate tint factors for glass with different shading coefficients.

4. Allows zone changes to be made after (or during) entry. It automatically adjusts multipliers for each respective zone.

5. It will automatically calculate the summer, winter, and prorated EPI points for each design option and orientation, i.e., NW glass, S wall, and provides for their display.

6. Calculates the total EPI for the residential building.

Features 5 and 6 are particularly useful as an aid to energy efficient building design as will be shown later.

PROGRAM OPERATION

1. The program is user friendly and self-prompting. To run the program, simply turn on the computer, insert the program disc in drive and it will automatically be ready to operate. Typing in the words "Run Disk" will also boot it up.

2. Answer all the questions with "Y" for yes and "N" for no or appropriate numbers (1,2,3, etc.) or by the preface code letters or numbers on the menu.

3. The program length exceeded 48K capacity of the Apple II+ and had to be broken into two parts and linked together. If the menu sequence is followed, entry and calculation time will be the shortest. If the word "DISK" is shown after a menu item, it means the disk drive will have to operate before that item can be addressed.

4. To gain access to the main menu, a prompt statement asks which side of the house you wish to work on. Type in an appropriate number for North, East, West, etc.

5. There are several residential files already saved. The files named NFL1 and CFL1 correspond with the September 1982 edition of the Department of Community Affairs Residential Instruction Manual for North (Zone 1,2,3) and Central (Zone 4,5,6), respectively. It is recommended that the first time user call up one of the "(NFL) Series" files, then follow it through the menu items, change R-values, areas, and change other entries in order to gain familiarity with the program. As long as the "SAVE" menu option is not exercised, new files or changes to an existing file will not occur.

6. Data can be entered by typing in the appropriate value and then the return key. Data can be modified by typing in the new values and then return key. Note: When modifying insulation and glass data, you may retain the data at the cursor by pushing the return key. YOU DON'T HAVE TO RE-ENTER THE DATA YOU WISH TO KEEP! For example, if the area of the walls remains the same but you wish to evaluate the effect of the EPI by a change in R-value, simply push the return key when the cursor is on the first digit of the area, type in the new values when the cursor is on the first digit of the R-value, then hit the return key.

7. Each side of the house is worked on separately, but for simplicity, the walls, floor, ceiling, slab perimeter, and door areas and values can be entered under one side. The sample files have these entries under the north side.

8. When the screen prompts "SEE TOTAL OF OPTIONS?", answering "Y" will display the total GWP and GSP and a prorated EPI total for the component addressed (walls, ceiling, glass) for all sides of the house. Entering "N" allows entry or modification of data on that component for the side designated.

COMPUTER RUNS AND DATA ANALYSIS

The Department of Community Affairs for the State of Florida produced Residential Instruction manuals for three zones. Using the computer, the EPI can be calculated for the North Florida example used in this manual for single family residential construction. This is somewhat typical for that zone. (See Appendix B for the floor plan.)

Using the Form 902 (Appendix A), the basic construction features are:

Conditioned floor area = 1,537 SF
Net frame wall area = 1,321.4 SF insulated R11
Net door area = 40.6 SF standard wood or metal
Ceiling under attic = 1,387 SF insulated to R19
Ceiling single assembly = 338.3 SF insulated R19
Floor area = 1,537.2 SF off grade insulated to R11
Windows N 20 SF single, clear with 2' overhang
Windows E 24 FL single, clear with no overhang
Windows E 20 SF single, clear with 2' overhang
Windows S 36 SF single, clear with no overhang
Windows S 20 SF single, clear with 2' overhang
Windows W 138 SF single, clear with 2' overhang
Ductwork multiplier = 1.15 (insulated to R 3.5)
Gas heat HSM = 1.0 from 9G (-16 credit points)
AC EER = 8.0 CSM = 0.81 from 9H
Design Credit Points = -5 (ceiling fan = 1; 4 rooms with cross ventilation = 4)
Design Penalty Points = +8 (washer/dryer in conditioned space = 3; fireplace with inside combustion air = 5)

This data was entered in the computer and was saved as File NFL1 (see Appendix C). The EPI was determined to be 96 which was only 4 points under the maximum EPI allowed. Using the computer program, an analysis can now be made of the impact on the EPI using increased insulation levels, modifying the shading coefficient, and reducing the window areas. (See Appendix D.)

COMPONENT	ORIGNIAL			MODIFIED		
Cumulative	Measure	Prorated EPI	Total EPI	Measure	Prorated EPI	Total EPI
Ceiling	R19	11.8	96	R38	8.6	92.7
Wall, Floors & Doors	R11, Std. Wood	29.5	96	R19, Ins. Wood	20.9	83.7
Glass	Single Clear	64.3	96	Double Clear	53.2	72.1

For Florida builders, increasing ceiling insulation to R38 and walls and floors to R19, adding insulated doors and double glass windows represents an extraordinary expense to achieve an EPI of 72.1. Keeping all other factors the same, but changing the glass overhang to the maximum (12') only saves 7 EPI points. This is another costly option.

On the other hand, just reducing the window area on the west side from 138 SF to 69 SF would reduce the prorated glass EPI to 45.5 and the total EPI to 77.0. Reducing the area of all glass by one-half reduces the prorated glass EPI to 32.2 and the total EPI to 63.4. Another attractive option is to use tint filters or glass or solar screen with a shading coefficient of 0.24. That option would reduce the prorated glass EPI to 35.2 and the total EPI to 68.9

points for North Florida and to a total EPI of 57.0 for South Florida. As a service to Florida builders, the author developed an EPI Summary Sheet to serve as an energy efficient guideline (Appendix E). This data on the sheet shows that glass typically represents about 52 percent of the prorated EPI, walls 18 percent and the ceiling 12 percent.

The computer programs addressed in this paper demonstrates that a microcomputer can be effectively employed to make rapid calculations and perform cost effective analysis of compliance options under certain building codes.

FLORIDA MODEL ENERGY EFFICIENCY CODE FOR BUILDING CONSTRUCTION

FORM 902

BOB GRAHAM GOVERNOR

SECTION 9 9H POINTS METHOD

DEPARTMENT OF COMMUNITY AFFAIRS

CLIMATE ZONES NORTH 1 2 3

PROJECT NAME AND ADDRESS	Example: Single Family NORTH FLORIDA ZIP	JURISDICTION ZONE	
BUILDER	Aircastle, Inc.	PERMIT NO.	
OWNER	F. Norhouse	JURISDICTION NO.	

STATISTICS

☐ RENOVATION ☐ ADDITION ☐ MULTI-FAMILY	IF MULTI-FAMILY, NO. OF UNITS COVERED BY THIS CALCULATION: ☐ (SEPARATE CALCULATIONS REQUIRED FOR EACH WORST CASE UNIT TYPE.) SEC. H901.1	GLASS AREA AND TYPE — CLEAR: 258 SGL X DBL ☐	TINT OR FILM: SGL ☐ DBL ☐

GROSS WALL AREA AND INSULATION: CBS	R=	FRAME	R=	CONDITIONED FLOOR AREA	CEILING INSULATION: UNDER ATTIC	SGL. ASSEMBLY
		1620	11	1537	R= 19.0	R= 19.0

COOLING SYSTEM	PRIMARY HEATING SYSTEM	PRIMARY HOT WATER SYSTEM
[X] CENTRAL ☐ NONE ☐ UNITARY EER-SEER = 8.0	☐ STRIP [X] GAS ☐ NONE ☐ OIL ☐ SOLAR ☐ HEAT PUMP: COP = ☐.☐ ☐ OTHER: ______	[X] RESISTANCE ☐ SOLAR ☐ HEAT RECOVERY ☐ GAS ☐ DED. HEAT PUMP: COP = ☐ ☐ OTHER: ______

MAX. E.P.I. ALLOWED (from 9A): 100.0	CALCULATED E.P.I.: 96.0
CHECK IF COMPLYING BY "ALTERNATE PRESCRIPTIVE COMPLIANCE APPROACH" (SEC. 903.11)* ☐	
CERTIFIED BY: (owner/agent) DATE	FORM COMPLETION CHECKED BY: (building official) DATE

THIS DATA IS TO BE SENT TO DCA BY THE LOCAL BUILDING DEPARTMENT.

9A MAX. E.P.I. ALLOWED (CALCULATED E.P.I. MUST NOT EXCEED VALUE SHOWN BELOW)

CONDITIONED FLOOR AREA	0-900	901-1100	1101-1300	1301-1500	1501-1700	1701-1900	1901-2100	2101-2300	2301-ABOVE		
BASE E P I	120	115	110	105	100	95	90	85	80		
DEDUCTIONS	A/C EFFICIENCY LESS THAN 8.0 EER/SEER (7.5 HEAT PUMP) (as of October 1, 1982)									−10.0	0
	IF MULTI-FAMILY: COMMON WALLS (maximum of 5 points)									− 2.5	0
	IF MULTI-FAMILY: COMMON CEILING and/or FLOOR (maximum of 12 points)									− 6.0	0
	TOTAL DEDUCTIONS										0

COMPUTE MAX. E.P.I. ALLOWED	BASE E.P.I.		DEDUCTIONS		MAX. E.P.I. ALLOWED
	100	−	0	=	100

*RESIDENCES WHICH COMPLY WITH THIS CODE BY THE "ALTERNATE PRESCRIPTIVE COMPLIANCE APPROACH" (SEC. 903.11) ARE REQUIRED TO MEET OR EXCEED ALL MINIMUM PRESCRIPTIVE LEVELS INDICATED BY SHADED BLOCKS ON THIS FORM, AND ALL OTHER APPLICABLE PRESCRIPTIVE REQUIREMENTS LISTED IN TABLE 9B. THE E.P.I. FOR A HOUSE COMPLYING UNDER THIS METHOD IS NOT CALCULATED BUT WILL BE THE MAXIMUM E.P.I. ALLOWED FOR THAT HOUSE SIZE AS SHOWN ON TABLE 9A. THE STATISTICS SECTION ABOVE SHALL BE COMPLETED AND SUBMITTED TO THE LOCAL BUILDING DEPARTMENT.

9B PRESCRIPTIVE MEASURES (CHECKLIST)

INFILTRATION: windows/doors	903.1	X	HVAC DUCT CONSTRUCTION	903.5	X
WATER HEATER - ASHRAE LABEL	903.2	X	PIPING INSULATION	903.6	X
SWIMMING POOLS	903.3		HVAC CONTROLS	903.7	X
SHOWER FLOW RESTRICTORS	903.4	X	HVAC SYSTEM EFFICIENCY SECTION	903.8	X
			CEILING INSULATION	903.10	X

RESIDENTIAL CALCULATION

FORM 902 — CLIMATE ZONES 1 2 3

COMPONENT			WINTER AREA	× WPM	= GROSS WINTER POINTS	SUMMER AREA	× SPM	= GROSS SUMMER POINTS
WALLS	CONCRETE	R 2.7 - 3.9		19.3			11.5	
		R 4-5.9		15.6			9.9	
		R 6 & UP		13.1			9.2	
	FRAME OR BRICK VENEER	R 11 - 18.9	1321.4	7.8	10306.9	1321.4	9.2	12156.9
		R19-25.9		4.9			5.6	
		R26 & UP		3.6			4.2	
	COMMON			7.8			2.5	
DOORS	WOOD OR METAL		40.6	247.7	10056.6	40.6	36.4	1477.8
	INSULATED			235.5			14.5	
	STORM DOOR			124.4			29.0	
	COMMON			61.9			4.5	
CEILING	UNDER ATTIC	R 19 - 21.9	1387.6	5.0	6938	1387.6	5.5	7631.8
		R22-29.9		4.1			5.0	
		R30 & UP		3.3			3.7	
	SINGLE ASSEMBLY NO ATTIC	R 6-7.9		14.2			14.9	
		R 8-9.9		10.9			11.3	
		R10-11.9		9.2			9.5	
		R12-18.9		6.7			7.0	
		R 19 - 21.9	338.3	5.0	1691.5	338.3	5.5	1860.7
	COMMON			4.8			1.5	
FLOOR OVER UNCONDITIONED SPACE	WOOD	R 0-6.9		15.5			4.8	
		R 7-10.9		6.5			2.1	
		R 11 - 18.9	1537.2	5.6	8608.3	1537.2	1.8	2767.0
		R19 & UP		4.0			1.3	
	CONCRETE	R 0-2.9		19.4			6.0	
		R 3-5.9		12.4			3.7	
		R 6-10.9		9.3			2.6	
		R 11 - 18.9		6.2			2.2	
		R19 & UP		4.4			1.6	
	COMMON			4.8			1.5	

SLAB ON GRADE	EDGE INSULATION		PERIMETER	WPM	
	PERIMETER	R 0 - 2.9		92.7	No
		R 3-5.9		69.5	Slab
		R 6 & UP		46.4	

OR	AREA	SGL	DBL	WOF 9F	GWP
N	20	157.4	120.8	1.0	3148
NE		157.4	120.8		
E	24	157.4	120.8	.99	3739.8
SE		157.4	120.8		
S	36	157.4	120.8	.71	4023.1
SW		157.4	120.8		
W	138	157.4	120.8	.94	20417.9
NW		157.4	120.8		
H		46.4	79.3		
S	20	157.4		.76	2392.5
E	20	157.4		1.0	3148

GLASS — DO NOT INCLUDE INTERIOR SHADING

OR	AREA	SINGLE CLR	SINGLE TIN	DOUBLE CLR	DOUBLE TIN	SOF 9F	GSP
N	20	146	123	120	101	1.0	2920
NE		221	186	190	159		
E	24	289	242	251	209	1.0	6936
SE		261	219	226	189		
S	36	190	160	160	134	1.0	6840
SW		261	219	226	189		
W	138	289	242	251	209	.94	37489.1
NW		221	186	190	159		
H		489	408	432	360		
S	20					.91	3458
E	20					.75	4335

1 2 3

GLASS AREA MUST NOT EXCEED: SGL/CLR 15% OF FLOOR AREA, SGL/TINT 17% OF FLOOR AREA, DBL/CLR 18% OF FLOOR AREA, DBL/TINT 20% OF FLOOR AREA.

H = HORIZONTAL GLASS (SKYLIGHTS). FOR SC LESS THAN 0.83 SEE SEC. 902.2d

TOTAL GROSS WINTER POINTS	74470.7

TOTAL GROSS SUMMER POINTS	87872.3

DUCT MULT

R = 3.5	74470.7	1.15	85641.3
R = 5.0		1.12	
R = 6.7		1.09	
DUCT IN COND. SPACE		1.00	

R = 3.5	87872.3	1.15	101053.1
R = 5.0		1.12	
R = 6.7		1.09	
DUCT IN COND. SPACE		1.00	

HSM FROM 9G	85641.3 × 1.0	85641.3

CSM FROM 9H	101053.1 × .81	81853

DIVIDE BY FLOOR AREA	85641 ÷ 1537	55.7 WINTER POINTS

DIVIDE BY FLOOR AREA	81853 ÷ 1537	53.3 SUMMER POINTS

CALCULATE E.P.I.

WINTER POINTS		SUMMER POINTS		HOT WTR PTS		CREDIT POINTS		PENALTY POINTS		E.P.I.
55.7	+	53.3	−	0 (9I)	−	21 (9C) + (9D)	+	8 (9E)	=	96

FEWER TOTAL POINTS ARE ENCOURAGED FOR MAXIMUM ENERGY SAVINGS

9C	DESIGN CREDIT POINTS (CP)	
CEILING FAN IN COND SPACE (max 5 CP)	1	1
MULTIZONE A/C SEPARATED BY DOOR	5	
CROSS VENTILATION (1 CP per room)	1	4
WHOLE HOUSE FAN (min.1.5 cfm/s.f.)	5	
WOOD STOVE	7	
FIREPLACE with outside combustion air	2	
9C TOTAL (not to exceed 12 points)		5

9D	HEATING SYSTEM CREDIT POINTS
NATURAL GAS/PROPANE HEATING	16.0
OIL HEATING	12.8

9E	DESIGN PENALTY POINTS
WASHER AND DRYER IN COND SPACE	3
TOTAL GLASS OPENS LESS THAN 40%	5
FIREPLACE W/ INSIDE COMBUSTION AIR	5

9F WINTER OVERHANG FACTOR (WOF)

FEET	N	NE	E	SE	S	SW	W	NW
0-0.9	1.00	0.98	0.99	0.74	0.71	0.82	0.93	1.00
1-1.9	1.00	0.98	0.99	0.75	0.73	0.83	0.93	1.00
2-2.9	1.00	0.98	0.99	0.77	0.76	0.84	0.94	1.00
3-3.9	1.00	0.98	0.99	0.81	0.79	0.87	0.94	1.00
4-4.9	1.00	0.98	0.99	0.84	0.83	0.89	0.94	1.00
5-5.9	1.00	0.99	1.00	0.87	0.87	0.92	0.95	1.00
6-6.9	1.00	0.99	1.00	0.90	0.90	0.93	0.96	1.00
7-7.9	1.00	0.99	1.00	0.93	0.94	0.96	0.97	1.00
8-8.9	1.00	0.99	1.00	0.95	0.96	0.97	0.98	1.00
9-9.9	1.00	1.00	1.00	0.97	0.98	0.98	0.98	1.00
10-10.9	1.00	1.00	1.00	0.99	0.99	0.99	0.99	1.00
11-11.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
12 UP	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

9F SUMMER OVERHANG FACTOR (SOF)

FEET	N	NE	E	SE	S	SW	W	NW
0-0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1-1.9	1.00	1.00	0.99	0.98	0.97	0.98	0.99	1.00
2-2.9	1.00	0.98	0.94	0.92	0.91	0.92	0.94	0.98
3-3.9	1.00	0.95	0.89	0.86	0.85	0.86	0.89	0.95
4-4.9	1.00	0.91	0.84	0.80	0.82	0.80	0.84	0.91
5-5.9	0.99	0.88	0.79	0.76	0.79	0.76	0.79	0.88
6-6.9	0.99	0.85	0.75	0.73	0.78	0.73	0.75	0.85
7-7.9	0.99	0.83	0.72	0.70	0.77	0.70	0.72	0.83
8-8.9	0.99	0.81	0.70	0.68	0.77	0.68	0.70	0.81
9-9.9	0.98	0.79	0.68	0.67	0.76	0.67	0.68	0.79
10-10.9	0.98	0.77	0.66	0.66	0.76	0.66	0.66	0.77
11-11.9	0.97	0.76	0.64	0.64	0.76	0.64	0.64	0.76
12 UP	0.97	0.75	0.63	0.64	0.76	0.64	0.63	0.75

9G HEATING SYSTEM MULTIPLIER (HSM)

HEAT PUMP	COP	2.2-2.3	2.4-2.5	2.6-2.7	2.8-2.9	3.0-3.1	3.2-3.3	3.4 & UP
	HSM	0.45	0.42	0.38	0.36	0.33	0.31	0.29
SOLAR HEATING SYSTEM	(BACKUP SYSTEM FRACTION) x (BACKUP SYSTEM HSM)							
ELECTRIC STRIP HEAT	1.00							
NATURAL GAS / PROPANE	1.0 (SEE TABLE 9D FOR CREDITS)							
OIL	1.0 (SEE TABLE 9D FOR CREDITS)							

9H COOLING SYSTEM MULTIPLIER (CSM)

ELEC.	EER/SEER	6.8-6.9	7.0-7.4	7.5-7.9	8.0-8.4*	8.5-8.9	9.0-9.4	9.5-9.9	10.0-10.4	10.5-10.9	11.0-11.9	12.0-UP
	CSM	1.00	0.93	0.87	0.81	0.76	0.72	0.68	0.65	0.62	0.59	0.54

GAS	COP	0.40-0.44	0.45-0.49	0.50-0.54	0.55-0.59	0.60-0.64	0.65-0.69	0.70 & UP	
	CSM	1.50	1.25	1.20	1.09	1.00	0.92	0.89	

*ALTERNATE PRESCRIPTIVE COMPLIANCE APPROACH MINIMUM AIR CONDITIONER EFFICIENCY LEVEL 8.0 SEER/EER FOR STRAIGHT COOL OR 7.5 FOR HEAT PUMPS.

NOTE: EER = COOLING MODE COP x 3.413 = ARI RATED COOLING OUTPUT IN BTUH ÷ TOTAL WATTS CONSUMED

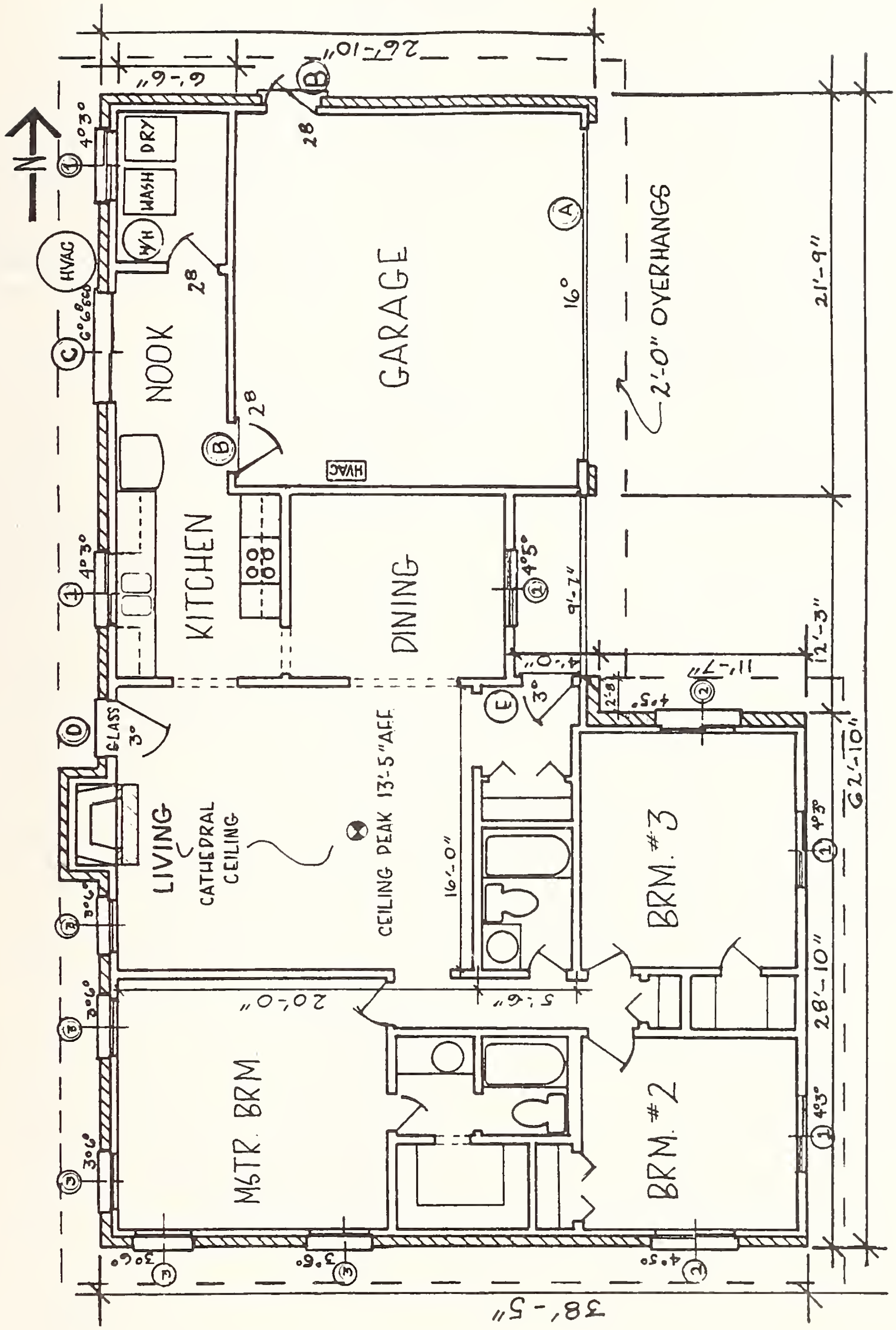
9I HOT WATER CREDIT POINTS (HWCP)

ELECTRIC RESISTANCE WATER HEATER											0
GAS WATER HEATER											10
INSTANTANEOUS WATER HEATER	ELECTRIC BACKUP										4.5
	GAS BACKUP										12.6
HRU (A/C) WATER HEATER	ELECTRIC BACKUP										6.7
	GAS BACKUP										13.9
HRU (HP) WATER HEATER	ELECTRIC BACKUP										9.7
	GAS BACKUP										14.5
HEAT PUMP WATER HEATER (DEDICATED HEAT PUMP)	COP	1.60 - 1.89	1.90 - 2.19	2.20 - 2.49	2.50 - 2.79	2.80 - 3.00					
	CREDIT POINTS	9.0	11.4	13.1	14.4	15.4					
SOLAR HOT WATER	OVERALL SOLAR FRACTION*	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
	CREDIT POINTS: ELECTRIC BACKUP	2.4	4.8	7.2	9.6	12.0	14.4	16.8	19.2	21.6	24.0
	CREDIT POINTS: GAS BACKUP	11.4	12.8	14.2	15.6	17.0	18.8	19.8	21.2	22.6	24.0

*PERCENT OF ANNUAL HOT WATER PROVIDED BY SOLAR SYSTEM ÷ 100 = OVERALL SOLAR FRACTION

APPENDIX B

EXAMPLE HOUSE CALCULATION
Section 9
North Florida



FLOOR PLAN
N.T.S.

```
1-SIDE OF HOUSE (COMPASS DIRECTION)
2-WALLS                                  (DISK)
3-DOOR                                   (DISK)
G-GLASS                                  (DISK)
4-CEILING
5-FLOOR
6-SLAB
7-DESIGN CREDIT POINTS
8-DESIGN PENALTY POINTS
H-HEATING SYSTEM MULTIPLIER
C-COOLING SYSTEM MULTIPLIER
HW-HOT WATER CREDIT POINTS
D-DUCT MULTIPLIER
S-SAVE HOUSE ON DISK                     (DISK)
T-TOTAL EPI                              (DISK)
Z-CHANGE ZONE                            (DISK)
LO-LOAD HOUSE                            (DISK)
P-TOGGLE PRINTER OPERATION
CHANGE-CHANGE FLOOR AREA &
DEDUCTIONS
```

```
ZONE(1-2-3)    HOUSE NAME:82NFL1
SIDE OF HOUSE:NORTH
WALLS
CONCRETE              SF=0        R =0
FRAME/BRICK VENEER  SF=1321.4   R =11
COMMON                SF=0        R =0
--------------------------------------
```

```
ZONE(1-2-3)    HOUSE NAME:82NFL1
SIDE OF HOUSE:NORTH
<CONCRETE>:
       .000                 .000
*     4.900         *      5.600
----------          ----------
       .000                 .000
<FRAME OR BRICK VENEER>:
   1321.400             1321.400
*     7.800         *      9.200
----------          ----------
  10306.920            12156.880
<COMMON>
       .000                 .000
*     7.800         *      2.500
----------          ----------
       .000                 .000
WINTER TOTAL10306.92
SUMMER TOTAL12156.88
EPI =14.6153546
PRESS <SPACE BAR> TO GOTO MENU
--------------------------------------
```

Notes:

MENU-1. Selecting 1,4,5,6,7,8,H,C,HW,D, or P will not require disk operation.

2. Selecting 2,3,G,S,T,Z, or LO will require disk operation one time; i.e., selecting 2 will allow entry into 3,G, S,T, and LO without further disk operation.

```
ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:NORTH
DOORS
WOOD OR METAL     SF=40.6
INSULATED         SF=0
STORM DOOR        SF=0
COMMON            SF=0
----------------------------------------
```

```
ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:NORTH
DOORS
WOOD OR METAL--------------------------
WINTER
40.6*247.7=10056.62
SUMMER
40.6*36.4=1477.84
INSULATED------------------------------
WINTER
0*235.5=0
SUMMER
0*14.5=0
PRESS SPACE TO FINISH
----------------------------------------
```

```
ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:NORTH
DOORS
STORM DOOR-----------------------------
WINTER
0*124.4=0
SUMMER
0*29=0
COMMON---------------------------------
WINTER
0*61.9=0
SUMMER
0*4.5=0
TOTAL WINTER POINTS:10056.62
TOTAL SUMMER POINTS:1477.84
EPI =7.5045283
PRESS <SPACE BAR> TO GOTO MENU
----------------------------------------
```

APPENDIX C
Data Entry and Calculation

```
ZONE(1-2-3)    HOUSE NAME:NFL1
CEILING
UNDER ATTIC          SF=1387.6 R=19
SINGLE ASSEMBLY      SF=338.3  R=19
COMMON               SF=0
CEILING AREA IS DIFFERENT THAN FLOOR ARE
A.(1537)
DO YOU WANT THIS CHANGED?N
-------------------------------------
```

```
ZONE(1-2-3)    HOUSE NAME:NFL1
CEILING
-------------------------------------
<UNDER ATTIC>
WINTER
1387.6*5=6938,
SUMMER
1387.6*5.5=7631.8
<SINGLE ASSEMBLY>
WINTER
338.3*5=1691.5
SUMMER
338.3*5.5=1860.65
TOTAL WINTER POINTS:8629.5
TOTAL SUMMER POINTS:9492.45
EPI =11.7904684
PRESS <SPACE BAR> TO GOTO MENU
-------------------------------------
```

```
ZONE(1-2-3)    HOUSE NAME:NFL1
DESIGN PENALTY POINTS
  ANSWER THE QUESTIONS BELOW WITH (Y/N)
ARE THE WASHER AND DRYER IN COND. SPACE?
TOTAL AMOUNT OF GLASS OPENS LESS THAN
40%?
IS THE FIREPLACE W/ INSIDE COMBUSTION
AIR?
TOTAL EPI PENALTY POINTS:+0
PRESS <SPACE BAR> TO GOTO MENU
-------------------------------------
```

```
ZONE(1-2-3)    HOUSE NAME:NFL1
DESIGN PENALTY POINTS
  ANSWER THE QUESTIONS BELOW WITH (Y/N)
ARE THE WASHER AND DRYER IN COND. SPACE?
Y
TOTAL AMOUNT OF GLASS OPENS LESS THAN
40%?N
IS THE FIREPLACE W/ INSIDE COMBUSTION
AIR?Y
TOTAL EPI PENALTY POINTS:+8
PRESS <SPACE BAR> TO GOTO MENU
-------------------------------------
```

```
ZONE(1-2-3)    HOUSE NAME:NFL1
FLOOR
WOOD                 SF=1537.2 R=11
CONCRETE             SF=0      R=0
COMMON               SF=0
FLOOR AREAS DO NOT MATCH (100)
DO YOU WANT TO RE-DO?N
-------------------------------------
```

```
ZONE(1-2-3)    HOUSE NAME:NFL1
FLOOR
WOOD-----------------------------------
WINTER
1537.2*5.6=8608.32
SUMMER
1537.2*1.8=2766.96
CONCRETE-------------------------------
WINTER
0*19.4=0
SUMMER
0*6=0
COMMON---------------------------------
WINTER
0*4.8=0
SUMMER
0*1.5=0
TOTAL WINTER POINTS:8608.32
TOTAL SUMMER POINTS:2766.96
EPI =7.40096292
PRESS <SPACE BAR> TO GOTO MENU
-------------------------------------
```

```
ZONE(1-2-3)    HOUSE NAME:NFL1
DESIGN CREDIT POINTS
ENTER THE NUMER OF EACH:
CEILING FAN IN COND SPACE(MAX 5)      1
MULTIZONE A/C SEPARATED BY DOOR       0
CROSS VENTILATION (1 PER ROOM)        4
WHOLE HOUSE FAN(MIN.1.5 CFM/S.F.)     0
WOOD STOVE                            0
FIREPLACE W. OUTSIDE COMBUSTION AIR   0
EPI CREDIT POINTS:-5
PRESS <SPACE BAR> TO GOTO MENU
-------------------------------------
```

```
ZONE(1-2-3)    HOUSE NAME:NFL1
HEATING SYSTEM CREDIT POINTS
ENTER HOT WATER CREDIT POINTS PER TABLE
BELOW     0
ELECTRIC RESISTANCE WATER HEATER--- 0.0
GAS WATER HEATER-------------------10.0
<HEAT PUMP WATER HEATER>
1.60-1.89=9
1.90-2.19=11.4
2.20-2.49=13.1
2.50-2.79=14.4
2.80-3.00=15.4
SOLAR HOT WATER CREDIT POINTS:
<HRU(A/C) WATER HEATER>
                 ZONE 1,2,3 4,5,6 7,8,9
ELECTRIC BACKUP            6.7   8.5    8.9
GAS BACKUP                 13.9 15      15.2
<HRU(HP) WATER HEATER>
ELECTRIC BACKUP            9.7   10.6   9.7
GAS BACKUP                 14.5 15.4   15.4
<INSTANTANEOUS WATER HEATER>
ELECTRIC BACKUP            4.5    4.5   4.5
 AS BACKUP                 12.6   12.6 12.6
-------------------------------------
```

```
ZONE(1-2-3)    HOUSE NAME:NFL1
HEATING SYSTEM MULTIPLIER
1-HEAT PUMP
2-ELECTRIC STRIP HEAT
3-NATURAL GAS/PROPANE
4-OIL
WHAT KIND OF HEATING SYSTEM DO YOU HAVE
(1-4)?
REENTER?3
-------------------------------------
```

```
ZONE(1-2-3)    HOUSE NAME:NFL1
HEATING SYSTEM MULTIPLIER
(1-4)?
REENTER?3
-------------------------------------
HEATING SYSTEM CREDIT POINTS ARE:16
HEATING SYSTEM MULTIPLIER IS:1
PRESS <SPACE BAR> TO GOTO MENU
-------------------------------------
```

```
ZONE(1-2-3)    HOUSE NAME:NFL1
COOLING SYSTEM MULTIPLIER
1-ELECTRIC
2-GAS
WHICH COOLING SYSTEM DO YOU HAVE(1-2)?1
-------------------------------------
```

```
ZONE(1-2-3)    HOUSE NAME:NFL1
COOLING SYSTEM MULTIPLIER
ELECTRIC
EER/SEER=8
COOLING SYSTEM MULTIPLIER:.81
PRESS <SPACE BAR> TO GOTO MENU
-------------------------------------
```

```
ZONE(1-2-3)    HOUSE NAME:NFL1
DUCT MULTIPLIER
1 IN. FIBERGLASS  MULT:1.15
1.5 IN. FIBERGLASS  MULT:1.12
2.0 IN. FIBERGLASS  MULT:1.09
WHAT IS THE MULTIPLIER?1.15
PRESS <SPACE BAR> TO GOTO MENU
-------------------------------------
```

```
ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:NORTH
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
SINGLE GLASS AREA=20
SC=1
THE OVERHANG(IN FEET)=2
SINGLE GLASS AREA=0
DOUBLE GLASS AREA=0
-------------------------------------
```

```
ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:NORTH
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
TINT POINTS:146
20*146*1=SUMMER:2920
20*157.4*1=WINTER:3148
GSP=2920
GWP=3148
DOUBLE GLASS TINT POINTS:6
GSP=0
GWP=0
TOTAL SUMMER POINTS:2920
TOTAL WINTER POINTS:3148
EPI=3.94795055
PRESS <SPACE BAR> TO GOTO MENU
-------------------------------------
```

APPENDIX C
Data Entry and Calculation

```
ZONE(1-2-3)   HOUSE NAME:NFL1
SIDE OF HOUSE:EAST
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
SINGLE GLASS AREA=24
SC=1
THE OVERHANG(IN FEET)=0
SINGLE GLASS AREA=20
SC=1
THE OVERHANG(IN FEET)=6
SINGLE GLASS AREA=0
DOUBLE GLASS AREA=0
----------------------------------------

ZONE(1-2-3)   HOUSE NAME:NFL1
SIDE OF HOUSE:EAST
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
TINT POINTS:289
24*289*1=SUMMER:6936
24*157.4*.99=WINTER:3739.824
TINT POINTS:289
20*289*.75=SUMMER:4335
20*157.4*1=WINTER:3148
GSP=11271
GWP=6887.824
DOUBLE GLASS TINT POINTS:6
GSP=0
GWP=0
TOTAL SUMMER POINTS:11271
TOTAL WINTER POINTS:6887.824
EPI=11.8144593
PRESS <SPACE BAR> TO GOTO MENU
----------------------------------------
----------------------------------------

ZONE(1-2-3)   HOUSE NAME:NFL1
SIDE OF HOUSE:WEST
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
SINGLE GLASS AREA=138
SC=1
THE OVERHANG(IN FEET)=2
SINGLE GLASS AREA=0
DOUBLE GLASS AREA=0
----------------------------------------
```

```
ZONE(1-2-3)   HOUSE NAME:NFL1
SIDE OF HOUSE:SOUTH
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
SINGLE GLASS AREA=36
SC=1
THE OVERHANG(IN FEET)=0
SINGLE GLASS AREA=20
SC=1
THE OVERHANG(IN FEET)=2
SINGLE GLASS AREA=0
DOUBLE GLASS AREA=0
----------------------------------------

ZONE(1-2-3)   HOUSE NAME:NFL1
SIDE OF HOUSE:SOUTH
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
TINT POINTS:190
36*190*1=SUMMER:6840
36*157.4*.71=WINTER:4023.144
TINT POINTS:190
20*190*.91=SUMMER:3458
20*157.4*.76=WINTER:2392.48
GSP=10298
GWP=6415.624
DOUBLE GLASS TINT POINTS:6
GSP=0
GWP=0
TOTAL SUMMER POINTS:10298
TOTAL WINTER POINTS:6415.624
EPI=10.8741861
PRESS <SPACE BAR> TO GOTO MENU

ZONE(1-2-3)   HOUSE NAME:NFL1
SIDE OF HOUSE:WEST
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
TINT POINTS:289
138*289*.94=SUMMER:37489.08
138*157.4*.94=WINTER:20417.928
GSP=37489.08
GWP=20417.928
DOUBLE GLASS TINT POINTS:6
GSP=0
GWP=0
TOTAL SUMMER POINTS:37489.08
TOTAL WINTER POINTS:20417.928
EPI=37.6753468
PRESS <SPACE BAR> TO GOTO MENU
----------------------------------------

ZONE(1-2-3)   HOUSE NAME:NFL1
TOTAL OF GLASS:
WINTER TOTAL:36869.376
SUMMER TOTAL:61978.08
EPI=64.3119428
PRESS SPACE TO GOTO MENU
----------------------------------------
```

EPI Calculation for Each Zone

```
ZONE(1-2-3)    HOUSE NAME:NFL1
GWP*DUCT CSM: 74470.7*       1.15= 85641.3
GSP*DUCT HSM: 87872.2*       1.15=101053.0
HSM*GWP      :      1.00* 85641.3= 85641.3
CSM*GSP      :       .81*101053.0= 81853.0
------------------------------------------
<WINTER/FLOOR AREA WITH MULT>
 85641.346/  1537.000=     55.720
<SUMMER/FLOOR AREA WITH MULT>
 81852.964/  1537.000=     53.255
PRESS SPACE TO CONTINUE
------------------------------------------

ZONE(1-2-3)    HOUSE NAME:NFL1
WINTER POINTS+                      55.720
SUMMER POINTS+                      53.255
HEATING SYSTEM CREDIT PTS:   -      16.000
HOT WTR POINTS-                       .000
CREDIT POINTS-                       5.000
PENALTY POINTS+                      8.000
TOTAL:                              95.975
PRESS <SPACE BAR> TO GOTO MENU
------------------------------------------

ZONE(7-8-9)    HOUSE NAME:NFL1
GWP*DUCT CSM: 26833.7*       1.15= 30858.7
GSP*DUCT HSM:133929.7*       1.15=154019.2
HSM*GWP      :      1.00* 30858.7= 30858.7
CSM*GSP      :       .81*154019.2=124755.5
------------------------------------------
<WINTER/FLOOR AREA WITH MULT>
 30858.734/  1537.000=     20.077
<SUMMER/FLOOR AREA WITH MULT>
124755.534/  1537.000=     81.168
PRESS SPACE TO CONTINUE
------------------------------------------

ZONE(7-8-9)    HOUSE NAME:NFL1
WINTER POINTS+                      20.077
SUMMER POINTS+                      81.168
HEATING SYSTEM CREDIT PTS:   -       8.000
HOT WTR POINTS-                       .000
CREDIT POINTS-                       5.000
PENALTY POINTS+                      8.000
TOTAL:                              96.245
PRESS <SPACE BAR> TO GOTO MENU
------------------------------------------
```

```
ZONE(4-5-6)    HOUSE NAME:NFL1
GWP*DUCT CSM: 47791.8*       1.15= 54960.5
GSP*DUCT HSM:110681.6*       1.15=127283.9
HSM*GWP      :      1.00* 54960.5= 54960.5
CSM*GSP      :       .81*127283.9=103099.9
------------------------------------------
<WINTER/FLOOR AREA WITH MULT>
 54960.545/  1537.000=     35.758
<SUMMER/FLOOR AREA WITH MULT>
103099.929/  1537.000=     67.079
PRESS SPACE TO CONTINUE
------------------------------------------

ZONE(4-5-6)    HOUSE NAME:NFL1
WINTER POINTS+                      35.758
SUMMER POINTS+                      67.079
HEATING SYSTEM CREDIT PTS:   -      12.000
HOT WTR POINTS-                       .000
CREDIT POINTS-                       5.000
PENALTY POINTS+                      8.000
TOTAL:                              93.837
PRESS <SPACE BAR> TO GOTO MENU
------------------------------------------
```

APPENDIX D
Analyzing Insulation Option

```
ZONE(1-2-3)    HOUSE NAME:82NFL1I
SIDE OF HOUSE:NORTH
WALLS
CONCRETE               SF=0       R =0
FRAME/BRICK VENEER SF=1321.4 R =19
COMMON                 SF=0       R =0
---------------------------------------

ZONE(1-2-3)    HOUSE NAME:82NFL1I
SIDE OF HOUSE:NORTH
<CONCRETE>:
       .000                  .000
*      4.900           *     5.600
----------             ----------
       .000                  .000
<FRAME OR BRICK VENEER>:
   1321.400              1321.400
*      4.900           *     5.600
----------             ----------
   6474.860              7399.840
<COMMON>
       .000                  .000
*      7.800           *     2.500
----------             ----------
       .000                  .000
WINTER TOTAL6474.86
SUMMER TOTAL7399.84
EPI =9.02713078
PRESS <SPACE BAR> TO GOTO MENU
-----------

---------     ----------

ZONE(1-2-3)    HOUSE NAME:82NFL1
SIDE OF HOUSE:NORTH
DOORS
WOOD OR METAL     SF=0
INSULATED         SF=40.6
STORM DOOR        SF=0
COMMON            SF=0
---------------------------------------

ZONE(1-2-3)    HOUSE NAME:82NFL1
SIDE OF HOUSE:NORTH
DOORS
WOOD OR METAL--------------------------
WINTER
0*247.7=0
SUMMER
0*36.4=0
INSULATED------------------------------
WINTER
40.6*235.5=9561.3
SUMMER
40.6*14.5=588.7
TOTAL WINTER POINTS:9561.3
TOTAL SUMMER POINTS:588.7
EPI =6.60377358
PRESS <SPACE BAR> TO GOTO MENU
                      -------------------
```

```
ZONE(1-2-3)    HOUSE NAME:82NFL1
CEILING
UNDER ATTIC          SF=1387.6 R=38
SINGLE ASSEMBLY      SF=338.3  R=38
COMMON               SF=0
CEILING AREA IS DIFFERENT THAN FLOOR ARE
A.(1537)
DO YOU WANT THIS CHANGED?N
--------------------------------------

ZONE(1-2-3)    HOUSE NAME:82NFL1
CEILING
--------------------------------------
<UNDER ATTIC>
WINTER
1387.6*3.3=4579.08
SUMMER
1387.6*3.7=5134.12
<SINGLE ASSEMBLY>
WINTER
338.3*5=1691.5
SUMMER
338.3*5.5=1860.65
TOTAL WINTER POINTS:6270.58
TOTAL SUMMER POINTS:6994.77
EPI =8.63067665
PRESS <SPACE BAR> TO GOTO MENU
         ----------------------------
--------

ZONE(1-2-3)    HOUSE NAME:82NFL1
FLOOR
WOOD                 SF=1537.2 R=19
CONCRETE             SF=0      R=0
COMMON               SF=0
FLOOR AREAS DO NOT MATCH (1537)
DO YOU WANT TO RE-DO?N
--------------------------------------

ZONE(1-2-3)    HOUSE NAME:82NFL1
FLOOR
WOOD----------------------------------
WINTER
1537.2*4=6148.8
SUMMER
1537.2*1.3=1998.36
CONCRETE------------------------------
WINTER
0*19.4=0
SUMMER
0*6=0
COMMON--------------------------------
WINTER
0*4.8=0
SUMMER
0*1.5=0
TOTAL WINTER POINTS:6148.8
TOTAL SUMMER POINTS:1998.36
EPI =5.30068966
PRESS <SPACE BAR> TO GOTO MENU
```

APPENDIX D
Analyzing Double Glass Option

```
ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:NORTH
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
SINGLE GLASS AREA=0
DOUBLE GLASS AREA=20
SC=1
THE OVERHANG(IN FEET)=2
DOUBLE GLASS AREA=0
-----------------------------------------

ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:NORTH
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
TINT POINTS:146
GSP=0
GWP=0
DOUBLE GLASS TINT POINTS:120
20*120.8*1=SUMMER:2400
20*120.8*1=WINTER:2416
GSP=2400
GWP=2416
TOTAL SUMMER POINTS:2400
TOTAL WINTER POINTS:2416
EPI=3.13337671

ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:SOUTH
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
SINGLE GLASS AREA=0
DOUBLE GLASS AREA=36
SC=1
THE OVERHANG(IN FEET)=0
DOUBLE GLASS AREA=20
SC=1
THE OVERHANG(IN FEET)=2
DOUBLE GLASS AREA=0
-----------------------------------------

ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:SOUTH
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
TINT POINTS:190
GSP=0
GWP=0
DOUBLE GLASS TINT POINTS:160
36*120.8*1=SUMMER:5760
36*120.8*.71=WINTER:3087.648
DOUBLE GLASS TINT POINTS:160
20*120.8*.91=SUMMER:2912
20*120.8*.76=WINTER:1836.16
GSP=8672
GWP=4923.808
TOTAL SUMMER POINTS:8672
TOTAL WINTER POINTS:4923.808
EPI=8.8456786
PRESS <SPACE BAR> TO GOTO MENU

ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:EAST
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
SINGLE GLASS AREA=0
DOUBLE GLASS AREA=24
SC=1
THE OVERHANG(IN FEET)=0
DOUBLE GLASS AREA=20
SC=1
THE OVERHANG(IN FEET)=6
DOUBLE GLASS AREA=0
-----------------------------------------

ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:EAST
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
TINT POINTS:289
GSP=0
GWP=0
DOUBLE GLASS TINT POINTS:251
24*120.8*1=SUMMER:6024
24*120.8*.99=WINTER:2870.208
DOUBLE GLASS TINT POINTS:251
20*120.8*.75=SUMMER:3765
20*120.8*1=WINTER:2416
GSP=9789
GWP=5286.208
TOTAL SUMMER POINTS:9789
TOTAL WINTER POINTS:5286.208
EPI=9.808203
PRESS <SPACE BAR> TO GOTO MENU
-----------------------------------------

ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:WEST
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
SINGLE GLASS AREA=0
DOUBLE GLASS AREA=138
SC=1
THE OVERHANG(IN FEET)=2
DOUBLE GLASS AREA=0
-----------------------------------------

ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:WEST
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
TINT POINTS:289
GSP=0
GWP=0
DOUBLE GLASS TINT POINTS:251
138*120.8*.94=SUMMER:32559.72
138*120.8*.94=WINTER:15670.176
GSP=32559.72
GWP=15670.176
TOTAL SUMMER POINTS:32559.72
TOTAL WINTER POINTS:15670.176
EPI=31.3792427
PRESS <SPACE BAR> TO GOTO MENU
```

```
---------------------------------------

ZONE(1-2-3)    HOUSE NAME:82NFL1
GWP*DUCT CSM:  65324.9*       1.15= 75123.7
GSP*DUCT HSM:  78959.8*       1.15= 90803.7
HSM*GWP       :       1.00* 75123.7= 75123.7
CSM*GSP       :        .81* 90803.7= 73551.0
-----------------------------------------
<WINTER/FLOOR AREA WITH MULT>
 75123.653/  1537.000=     48.877
<SUMMER/FLOOR AREA WITH MULT>
 73551.007/  1537.000=     47.854
PRESS SPACE TO CONTINUE
-----------------------------------------

ZONE(1-2-3)    HOUSE NAME:82NFL1
WINTER POINTS+                       48.877
SUMMER POINTS+ ,                     47.854
HEATING SYSTEM CREDIT PTS:   -       16.000
HOT WTR POINTS-                        .000
CREDIT POINTS-                        5.000
PENALTY POINTS+                       8.000
TOTAL:                               83.730
PRESS <SPACE BAR> TO GOTO MENU
-----------------------------------------
```

```
ZONE(7-8-9)    HOUSE NAME:82NFL1I
GWP*DUCT CSM:  23779.7*       1.15= 27346.7
GSP*DUCT HSM:120324.6*        1.15=138373.3
HSM*GWP       :       1.00* 27346.7= 27346.7
CSM*GSP       :        .81*138373.3=112082.3
-----------------------------------------
<WINTER/FLOOR AREA WITH MULT>
 27346.657/  1537.000=     17.792
<SUMMER/FLOOR AREA WITH MULT>
112082.346/  1537.000=     72.923
PRESS SPACE TO CONTINUE
-----------------------------------------

ZONE(7-8-9)    HOUSE NAME:82NFL1I
WINTER POINTS+                       17.792
SUMMER POINTS+                       72.923
HEATING SYSTEM CREDIT PTS:   -        8.000
HOT WTR POINTS-                        .000
CREDIT POINTS-                        5.000
PENALTY POINTS+                       8.000
TOTAL:                               85.715
PRESS <SPACE BAR> TO GOTO MENU
-----------------------------------------
```

Totals   Walls R-19, Ceiling R-38, Floor R-19, Insulated Doors

```
ZONE(1-2-3)    HOUSE NAME:82NFL1I
GWP*DUCT CSM:  56751.7*       1.15= 65264.5
GSP*DUCT HSM:  70402.4*       1.15= 80962.7
HSM*GWP       :       1.00* 65264.5= 65264.5
CSM*GSP       :        .81* 80962.7= 65579.8
-----------------------------------------
<WINTER/FLOOR AREA WITH MULT>
 65264.492/  1537.000=     42.462
<SUMMER/FLOOR AREA WITH MULT>
 65579.826/  1537.000=     42.667
PRESS SPACE TO CONTINUE
-----------------------------------------

ZONE(1-2-3)    HOUSE NAME:82NFL1I
WINTER POINTS+                       42.462
SUMMER POINTS+                       42.667
HEATING SYSTEM CREDIT PTS:   -       16.000
HOT WTR POINTS-                        .000
CREDIT POINTS-                        5.000
PENALTY POINTS+                       8.000
TOTAL:                               72.130
PRESS <SPACE BAR> TO GOTO MENU
-----------------------------------------
```

```
ZONE(7-8-9)    HOUSE NAME:82NFL1I
GWP*DUCT CSM:  19658.1*     , 1.15= 22606.8
GSP*DUCT HSM:105566.1*        1.15=121401.0
HSM*GWP       :       1.00* 22606.8= 22606.8
CSM*GSP       :        .81*121401.0= 98334.8
-----------------------------------------
<WINTER/FLOOR AREA WITH MULT>
 22606.850/  1537.000=     14.708
<SUMMER/FLOOR AREA WITH MULT>
 98334.804/  1537.000=     63.978
PRESS SPACE TO CONTINUE
-----------------------------------------

ZONE(7-8-9)    HOUSE NAME:82NFL1I
WINTER POINTS+                       14.708
SUMMER POINTS+                       63.978
HEATING SYSTEM CREDIT PTS:   -        8.000
HOT WTR POINTS-                        .000
CREDIT POINTS-                        5.000
PENALTY POINTS+                       8.000
TOTAL:                               73.687
PRESS <SPACE BAR> TO GOTO MENU
-----------------------------------------
```

Totals   Double glass, Walls R-19, Ceiling R-38, Floor R-19, Insulated Doors

APPENDIX D
Analyzing The Reduction of Glass Areas by ½

```
ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:WEST
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
SINGLE GLASS AREA=69
SC=1
THE OVERHANG(IN FEET)=2
SINGLE GLASS AREA=0
DOUBLE GLASS AREA=0
---------------------------------------

ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:WEST
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
TINT POINTS:289
69*289*.94=SUMMER:18744.54
69*157.4*.94=WINTER:10208.964
GSP=18744.54
GWP=10208.964
DOUBLE GLASS TINT POINTS:6
GSP=0
GWP=0
TOTAL SUMMER POINTS:18744.54
TOTAL WINTER POINTS:10208.964
EPI=18.8376734
---------------------------------------

ZONE(1-2-3)    HOUSE NAME:NFL1
TOTAL OF GLASS:
WINTER TOTAL:26660.412
SUMMER TOTAL:43233.54
EPI=45.4742694
PRESS SPACE TO GOTO MENU
---------------------------------------

ZONE(1-2-3)    HOUSE NAME:NFL1
GWP*DUCT CSM: 64261.8*       1.15= 73901.0
GSP*DUCT HSM: 69127.7*       1.15= 79496.8
HSM*GWP      :      1.00* 73901.0= 73901.0
CSM*GSP      :       .81* 79496.8= 64392.4
---------------------------------------
<WINTER/FLOOR AREA WITH MULT>
 73901.038/  1537.000=    48.081
<SUMMER/FLOOR AREA WITH MULT>
 64392.425/  1537.000=    41.895
PRESS SPACE TO CONTINUE
---------------------------------------

ZONE(1-2-3)    HOUSE NAME:NFL1
WINTER POINTS+                      48.081
SUMMER POINTS+                      41.895
HEATING SYSTEM CREDIT PTS:   -      16.000
HOT WTR POINTS-                       .000
CREDIT POINTS-                       5.000
PENALTY POINTS+                      8.000
TOTAL:                              76.976
```

½ Glass West Side Only   Total

```
ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:NORTH
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
SINGLE GLASS AREA=10
SC=1
THE OVERHANG(IN FEET)=2
SINGLE GLASS AREA=0
DOUBLE GLASS AREA=0
---------------------------------------

ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:NORTH
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
TINT POINTS:146
10*146*1=SUMMER:1460
10*157.4*1=WINTER:1574
GSP=1460
GWP=1574
DOUBLE GLASS TINT POINTS:6
GSP=0
GWP=0
TOTAL SUMMER POINTS:1460
TOTAL WINTER POINTS:1574
EPI=1.97397528

ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:EAST
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
SINGLE GLASS AREA=12
SC=1
THE OVERHANG(IN FEET)=0
SINGLE GLASS AREA=10
SC=1
THE OVERHANG(IN FEET)=6
SINGLE GLASS AREA=0
DOUBLE GLASS AREA=0
---------------------------------------

ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:EAST
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
TINT POINTS:289
12*289*1=SUMMER:3468
12*157.4*.99=WINTER:1869.912
TINT POINTS:289
10*289*.75=SUMMER:2167.5
10*157.4*1=WINTER:1574
GSP=5635.5
GWP=3443.912
DOUBLE GLASS TINT POINTS:6
GSP=0
GWP=0
TOTAL SUMMER POINTS:5635.5
TOTAL WINTER POINTS:3443.912
EPI=5.90722967
```

APPENDIX D

Analyzing Reduction of Glass Areas by ½

```
ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:SOUTH
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
SINGLE GLASS AREA=18
SC=1
THE OVERHANG(IN FEET)=0
SINGLE GLASS AREA=10
SC=1
THE OVERHANG(IN FEET)=2
SINGLE GLASS AREA=0
DOUBLE GLASS AREA=0
SC=SHADING COFFICIENT(1=CLEAR)
TINT POINTS:190
18*190*1=SUMMER:3420
18*157.4*.71=WINTER:2011.572
TINT POINTS:190
10*190*.91=SUMMER:1729
10*157.4*.76=WINTER:1196.24
GSP=5149
GWP=3207.812
DOUBLE GLASS TINT POINTS:6
GSP=0
GWP=0
TOTAL SUMMER POINTS:5149
TOTAL WINTER POINTS:3207.812
EPI=5.43709304
```

```
ZONE(1-2-3)    HOUSE NAME:NFL1
TOTAL OF GLASS:
WINTER TOTAL:18434.688
SUMMER TOTAL:30989.04
EPI=32.1559714
PRESS SPACE TO GOTO MENU
----------------------------------------

ZONE(1-2-3)    HOUSE NAME:NFL1
GWP*DUCT CSM: 56036.0*      1.15= 64441.5
GSP*DUCT HSM: 56883.2*      1.15= 65415.6
HSM*GWP      :       1.00* 64441.5= 64441.5
CSM*GSP      :        .81* 65415.6= 52986.7
----------------------------------------
<WINTER/FLOOR AREA WITH MULT>
 64441.455/  1537.000=    41.927
<SUMMER/FLOOR AREA WITH MULT>
 52986.673/  1537.000=    34.474
PRESS SPACE TO CONTINUE
----------------------------------------

ZONE(1-2-3)    HOUSE NAME:NFL1
WINTER POINTS+                        41.927
SUMMER POINTS+                        34.474
HEATING SYSTEM CREDIT PTS:   -        16.000
HOT WTR POINTS-                         .000
CREDIT POINTS-                         5.000
PENALTY POINTS+                        8.000
TOTAL:                                63.401
```

Totals: ½ Glass Area All Exposures

Analyzing Shading Coefficient (SC) = 0.24 for Glass

```
ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:SOUTH
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
SINGLE GLASS AREA=36
SC=.24
THE OVERHANG(IN FEET)=0
SINGLE GLASS AREA=20
SC=.24
THE OVERHANG(IN FEET)=2
SINGLE GLASS AREA=0
DOUBLE GLASS AREA=0
SC=SHADING COFFICIENT(1=CLEAR)
TINT POINTS:55.48
36*55.48*1=SUMMER:1997.28
36*157.4*.71=WINTER:4023.144
TINT POINTS:55.48
20*55.48*.91=SUMMER:1009.736
20*157.4*.76=WINTER:2392.48
GSP=3007.016
GWP=6415.624
DOUBLE GLASS TINT POINTS:6
GSP=0
GWP=0
TOTAL SUMMER POINTS:3007.016
TOTAL WINTER POINTS:6415.624
EPI=6.13054002
PRESS <SPACE BAR> TO GOTO MENU
----------------------------------------
```

```
ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:EAST
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
SINGLE GLASS AREA=24
SC=.24
THE OVERHANG(IN FEET)=0
SINGLE GLASS AREA=20
SC=.24
THE OVERHANG(IN FEET)=6
SINGLE GLASS AREA=0
DOUBLE GLASS AREA=0
SC=SHADING COFFICIENT(1=CLEAR)
TINT POINTS:79.24
24*79.24*1=SUMMER:1901.76
24*157.4*.99=WINTER:3739.824
TINT POINTS:79.24
20*79.24*.75=SUMMER:1188.6
20*157.4*1=WINTER:3148
GSP=3090.36
GWP=6887.824
DOUBLE GLASS TINT POINTS:6
GSP=0
GWP=0
TOTAL SUMMER POINTS:3090.36
TOTAL WINTER POINTS:6887.824
EPI=6.49198699
```

APPENDIX D

Analyzing Shading Coefficient = 0.24 for Glass (cont.)

```
ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:NORTH
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
SINGLE GLASS AREA=20
SC=.24
THE OVERHANG(IN FEET)=2
SINGLE GLASS AREA=0
DOUBLE GLASS AREA=0
SC=SHADING COFFICIENT(1=CLEAR)
TINT POINTS:44.92
20*44.92*1=SUMMER:898.4
20*157.4*1=WINTER:3148
GSP=898.4
GWP=3148
DOUBLE GLASS TINT POINTS:6
GSP=0
GWP=0
TOTAL SUMMER POINTS:898.4
TOTAL WINTER POINTS:3148
EPI=2.63266103

ZONE(1-2-3)    HOUSE NAME:NFL1
TOTAL OF GLASS:
WINTER TOTAL:36869.376
SUMMER TOTAL:17274.7888
EPI=35.227173

ZONE(1-2-3)    HOUSE NAME:NFL1
GWP*DUCT CSM:  74470.7*      1.15=  85641.3
GSP*DUCT HSM:  43168.9*      1.15=  49644.3
HSM*GWP     :       1.00*  85641.3=  85641.3
CSM*GSP     :        .81*  49644.3=  40211.8
----------------------------------------
<WINTER/FLOOR AREA WITH MULT>
 85641.346/  1537.000=     55.720
<SUMMER/FLOOR AREA WITH MULT>
 40211.848/  1537.000=     26.163
PRESS SPACE TO CONTINUE
----------------------------------------

ZONE(1-2-3)    HOUSE NAME:NFL1
WINTER POINTS+                          55.720
SUMMER POINTS+                          26.163
HEATING SYSTEM CREDIT PTS:   -          16.000
HOT WTR POINTS-                           .000
CREDIT POINTS-                           5.000
PENALTY POINTS+                          8.000
TOTAL:                                  68.882
```

```
ZONE(1-2-3)    HOUSE NAME:NFL1
SIDE OF HOUSE:WEST
GLASS
SC=SHADING COFFICIENT(1=CLEAR)
SINGLE GLASS AREA=138
SC=.24
THE OVERHANG(IN FEET)=2
SINGLE GLASS AREA=0
DOUBLE GLASS AREA=0
SC=SHADING COFFICIENT(1=CLEAR)
TINT POINTS:79.24
138*79.24*.94=SUMMER:10279.0128
138*157.4*.94=WINTER:20417.928
GSP=10279.0128
GWP=20417.928
DOUBLE GLASS TINT POINTS:6
GSP=0
GWP=0
TOTAL SUMMER POINTS:10279.0128
TOTAL WINTER POINTS:20417.928
EPI=19.9719849

ZONE(7-8-9)    HOUSE NAME:NFL1A
TOTAL OF GLASS:
WINTER TOTAL:13510.952
SUMMER TOTAL:30492.028
EPI=28.6291347

ZONE(7-8-9)    HOUSE NAME:NFL1A
GWP*DUCT CSM:  26833.7*      1.15=  30858.7
GSP*DUCT HSM:  69141.8*      1.15=  79513.1
HSM*GWP     :       1.00*  30858.7=  30858.7
CSM*GSP     :        .81*  79513.1=  64405.6
----------------------------------------
<WINTER/FLOOR AREA WITH MULT>
 30858.734/  1537.000=     20.077
<SUMMER/FLOOR AREA WITH MULT>
 64405.631/  1537.000=     41.903
PRESS SPACE TO CONTINUE
----------------------------------------

ZONE(7-8-9)    HOUSE NAME:NFL1A
WINTER POINTS+                          20.077
SUMMER POINTS+                          41.903
HEATING SYSTEM CREDIT PTS:   -           8.000
HOT WTR POINTS-                           .000
CREDIT POINTS-                           5.000
PENALTY POINTS+                          8.000
TOTAL:                                  56.981
```

Totals for Shading Coefficients = 0.24 for Glass All Exposures

Energy Performance Index [EPI] Summary Form

Under the provisions of Section 9 of the Floride Model Energy Efficiency Code for Building Construction, an Energy Performance Index (EPI) is used as an indicator of the energy efficiency of a house. In order to comply with Section 9 of the Code, all houses constructed after October 1, 1980 must attain an EPI of 100 points or less.

This summary form provides a brief description of the factors that affect the energy performance of a house. The box scores can be used to evaluate the potential energy efficiency of a house against one that marginally complies with an EPI of 100 points. The lower the net EPI, the more energy efficient the house should be.

CONDITIONED AREA = ________ Square Feet
NET ENERGY PERFORMANCE INDEX (EPI) ________ Points

GLASS

Marginal Score	Your Score
52	

Window design can have a major impact on the overall EPI of a house. Factors that can improve the energy performance of windows are: 1) reduced glass area; 2) minimum glass on east and west exposures; 3) sufficient overhangs; 4) operable windows; 5) designs that allow cross ventilation; 6) permanently tinted glass or solar screen; and 7) double-pane windows.

WALLS

Marginal Score	Your Score
18	

For houses of comparable size, one with a compact floor plan will have less total wall area. Insulation should be added to all walls and partitions separating conditioned and unconditioned areas. R6 is recommended for masonry walls; R11 for frame walls.

CEILING

Marginal Score	Your Score
13	

Due to high summer temperatures, insulation equivalent to R19 should be installed above ceilings. Remember that a two-story house reduces ceiling and floor areas and, therefore, can be more energy efficient than a single-story house of comparable size.

FLOORS

Marginal Score	Your Score
10	

Off grade. Insulation equivalent to R11 should be used under the floors of off-grade houses.
Slab. Perimeter insulation equivalent to R6 is recommended for slab houses in northern and central Florida.

DOORS

Marginal Score	Your Score
7	

Doors can waste large amounts of energy. A moderately sized home should have no more than three exterior doors. Tight-fitting insulated doors are recommended for all Florida climate zones. Storm doors should be considered in northern Florida.

THERMAL ENVELOPE SUBTOTAL	
Marginal Score	Your Score
100	

This subtotal represents the energy efficiency of the structural characteristics of a house.

Marginal Score	Your Score
1.12	

located in attics or crawl spaces should be insulated with the equivalent of 1½ to 2 inches of fiberglass insulation to reduce energy losses.

A. C. MULTIPLIER

Marginal Score	Your Score
.93	

Efficient air-conditioning systems are important in Florida's semi-tropical climate. An air-conditioner with a SEER of 8.5 or higher is recommended. Some water-source heat pumps have excellent SEER ratings and should be considered where appropriate.

HEATING MULTIPLIER

Marginal Score	Your Score
1.0	

Efficient heating systems are important in the cooler climates of northern and central Florida. The more efficient units include heat pumps, solar heating with a conventional backup system, and natural gas heating.

EPI SUBTOTAL

Marginal Score	Your Score
104	

This subtotal represents the energy efficiency of the structural characteristics and the air-conditioning and heating equipment.

WATER HEATING CREDIT

Marginal Score	Your Score
0	

A water heater is a major energy user in a home. Efficient water heating systems are solar systems with conventional backup, heat recovery systems from air-conditioners or heat pumps, natural gas and heat pump water heaters.

DESIGN CREDITS

Marginal Score	Your Score
-4	

A maximum of ten credit points can be subtracted from the EPI subtotal if ceiling fans, whole-house fans, multizone air-conditioners, or windows that provide cross ventilation are included in the house design.

DESIGN PENALTY

Marginal Score	Your Score
0	

Window designs that allow less than 40 percent of the glass area to open are penalized five points. Placing a washer and a dryer in conditioned space is penalized three points. Penalty points are added to the EPI subtotal.

NET EPI

Marginal Score	Your Score
100	

A low EPI indicates an energy-efficient house. In today's energy-conscious market, houses that save energy have a selling advantage over conventional houses. In addition to the factors that affect the EPI of a house, other energy-saving features that should be considered are vapor barriers, landscaping and house orientation, thermal mass, compact floor plans, thermostat controls, and fireplaces.

Florida
Energy
Extension
Service

Prepared by Gary D. Cook, Building Construction Specialist, Energy Extension Service

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Automated Checking of Simply-Supported Prismatic Reinforced Concrete Beams for Compliance With Code Requirements

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INTRODUCTION

Building regulations in their various forms are an important part of the construction industry because they establish standards of quality which are intended to assure at least minimal levels of performance and safety (1,2). Regulations are basically logical processes in that a user is obliged to identify the appropriate criteria based upon comparing the case at hand with those provided for in the regulations. It is essentially an "if-then" process.

As regulations become more extensive and sophisticated the logical complexity of the regulations correspondingly increases. Because most bodies of regulation are presented in narrative form, the user is forced to consider alternatives and information sequentially. In addition, inherent limitations of language and sometimes awkward phraseology combine with the sequential presentation to make full and accurate comprehension difficult (3). For example, consider paragraph 11.4.1 of ACI 318-83 (1):

> "For members with effective prestress force not less than 40 percent of the tensile strength of flexural reinforcement, unless a more detailed calculation is made in accordance with Section 11.4.2,
>
> $$V_c = (0.6\sqrt{f'_c} + 700\,\frac{V_u d}{M_u})\, b_w d \qquad (11\text{-}10)$$
>
> but V_c need not be taken less than $2\sqrt{f'_c}\, b_w d$ nor shall V_c be taken greater than $5\sqrt{f'_c}\, b_w d$ nor the value given in Section 11.4.3 or 11.4.4. The quantity $V_u d/M_u$ shall not be taken greater than 1.0, where M_u is factored moment occurring simultaneously with V_u at section considered. When applying Eq. (11-10), d in the term $V_u d/M_u$ shall be the distance from extreme compression fiber to centroid of prestressed reinforcement.

Decision Logic Table Methodology

The use of decision logic tables (DLTs) as a means to document logically complex problems, e.g., codes and regulations pertaining to engineering was suggested by Fenves in 1966 (4). Subsequently, with Goel, the AISC specification for steel construction was cast into DLT form. A computer routine was also developed to enable automated constraint processing of the regulations in DLT form (5). Noland developed methods for systematically preparing the logical components of DLTs and cast the ACI 318-71 into that format in 1975 (6).

A DLT is a two dimensional tabular presentation of the logical elements of a problem in which the conditions and logical alternatives and applicable results or outcomes are presented. The DLT of Figure 1 represents a portion of ACI 318-83 Section 12.10.5.3.

DLT 12.10(f)	Tension Zone Termination - 3	1	2	3	4
C1	Bar size $\leq$ #11?	Y	Y	Y	N
C2	Continuing reinforcement provides double the area required for flexure at the cutoff point?	Y	Y	N	I
C3	$V_u \leq \phi \frac{3}{4} (V_c+V_s)$?	Y	N	I	I
A1	Provisions = satisfied	X			
A2	Provisions $\neq$ satisfied		X	X	X

Figure 1 - DLT example from ACI 318-83, Section 12.10

Comparisons which must be made, in the case of Figure 1, in order to determine compliance with code provisions are termed "conditions" and identified as C1, C2,... The vertical columns numbered 1,2,3, and 4 are "decision rules." Rule 1 is interpreted for example: If the response to Condition 1 is yes (Y) and the response to Condition 2 is Y and the response to Condition 3 is Y then the provisions are satisfied as indicated by an X opposite Action A1 in the table.

In the case of the problem of Figure 1, all other decision rules result in the outcome "provisions are not satisfied." The symbol "I" in a given decision rule indicates that the response to that condition of that row in the DLT is immaterial to the outcome when responses to other conditions in the rule determine the outcome. Because each I allows a Y or N response, there are seven unique ways in which provisions will not be satisfied in the problem of

Figure 1 and only one way of satisfying the provisions.

Methods have been developed for systematically enumerating the decision rules and developing the portion of DLTs above the double horizontal lines such that all and only logically correct sets of Y(yes) - N(no) responses are included (6).

In general, building regulations, or codes, or specifications require many DLTs to document the logical processes and identify the results. In such a system of DLTs many will be such that the outcome is a numerical design value which is required by another DLT, such as Figure 1, in order to establish compliance with provisions.

AUTOMATED CONSTRAINT PROCESSING

Automated constraint processing, i.e., checking the characteristics of a given design against the minimum characteristics required by regulation via computer, permits extensive and complex regulations to be more comprehensively and accurately utilized (7). The basic methodology developed by Goel (5) provides a means for automated processing of any set of regulations which are properly presented in DLT form.

The DLT processor methodology requires that each DLT in a set be numbered, that each piece of information (datum) required to execute[1] the DLT and each datum developed by the DLT be labeled and numbered, and that the datum source be identified, e.g., user supplied or supplied by another DLT. Datum sources, labels and numbers are displayed in a "datum table" associated with each DLT.

Figure 2 is the datum table associated with the DLT of Figure 1. The symbol "X" in the Source column indicates that the source is the user and the numbers refer to other DLTs as the source of a particular datum. The numbers in the "Number" column are datum numbers. A set of DLTs and their associated Datum Tables thus represents an interrelated data network in which the ingredients of each datum are identified and the datum or data which depend upon a given datum are identified. It is necessary to provide a number of problem-unique subroutines to the constraint processor to develop information required for DLT execution.

---

[1]"Executing" a DLT means to respond to the conditions C1, C2,... using specific values of data for the case at hand, comparing the set of responses obtained with those in the decision rules to the right of the double vertical lines and identifying the appropriate Action (outcome) A1, A2,...

Datum 12.10(f)	Source	Label	Number
Bar size.	X	SZB	333
If continuing reinforcement provides double the area required for flexure at the cutoff point.	X	BLRD	262
Factored shear force at section.	55	V_u	174
Nominal shear strength of concrete.	132	V_c	170
Nominal shear sgrength of shear reinforcement.	71	V_s	188
Strength reduction factor.	X	ϕ	41

Figure 2 - Datum table for DLT 12.10(f) of Figure 1

The DLT processor methodology uses a procedure called "conditional execution" of DLTs in which only the information required for checking a given specific design is developed rather than the less efficient developing of all the information implied in a complete set of DLTs. In conditional execution, the DLT processor initially attempts to execute the highest level DLT in a given system of DLTs. If all the datum necessary is present, the DLT is executed and, processing is completed. If not, execution of the first DLT is suspended and the DLT or DLTs which provide required data are executed. Execution of these DLTs in turn may be suspended pending execution of other DLTs which provide data to them.

PROGRAM ACICK

ACICK is an automated constraint processor which checks the design of simply-supported, reinforced, prismatic concrete beams for compliance with the provisions of ACI 318-83 (1) pertaining to shear and flexure. It was prepared using the DLT processor (5) to handle the execution of approximately 150 DLTs which document the shear and flexural provisions (8). A number of subroutines were developed to handle the problem-unique computational requirements. The processor is limited to singly-reinforced beams and shear reinforcement placed at an angle of 90 degrees to the longitudinal reinforcement. The processor was scaled to allow from 1 to 40 different beam designs to be checked at up to 9 cross-sections per beam. Beam loading may be concentrated, uniform, or a combination of both. Program input consists of:

A 4 control datum,
B up to 5 beam geometry datum,
C up to 5 material property datum,
D up to 9 reinforcement details datum,
E up to 4 loading information datum,
F up to 10 design assumption datum and
H an end-of-input symbol, 0.0.

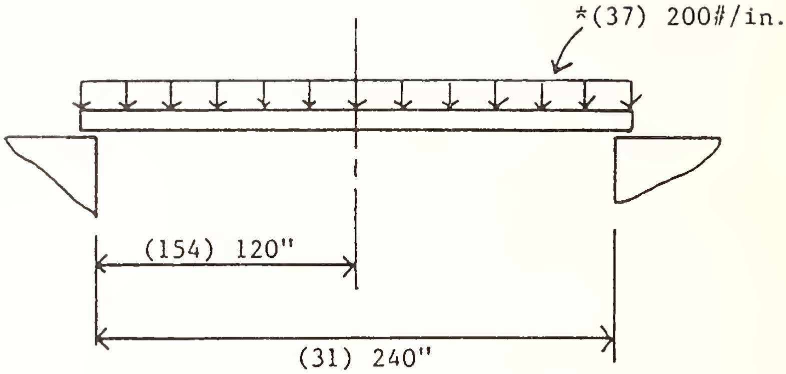
Except for the control datum and end-of-input datum, datum is entered in the form: datum number, datum, e.g., 27,25 in which datum number is 27 and 25 is "total depth of member." The user needs to input only the datum required, in any order, for the check being made. For input categories C,D,E, and F above, the maximum amount of input will not usually be required because in the absence of a specified value a default value will be assumed which represents the majority of cases. For example, unless otherwise specified, modulus of elasticity of reinforcement will be set at 29,000,000.

Four levels of output are available and may be chosen by appropriately selecting an output option code which is one of the control datum. Level one provides: a trace of the DLT execution from DLT to DLT, the status of each provision, comments, and a data list. Level two provides: status of each provision and comments, Level three: status of each provision, and Level four: a list of violated provisions only.

The processor is operational in a time-share mode. The user must initially create a data input file consisting of information in categories A-H above. Subsequently, after calling the processor, the user will be queried in an interactive mode for additional information starting with the name of the input file and including the type of checking to be done. Selection of datum to be input interactively was essentially arbitrary and was done to illustrate a mode of usage. The processor could have been prepared such that all or none of the datum could be entered in this manner. The processor and its usage are described in reference 9.

EXAMPLE

A simple example of processor usage is presented below in which the beam of Figure 3 is checked for compliance with code flexural provisions only at mid-span. Output level 2 was selected.



f'_c = 3000 psi

f_y = 60000 psi

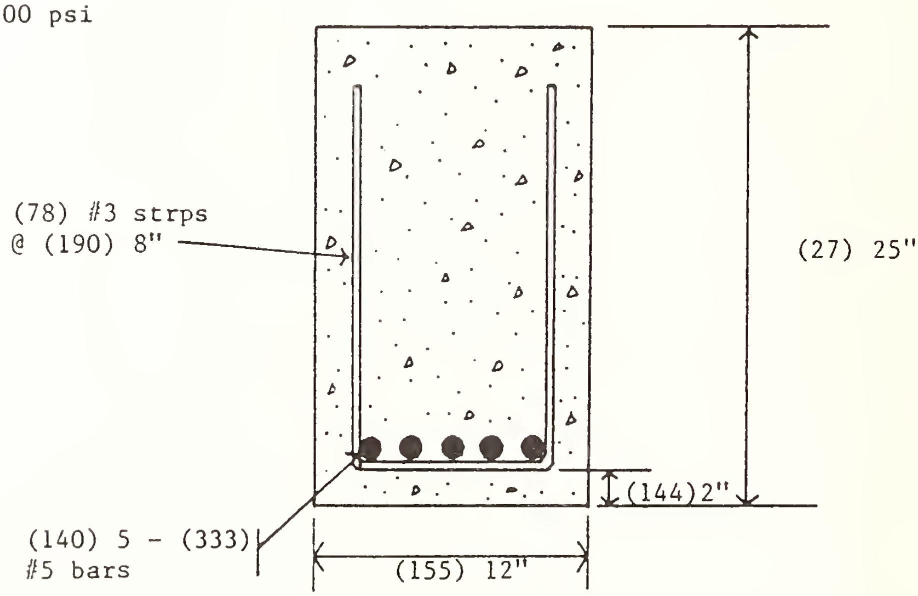


Figure 3 - Simple Beam Example

*Numbers in parenthesis are datum numbers.

```
OLD.EXDATF1
/LIST
THIS IS EXAMPLE NUMBER ONE-CHECK FLEXURE REQUIREMENTS AT MIDSPAN
2                                                                   Control
1                                                                   Information
1
27,25
155,12
31,240                  Geometry
154,120
118,240
16,3000                 Material Properties
49,60000
333,5
78,3
140,5                   Reinforcement Details
144,2
142,1
77,1
39,1                    Loading Information
37,200
0.0                     End-of-input Sympol
/CALL.CK1

  WHAT IS THE NAME OF YOUR INPUT FILE?

? EXDATF1

  WOULD YOU LIKE TO CHECK FLEXURE REQUIREMENTS ? (Y/N)

? Y

  WOULD YOU LIKE TO CHECK SHEAR REQUIREMENTS? (Y/N)

? N

  CHECKING OF BEAM NUMBER  1  CROSS SECTION NO  1 IS COMPLETE.
  OUTPUT CAN BE FOUND ON FILE OUTACI.

/OLD.OUTACI
/LIST

   84/06/29.

   11.42.01.

      THIS IS EXAMPLE NUMBER ONE-CHECK FLEXURE REQUIREMENTS AT MIDSPAN
```

```
OUTPUT LEVEL 2 WAS CHOSEN
STATUS OF EACH CHECK+COMMENTS

NUMBER OF BEAMS TO BE CHECKED=  1

          THE FOLLOWING NUMERICAL DATA HAS BEEN SUPPLIED FOR
          BEAM NUMBER  1   CROSS SECTION NO.  1

DATA DESCRIPTION.   VALUE

FY= 60000.0 PSI

FC=   3000. PSI
NUMBER OF BARS=  5.0
SIZE OF BARS= # 5.0
THE FLEXURAL REINFORCEMENT IS ALL THE SAME BAR SIZE.
THE FLEXURAL REINFORCEMENT IS ALL IN THE SAME ROW.
CONCRETE COVER=  2.0 IN
WIDTH OF THE SECTION=  12.0 IN
DEPTH OF THE SECTION=  25.0 IN
LENGTH OF THE BEAM=  240.0 IN
SPACING OF LATERAL SUPPORTS=  240.0 IN
SIZE OF THE STIRRUPS= #  3.0
DISTANCE FROM THE FACE OF LEFT SUPPORT=  120.0 IN
UNIFORM LOAD ON THE BEAM=  200.0 LBS/IN


     BEAM NUMBER  1    CROSS SECTION NO.    1
     ***    START EXECUTION WITH TABLE 119      ***


     PROVISIONS OF SECT 10.2.2 FOR STRAIN DISTRIBUTION
     ASSUMPTIONS ARE SATISFIED.


     PROVISIONS OF SECT 10.2.3 FOR MAXIMUM CONCRETE
     STRAIN ARE SATISFIED.


     PROVISIONS OF SECT 10.2.4 FOR STRESS-STRAIN OF
     STEEL ARE SATISFIED.


     PROVISIONS OF SECTION 10.2.7 FOR CONCRETE STRESS-STRAIN
     CHARACTERISTICS ARE SATISFIED.


     PROVISIONS COVERING THE SHAPE OF CONCRETE STRESS-STRAIN
     ARE SATISFIED.
```

PROVISIONS OF SECTION 10.2 FOR DESIGN ASSUMPTIONS
HAVE BEEN CHECKED.

PROVISIONS OF SECT 10.3 FOR GENERAL PRINCIPLES AND
REQUIREMENTS ARE APPLICABLE.

PROVISIONS OF SECTION 10.3.1 ARE SATISFIED BECAUSE STRAIN
COMPATIBILITY WAS USED WITH THE ASSUMPTIONS OF SECTION 10.2

PROVISIONS OF SECT 10.3.3 FOR MAXIMUM REINFORCEMENT RATIO
ARE SATISFIED.

REINFORCEMENT RATIO= .00579
MAXIMUM REINFORCEMENT RATIO= .01604

PROVISIONS OF SECTION 10.3.4 ARE SATISFIED.

PROVISIONS OF SECT 10.3 FOR GENERAL PRINCIPLES AND
REQUIREMENTS HAVE BEEN CHECKED.

PROVISIONS OF SECT 10.4 FOR LATERAL SUPPORT OF A
FLEXURAL MEMBER ARE SATISFIED.

POSITIVE REINFORCEMENT IS REQUIRED.

PROVISIONS OF SECTION 10.5.1 ARE SATISFIED FOR
MINIMUM REINFORCEMENT RATIO.

REINFORCEMENT RATIO= .00579
MINIMUM REINFORCEMENT RATIO= .00333

PROVISIONS OF SECTION 10.6 ARE APPLICABLE.

EQ. 10-4 MUST BE CHECKED TO VERIFY THE CORRECT DISTRIBUTION
OF FLEXURAL REINFORCEMENT.

Z= 117.384 WHICH SHOULD BE LESS THAN 175 KSI

PROVISIONS OF SECT. 10.6.4 ARE SATISFIED FOR DISTRIBUTION OF FLEXURAL REINFORCEMENT AT MAXIMUM POSITIVE AND NEGATIVE MOMENT SECTIONS.

PROVISIONS OF SECT 10.6 FOR DISTRIBUTION OF FLEXURAL REINFORCEMENT IN BEAMS HAVE BEEN CHECKED.

```
THE FLEXURAL STRENGTH OF THE MEMBER IS ADEQUATE.
         REQD MOMENT CAPACITY(IN-LBS)=  1440000.
     PROV MOMENT CAPACITY*FEE(IN-LBS)=  1739984.
```

CHECKING OF PROVISIONS OF CHAPTER 10-FLEXURE AND AXIAL LOADS-HAS BEEN COMPLETED.

CONCLUSIONS

The authors believe that automated constraint processing is an effective means to enable complete and accurate usage of building regulations. The DLT processor developed by Goel and Fenves, and slightly modified by the authors, is generic and capable of being used to automate any body of regulations or other type of logical process if the logical process is cast into DLT form.

There are improvements which should be made in the DLT processor, as one might expect for any program of its complexity, such as improving operational efficiency and modifying to enable on-line changes in design to be made.

ACKNOWLEDGEMENTS

The authors greatly appreciate the help and cooperation of Surendra Goel in the initial stages of planning the work described herein, for supplying the DLT processor, and for assistance and review associated with making the processor operational on a different computer than for which it was originally programmed.

The DLT formulation of the 1977 ACI 318, and development of the simple beam constraint processor complying with the flexure and shear requirements of the 1983 ACI 318 were supported by the U.S. Army Corps of Engineers - WES.

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Emerging Engineering Methods Applied to Regulatory Fire Safety Needs

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SUMMARY

The development of fire science has progressed to a point where an analytical engineering methodology for fire protection design is emerging. This presentation outlines the elements of such a method and provides an example of one facet and a broad range of references for those interested in deeper examination.

This presentation is built on the premise that the state of fire science has now advanced to the point where it is possible to assemble and apply a scientifically based fire protection engineering technology as a useful tool in the building regulatory process. This emerging approach is based on the fact that fire is an energy process that produces an energy bearing fluid (i.e. smoke and gases). That fluid obeys the physical laws of conservation of mass, momentum and energy.

Historically, at least until the past decade, fire research was largely empirical and much of fire testing was abstract and definable only in terms of the testing apparatus used. While empirical research has resulted in some major impacts on methods that have been applied to fire safety, these impacts have been sporadic. Conversely, many test procedures have become dominant forces unto themselves without a base in science.

Three or four decades ago this combination of empirical research, surrogate test values, and validation by experience was sufficient. Most buildings were inherently massive and highly compartmented. Wood and paper were the prime combustibles of concern. The rate of change in building technology was slow and the cumulative history of how buildings reacted when exposed to fire or other stress was a reasonable prediction of future expectations. It was in that atmosphere that our current system of consensus code and test standards arose.

The code and its companion standard and test system were designed to address not just fire safety but rather the total scope of public health and safety. Whenever credible technology existed it was incorporated. But when it was not available, committee consensus judgment was used. In the case of fire safety, technology input has been a minor influence; judgment has been the dominant force. The result is a rigid set of requirements and a regulatory system that has difficulty in accommodating the new materials, new designs, and new expectations on both cost and safety. Until recently it was not the practice of consensus bodies to record their objectives or expectations when setting requirements. Even today only a few bodies, such as the ASTM, include any type of commentary as part of their official output. Usually the value and intent of code requirements are not apparent.

Virtually every code has an equivalency clause that permits alternative approaches provided equal performance can be achieved. It is, however, difficult to demonstrate the required equivalency factors that need to be considered are established by consensus. As a result the code document rather than its original purpose frequently becomes the objective. Expertise becomes entombed in relating fixed requirements to building materials and systems. Sometimes the ability to test and measure a parameter rather than the importance of that parameter determines the requirement. Under this concept innovation, rational design, and cost control have frequently been constrained and frustrated.

Over the past several decades, however, a relatively small but fortunately persistent group of research scientists and engineers have labored in laboratories and universities around the world. They have dedicated their efforts to determining the basic principals of unwanted fire; measuring the variables involved; and (in recent years) developing coordinated engineering approaches to predict the course of fire, the response of fire safety features, and the resulting impact on people, property, and productive missions. As a result, there is a progressively emerging fire protection engineering technology that can potentially be used to evaluate the fire safety performance of a building or other structure that differs widely from the current prescriptions of the code. It can also provide an assessment of the impact of a code requirement as it applies to a specific building or set of circumstances.

With the current state of knowledge, it is now possible to make at least a first order quantitative engineering evaluation of fire development and impact from the moment of ignition to the final determination of the results of the fire.

Such an engineering approach can be the basis for individual building analysis or the appraisal of the generalized requirements for regulatory purposes. Also, by combining engineering technology with probabilistic evaluation of the likelihood of events and conditions, significant advances can be made in the technology of fire risk analysis.

In order to assemble this emerging technology in a useful fashion a conceptual model that partitions the problem in a manner responsive to the available and emerging engineering capabilities is needed. Figure 1 is a diagram of such a model. The model is designed to treat fire as a energy induced stress on the building and to measure the response of the building and its fire protection systems to that stress. The model also considers the analytical aspects of human response.

Useable analytical calculation methods now exist for each of the elements shown in Figure 1. In a number of cases several established engineering approaches are available. A partial list of sources for these procedures are listed in the references and biographical listing included with this paper.

The listed references are not necessarily the most advanced engineering methodology but rather those which are available in the open literature to engineers or scientists willing to expend the effort to obtain and use them.

As the new fire protection engineering technology emerges it produces an increasing demand for data. The types of data needed are measurements of physical values that meet the demands of the calculation systems. The testing community is responding with increased emphasis on the development of valid reproducible tests of engineering quantities while stepping away from tests that only rank order or provide measurement in terms of arbitrary values relatable only to the test device involved.

Meeting the dual challenge of improvement of the calculation methods and the provision of the supporting data is key to moving fire safety from an indefinite to a definite technology.

Fire protection engineering technology is past the embryonic stage but is still a struggling child that continues to require support and encouragement. The development of the underlying science and the production of scientifically based data must continue to nurture this technology.

It is reasonable to expect that the maturity of fire protection engineering as a fully useful and credible technology of significant value to the design community will occur. The pace at which technology replaces subjective judgment is a function of the level of interest, demand, and support given by the design, the fire protection engineering, and related research and testing communities. Key to this technology development are the assembly of research into appropriate engineering forms, the production and cataloging of the essential data, and continued emphasis on proof testing and other verification programs.

The use of a fire protection engineering approach is viable for either individual building analyses or generalized requirements for codes. In the first case the actual building condition and arrangements are considered. In the second case, it is necessary to establish the characteristic allowable fuel condition for the occupancy under consideration and applied this to a series of test cases representing an array of building arrangements for that occupancy.

An example of the total analysis approach applied to a specific building was described in some detail by Nelson [1] at the Conference on Communications Between the Fire Research Community and the Owner-Operators of Buildings held at the National Academy of Sciences in November of last year. A subsequent presentation by Nelson [2] to the 1984 meeting of the National Conference of States on Building Codes and Standards presented a series of example procedures for some of the elements of the model where the use of relatively simple calculations can greatly assist both the designer and the regulatory official in appraising hazard in a specific situation. Space limits this presentation to the outline of a calculation of just a single element.

The formula used was selected on the basis of simplicity and the existance (or potential to produce) the input data required. While it and the other formulas suggested by Nelson, [2] have been proposed by competent researchers, it is important to recognize that the outputs are approximations rather than exact solutions and in some instances are yet to be subjected to large scale validation testing.

Smoke Passage through a Opening

Using the formulas and data presented in the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) publication "Design of Smoke Control System for Buildings" [3] an approximation of the volume of smoke that would flow through an opening such as a crack above the door, a transfer grill, or an opening through the ceiling can be derived and expressed by the equation:

$$V = 7210\ A\ \left(\frac{1}{530} - \frac{1}{T}\right)^{1/2} h^{1/2} \left(\frac{T}{530}\right)^{1/2*}$$

*Since this paper is for an audience involving building designers those dimensions commonly used are given in the English system.

where

V = Volume flow (cfm)
A = Area of the opening (square feet)
T = Smoke temperature (°R = °F+460)
h = Smoke Depth (feet below center line of opening)

This formula assumes room temperature of about 70°F.(530R). If used for large vertical openings such as doorways it is necessary to treat the doorway as a series of small parallel openings and calculate the volume through each section with the value of h adjusted in each case. This to account for the pressure gradient from top to bottom of the door. Figure 2 shows the results of this calculation for several different size openings 7 feet above the floor with the smoke at several different depths and temperature levels.

Validation Testing

The Center for Fire Research has underway two separate programs to assess the confidence and credibility that can be applied to the modeling formulas. One, being conducted at the Center itself, addresses the basic fire growth and smoke movement model in and close to the room of fire origin. This validation program is a long term process, involving carefully iterated steps to produce statistically valid measurements of the confidence that can be placed in the models.

On a shorter term basis, a less detailed and statistically significant, but equally important series of verification tests are now underway in a facility built under a NBS grant at the Factory Mutual Research Corporation facilities in West Gloucester, Rhode Island. These facilities were built as part of a program under the sponsorship of the Department of Health and Human Services. The initial fire tests to calibrate the facility have been conducted. A program of carefully controlled fire tests of progressively increasing severity are now underway. Candidate solution procedures such as those presented in this paper, as well as more complex models, are being executed at NBS and then compared with the fire results produced at the test site.

In conclusion it is reasonable to state that:

1. There is a newly emerging analytical fire protection engineering technology able to support design considerations and decisions.

2. The emergence and use of this technology can provide the best means of freeing design from present constraints imposed by regulations while assuring that safety obligations are met.

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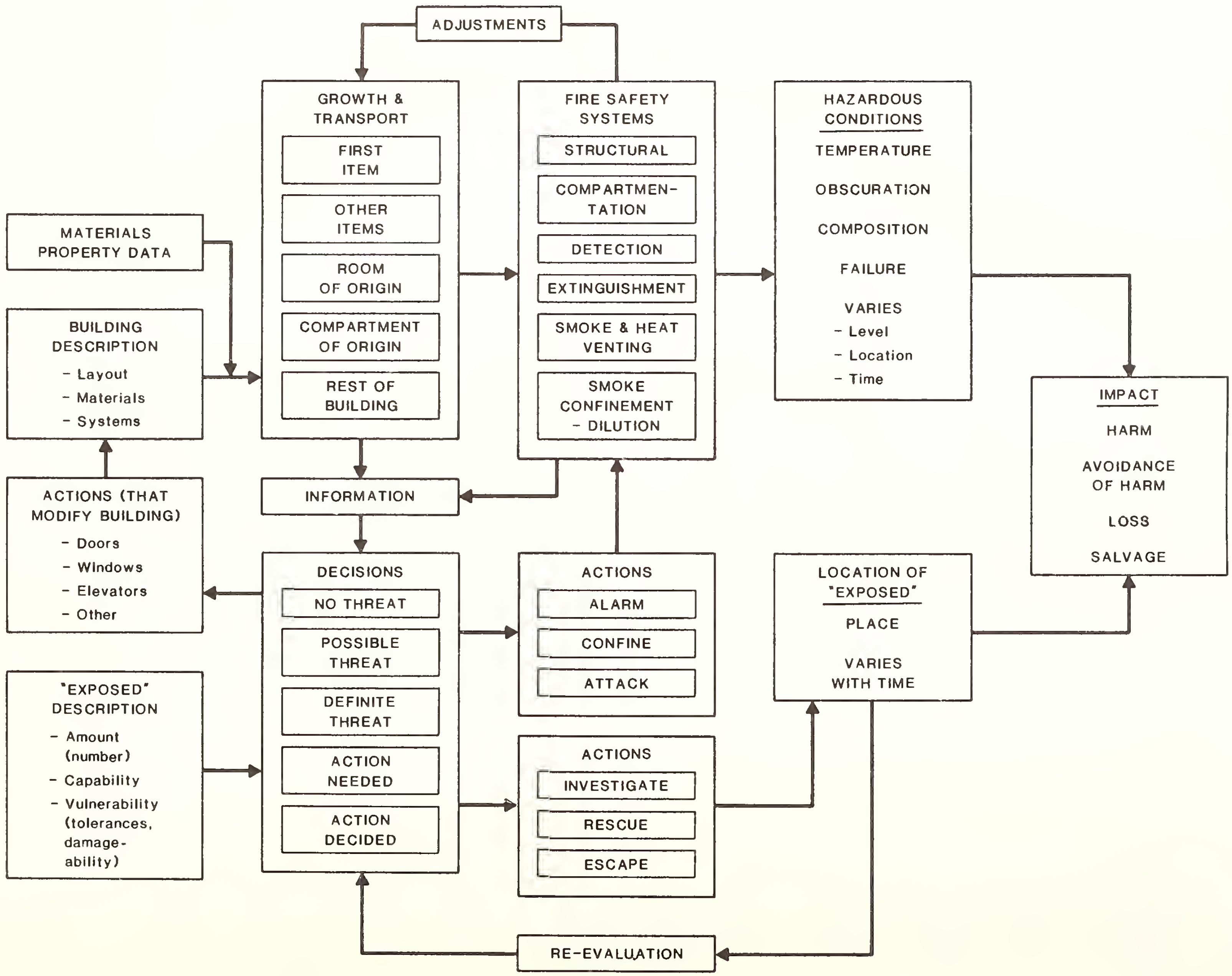
ADJUSTMENTS
MATERIALS PROPERTY DATA
BUILDING DESCRIPTION
- Layout
- Materials
- Systems
ACTIONS (THAT MODIFY BUILDING)
- Doors
- Windows
- Elevators
- Other
"EXPOSED" DESCRIPTION
- Amount (number)
- Capability
- Vulnerability (tolerances, damage-ability)
GROWTH & TRANSPORT
FIRST ITEM
OTHER ITEMS
ROOM OF ORIGIN
COMPARTMENT OF ORIGIN
REST OF BUILDING
INFORMATION
DECISIONS
NO THREAT
POSSIBLE THREAT
DEFINITE THREAT
ACTION NEEDED
ACTION DECIDED
FIRE SAFETY SYSTEMS
STRUCTURAL
COMPARTMEN-TATION
DETECTION
EXTINGUISHMENT
SMOKE & HEAT VENTING
SMOKE CONFINEMENT - DILUTION
ACTIONS
ALARM
CONFINE
ATTACK
ACTIONS
INVESTIGATE
RESCUE
ESCAPE
RE-EVALUATION
HAZARDOUS CONDITIONS
TEMPERATURE
OBSCURATION
COMPOSITION
FAILURE
VARIES
- Level
- Location
- Time
LOCATION OF "EXPOSED"
PLACE
VARIES WITH TIME
IMPACT
HARM
AVOIDANCE OF HARM
LOSS
SALVAGE

FIGURE 1

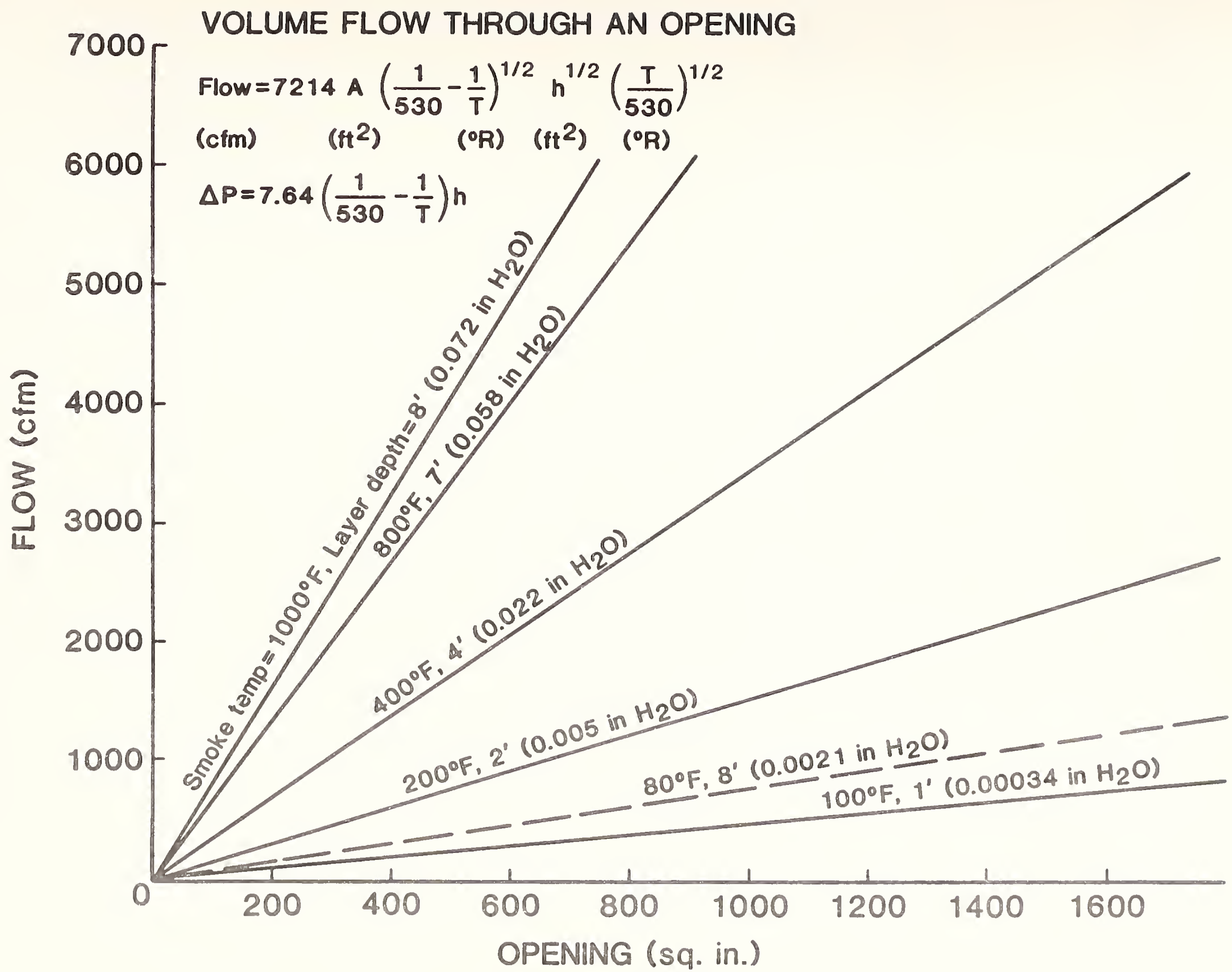
VOLUME FLOW THROUGH AN OPENING
Flow=7214 A $\left(\frac{1}{530}-\frac{1}{T}\right)^{1/2}$ $h^{1/2}$ $\left(\frac{T}{530}\right)^{1/2}$
(cfm) (ft^2) (°R) (ft^2) (°R)
$\Delta P=7.64\left(\frac{1}{530}-\frac{1}{T}\right)h$
Smoke temp=1000°F, Layer depth=8' (0.072 in H_2O)
800°F, 7' (0.058 in H_2O)
400°F, 4' (0.022 in H_2O)
200°F, 2' (0.005 in H_2O)
80°F, 8' (0.0021 in H_2O)
100°F, 1' (0.00034 in H_2O)
FLOW (cfm)
7000
6000
5000
4000
3000
2000
1000
0
200
400
600
800
1000
1200
1400
1600
OPENING (sq. in.)

FIGURE 2

Survey of the State of the Art of Mathematical Fire Modeling

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INTRODUCTION

In the past decade, considerable effort and resources have been directed at the development and use of mathematical modeling for predicting the fire response of products in a particular fire situation. Recently, Underwriters Laboratories Inc. (UL) undertook a survey of the state of the art of mathematical fire modeling for predicting the growth of a fire within a room under the sponsorship of the Society of the Plastics Industry. The purposes of the survey were:

1. To gain a better perspective of mathematical fire modeling.

2. To assist in making mathematical modeling more useful to the practicing fire protection engineer.

3. To make mathematical modeling more understandable to those not specifically equipped to understand the detailed physics and mathematics of mathematical modeling.

4. To identify possible applications.

5. To make recommendations for further work in developing mathematical modeling into a practical engineering tool.

In a few words, the objective was to assist in bridging the application of mathematical fire modeling from fire researcher to fire practitioner. My comments are aimed at explaining mathematical fire modeling in terms that relate to this objective of UL's work.

Mathematical fire modeling should be recognized as a tool which can be used in dealing with fire protection engineering analysis and design problems, just as similar design methods are used in other engineering disciplines. Our study shows that while much has been accomplished, there is still much to be done.

The elements of the study involved:

1. Studying existing mathematical fire models which address the prediction of the development of fire in a single compartment from the time of initial ignition to the onset of room flashover.

2. Preparing a review of these models to enable potential users and others interested to obtain an overall understanding of the field of mathematical fire modeling.

3. Developing recommendations for potential future efforts in the area of fire model development and application.

The study has been included in a Report to the Society of the Plastics Industry (1). The Report is available from SPI.

Seven mathematical models were examined. Two models were studied in detail. These were: (1) The Ohio State University Model (OSU Model) and (2) The Harvard Model (Mark 5 Version).

Five other models were reviewed more generally. These were: (1) The National Bureau of Standards Model (N.B.S. Model), (2) The IIT Research Institute Fire Model (IITRI Model), (3) The Dayton Aircraft Cabin Fire Model - Version 3 (DACFIR Model), (4) University of Notre Dame Model - UNDSAFE II (UNDSAFE Model) and (5) Enclosure Fire Dynamics Model for Interior Aircraft Fires - (EFDM Model).

The survey and study considered such factors as: (1) Situation(s) modeled, (2) Assumptions made, (3) Input required, (4) Physics and mathematics involved, (5) Output or results obtained, (6) Documentation and availability of such documentation to potential users, (7) Limitations of the model and (8) Needs to make further improvement(s)/further development and progress in the use of the model.

Recently, UL has also studied the analytical techniques of predicting the effects of fires on the structural integrity of steel frame/concrete slab structures and buildings.

BACKGROUND

Fire modeling has been an evolving process. In the early part of this century, full-scale and reduced size replicas of actual fire situations were first used as physical models of actual fire situations. This led to the development of standardized fire test methods as physical models of real fires. Test data often provides information regarding relative performance which is useful primarily in the context of experience. Full-scale tests are conducted to demonstrate specific performance. In recent years, mathematical treatments of existing fire test data have been developed and applied to extend the application of such data through interpolations and extrapolations. Mathematical modeling efforts at this point in time, are directed at three separate elements of fire evaluation. These are: 1) Room fire growth models, 2) Models to calculate heat transfer from room fires to structural elements, and 3) Models designed to calculate the response of the structural elements to the effects of heating.

ROOM FIRE GROWTH MODELS

In recent years, mathematical modeling of developing fires has received increasing attention, because of a desire to be able to predict the growth and spread of fire through a building on a rational basis.

There are two basic approaches to mathematical modeling to predict fire development in an enclosure. These are: 1. Probabilistic Models, and 2. Computational Models.

This study did not dwell on probabilistic models. However, a brief comment is in order.

Probabilistic Models

The probabilistic models describe the fire development as a sequence of events (such as ignition, flame spread, heat transfer, etc.) and consider the change from one event to the next in terms of probability of occurrence and time. These models make little use, if any, of the chemistry and physics involved in a compartment fire. Model inputs are provided by studying past fires and developing statistics on how those fires developed. However, this modeling approach has the weakness that there is not a high degree of assurance that the model is a good fit to the specific situation of interest.

Computational Models

There are two relevant types of computational models: zone models and field models.

Observation of fire in a compartment makes it evident that a horizontal interfacial plane develops between the smoky upper layer and the relatively clear lower layer in the compartment. The respective smoky upper layer, and clear layer are also distinguished by significant differences in the temperature of the gases in the two layers. These two "layers" are the "zones" in the concept of "zone models," as indicated by ILL. 1. Fresh air enters the compartment into the clear lower zone, is drawn into the fire, heated, mixed with fire gases and carried into the smoky upper layer. The smoky gases in the upper layer, in turn, flow out from the compartment.

Examination of the process will reveal that heat produced by the burning fuel causes an increase in the temperature of the air in the upper layer. The equation which permits this to be calculated is quite simple:

$$t_2 = t_1 + \Delta t$$

$$= t_1 + \frac{q}{m \cdot C_p}$$

where, q is heat, Btu; m is mass, lb and C_p is specific heat, Btu/Lb-F.

Since this is a process that changes with time, the equation can be rewritten as a rate function, that is, using heat release rate and mass flow rate:

$$t_2 = t_1 + \frac{\dot{q}}{\dot{m} \cdot C_p}$$

where, $\dot{q}$ is heat release rate Btu/min; $\dot{m}$ is mass flow rate lb/min and C_p is specific heat, Btu/lb-F.

The specific heat value can be obtained by using the specific heat value for air, which can be obtained from a handbook. The mass of air being heated can be calculated by determining the volume of the upper part of the room, that is, the volume of the hot zone, $V = l \cdot w \cdot d$ where l is length, w is width and d is depth. Mass is: $m = V \cdot \rho$, where ρ = density of air.

Density can be obtained from a handbook. The remaining value needs to be obtained by experimentation.

For uniformly burning, simple surfaces, a heat release rate calorimeter can be used to obtain heat release rate data.

In a slightly more complex case, it can be idealized. An object, such as a piece of furniture, can be placed under a calorimetric hood, as shown in ILL. 2, and burned. The heat release rate measured can then be used directly as input data. In the future, building codes might be able to adopt requirements which would use such a test to regulate the size and type of furniture that might be placed in a hotel room or a restaurant.

In a more complicated situation, such as the case where the room wall surfaces become ignited, as shown by ILL. 3, additional information is needed. First of all, the computer program - or mathematical model - must be more complex to handle the more complex fire developments. In this case, there needs to be knowledge of specific flame propagation rates for the wall surface, since the amount of wall surface burning over the time period changes. The computer programmed model must be able to use flame travel rates to calculate how far the fire has spread at various points in time. The concept is really quite simple.

Secondly, there is a need to know something about the rate at which heat is released as the wall surface material burns. This is typically determined using data from a heat release rate calorimeter.

Thus, the zone mathematical model is built around the simple concept of the temperature rise produced by heat release. The typical zone model requires input data including: (1) Room geometry and openings - to permit calculation or estimation of mass flow and heat transfer, (2) Heat release rate data for burning materials, (3) Flame spread data and (4) Ignition data.

The computer simply serves to perform the necessary calculations, and as a keeper of the record of how far flames have spread by a given point in time, how much total heat is being released, and so forth.

As you can visualize, when other zones of the compartment such as cold lower layer, vent, etc., are added to the zones and process previously described, the calculations become more complex due to the many interactions between these zones; however, the concept of making the calculations remain the same.

One of the advantages of the zone-model approach, is that various portions of the model can be separately studied by different teams of investigators. At present, this is being done and the respective efforts are being coordinated through the Ad Hoc Committee on mathematical modeling being administered by the NBS.

Field Models

In a field model of a compartment fire, the space is divided into many small elements and partial differential equations are applied to each element to calculate various fire parameters. These may be either two dimensional or three dimensional.

Rather than relying on preselected processes, as is done with zone models, field models employ the fundamental field equations to express conservation of mass, momentum and energy, in each one of the individual subdivided elements.

A field model can differentiate between the temperature of the ceiling immediately above the fire and that farther away. However, its successful application to problems with multiple parameters requires extreme computer power, perhaps beyond present or even future capabilities, especially for complex situations.

Field models may be used to help validate zone models. Field and zone models are not mutually exclusive, nor are they competing with each other. Indeed, these two types of models approach the same problem from two different perspectives. Zone models can be seen as an engineering tool and field models as a more scientific instrument.

Further details of the models are unimportant for the purpose of this paper. It is worth taking a quick look at the results of modeling applications, however, in general terms.

ILLS. 4, 5 and 6 show some data for the Harvard Model. These tests were conducted using an 8 ft by 12 ft by 8 ft room with a doorway opening of 30 in. by 80 in. in one wall.

ILL. 4 shows the experimental versus calculated values of the hot layer temperature. ILL. 5 shows the experimental versus predicted values of upper layer depth. ILL. 6 shows the experimental versus predicted gas (CO and CO_2) and particulate (smoke) concentrations. The comparison between the calculated and the experimental results in these three illustrations is only valid to about 5-1/2 min because of sprinkler operation during the test at that time. The sprinkler operation is not incorporated in the model as of yet. There is remarkable accuracy of prediction of hot layer position and temperature before the sprinkler operation. The lack of correspondence between the calculated and the experimental results for carbon monoxide (CO) concentration in ILL. 6 is indicative of rudimentary understanding of that aspect and may be due to poor physics incorporated in the model.

The Harvard model and its enriched (newer) versions are being studied in Japan (2). A somewhat enriched version of the Harvard model, developed at N.B.S., has been used for preliminary simulations of fires in typical Japanese residential rooms.

MODELS FOR STRUCTURAL ELEMENT RESPONSE TO FIRE

Adequate fire protection of structural members is an important consideration in the design of modern steel buildings. In recent years, building officials, architects, engineers and the construction industry have become increasingly aware of the inadequacy of current approaches to fire safety based on standard tests for fire endurance of isolated components (3). Development of analytical techniques for realistic evaluation of structural fire resistance has received considerable attention both here and abroad. Recognizing the importance of the analytical approach, all the building codes incorporate it as an option to determine that the structural elements of the required fire resistance ratings have been used in the buildings.

A computer program identified as FASBUS II (Fire Analysis of Steel BUildings Systems II) analyzes the structural integrity of steel frame/concrete slab structures during fire exposure. The American Iron and Steel Institute (AISI), the Illinois Institute of Technology Research Institute (IITRI) and Wiss, Janney, Elstner and Associates developed the program (3). Performance descriptions and physical conditions of steel and concrete building components during fire exposure can be obtained through FASBUS II. To do so, three items are entered into the computer time/temperature history during fire exposure of the components, connection details and size. A test structure was constructed to validate the FASBUS II program at NBS.

The required temperature distribution history of the building elements for the FASBUS II program is obtained by using a computer program known as FIRES-T3 (FIre REsponse of Structures - Thermal-THREE - Dimensional Version). This program was developed by the Fire Research Group of the University of California at Berkeley (4). One, two and three-dimensional heat flow problems can be solved using FIRES-T3. In this program, the building element is analyzed for a specified time-temperature curve such as ASTM E-119 or any other given curve. Thus, the time-temperature curve obtained from any of the room fire growth models discussed earlier can be used as an input to the FIRES-T3 program.

Recently, FASBUS II and FIRES-T3 programs were used in analyzing the fireproofing requirements for the large perimeter steel girders of 2-steel framed high-rise buildings on the west coast. As we understand, these studies were instrumental in gaining the approval of the local building officials for a reduction in the fireproofing requirements.

Harvard model and FASBUS II have been transferred to UL-Northbrook's main frame computer. UL is currently compiling the FIRES-T3 program.

LIMITATIONS

Although comparison of test results with computer prediction presented earlier shows fairly good agreement, such is not always the case. The degree or magnitude of difference may vary considerably. Such discrepancies occur because of one or more limitations or weaknesses of the specific model. The usefulness of the predictions of models in material evaluation and hazard assessment depends on the degree to which these limitations or weaknesses can be identified and adjusted to or overcome.

Among the limitations and weaknesses of mathematical fire modeling are:

1. Approximations in Zone Representation:

   In zone models, the accuracy of a zone treatment will always be limited by the arbitrary assumptions used to specify the location of each zone, behavior in each zone and exchanges between zones.

2. Chemical and Physical Processes:

   Not all of the physical, chemical and fluid-dynamic theories which comprise a fire situation are well understood, and many are completely ignored in the models.

3. Chemical and Physical Processes Inadequately Modeled:

The lack of a sufficiently detailed understanding of fire science makes it necessary that mathematical fire modeling rely on both empirical and theoretical methods. Empirical approaches, if not developed with care, may be inaccurate or inadequate. The processes which are theoretically inadequately modeled include: temperature gradients in the fire area, heat transfer by radiation between various zones, flame shape and its orientation, flame spread over combustible materials and mixing between upper hot layer gases and lower, cool layer air.

4. Configuration Limitations:

Mathematical models to date, have been developed with specific configurations in mind. This places limitations on both the enclosure geometry and the geometry or orientation of the product or material of interest.

5. Availability of Input Data:

The input data for various models are to be obtained from either large-scale or small-scale fire experiments. Certain input data are to be derived from the general literature. Where input data are to be developed through fire tests, the specific method of test is not usually well defined.

6. Quality of Input Data:

A number of input parameters, such as the heat of combustion of the ignition source and the thermal properties of the materials required in the model are taken from the general literature or given "best estimate" values.

If tests conducted to obtain input data are not appropriate, are not applicable or are not conducted properly, experimental data obtained for input may be questionable.

7. Mathematical Limitations:

Limitations may affect the values of variables which can be handled, the computer time involved, or even the physical arrangements that can be simulated.

8. Additional Limitations of Field Models

Field models also have additional weaknesses in terms of computer requirements. Until recently, field models have been limited to two dimensions and are still limited to relatively simple situations.

Mathematical modeling remains largely the domain of mathematicians, chemists and physicists. As the potential usefulness and power of mathematical modeling has become evident, fire protection engineers and others concerned with fire have displayed a growing interest. At present, none of the models or the methods required to provide input data have been developed to the point where they are available as "off the shelf" ready-to-use methods. Thus, mathematical fire modeling is not readily available to the typical Fire Protection engineer.

APPLICATIONS

Some limited applications have been made with mathematical modeling. Other applications have been suggested. The following are among actual or potential applications and uses of mathematical fire modeling.

1. Evaluations of Materials and Products - Mathematical modeling should prove to be useful in assessing the impact of existing and new materials and products on potential fire hazards. Such evaluations can potentially be used to screen materials and products and provide a ranking in this regard.

2. Fire Hazard/Risk Assessment - There are two general sources of information needed for performing risk assessments - experience (statistical records of fire incidents; experiences of fire fighters) and experimentation. The mathematical modeling holds promise of predictive capability for evaluating the fire performance (response) of products based on product properties, in a particular situation, rapidly and at a fraction of the cost of full-scale testing.

3. Fuel Load Calculations - Allowable fuel loads can be calculated. This would involve determination of the amount of combustible material that can be placed in the room before predetermined limits of temperature, heat, and smoke would be exceeded during a fire.

4. Generalizations or Avoidance of Full-Scale Tests - The models would be valuable to extend and generalize the results of full-scale tests or in some cases to avoid the necessity for a test in the first place.

5. Identification of Critical Characteristics of Materials - The fire models can be used to identify those characteristics of a material which should be measured in order to assess its fire hazard properties. In that way, the model could be used to define standard fire test procedures.

6. Optimization of Fire Experiment Design - Through the use of a fire model, the design of a fire experiment can be optimized, thereby identifying fire parameters that are most important to measure.

7. Identification of Areas Where Research Needed - The models can be used to identify the areas where more research is needed, e.g., in modifications of materials, in modifications of existing test methods, or development of new test methods.

8. Assessment of Fire Detection, Suppression and Extinguishing Systems - Modeling can be used to assess fire detection, suppression and extinguishing systems.

9. Reconstruction of Events In Fire Investigations - A model might be used during fire investigations to reconstruct the events and assist in identifying plausible fire scenarios.

10. Education and Training - The results generated by a fire model can be used for education and training.

RECOMMENDATIONS FOR FURTHER WORK IN MODELING

Considerable progress has been made in the development of mathematical fire models. Before any of the existing mathematical models can be used extensively or practically for the various potential applications which I have just identified, further work is needed. Further development of various models is required. As this occurs, the reliability and accuracy of predictions and the range of validity must be established. In any event, modeling must be translated into a form more readily usable by practicing fire protection engineers and others interested in fire protection.

Based on this study, the main areas in which future work in mathematical modeling can be directed include:

(1) developing, understanding and incorporating better/more accurate and applicable physics and chemistry for specific models,

(2) validation of models and

(3) transferring mathematical modeling to a more readily usable form - develop users' guides/manuals.

Specific further activities which can be undertaken are:

1. Encourage various researchers and potential users to develop "hands on" experience with the installation and use of its computer program. Harvard model is particularly identified as a primary candidate for further study, development and application.

2. Thoroughly analyze all existing data that may be used to validate the model to quantitatively determine:

   1. Accuracy of results
   2. Range of applicability
   3. Sources of error
   4. Further experiments needed

3. Conduct appropriate fire experiments.

4. Develop material property data needed for model.

5. Further quantify accuracy and range of applicability of the model, and identify sources of error.

6. Conduct sensitivity analyses to determine accuracy needed in input data. (This assumes that all the relevant chemical and physical processes are included and adequately modeled.)

7. Identify and implement model changes to eliminate errors and extend applicability.

8. Apply model to material evaluation and hazard/risk assessment.

SUMMARY

Significant progress has been made in mathematical modeling of fires. Models, such as the Harvard zone model, have been applied to several fire situations with some degree of success. Such models can be regarded as additional tools that would be available to the building officials, engineers and others interested in evaluating the performance of the products and/or the systems in a fire environment. Further development is required, but the foundation has been laid and the future holds increasing practical applications of modeling to the solution of fire problems. The greatest need, therefore, at this point, is to take further specific steps to transform mathematical modeling into a form more readily usable by the practicing fire protection engineer.

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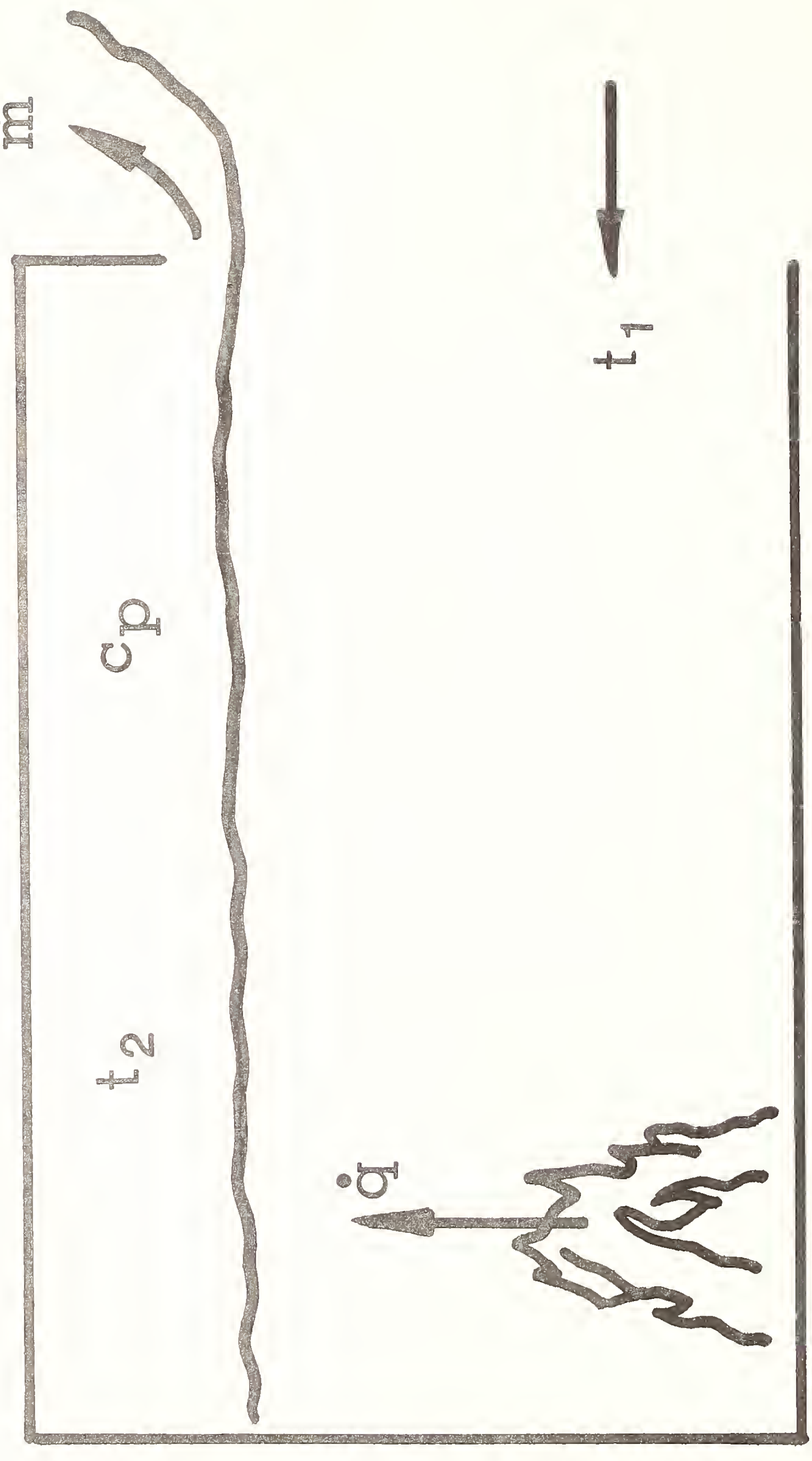
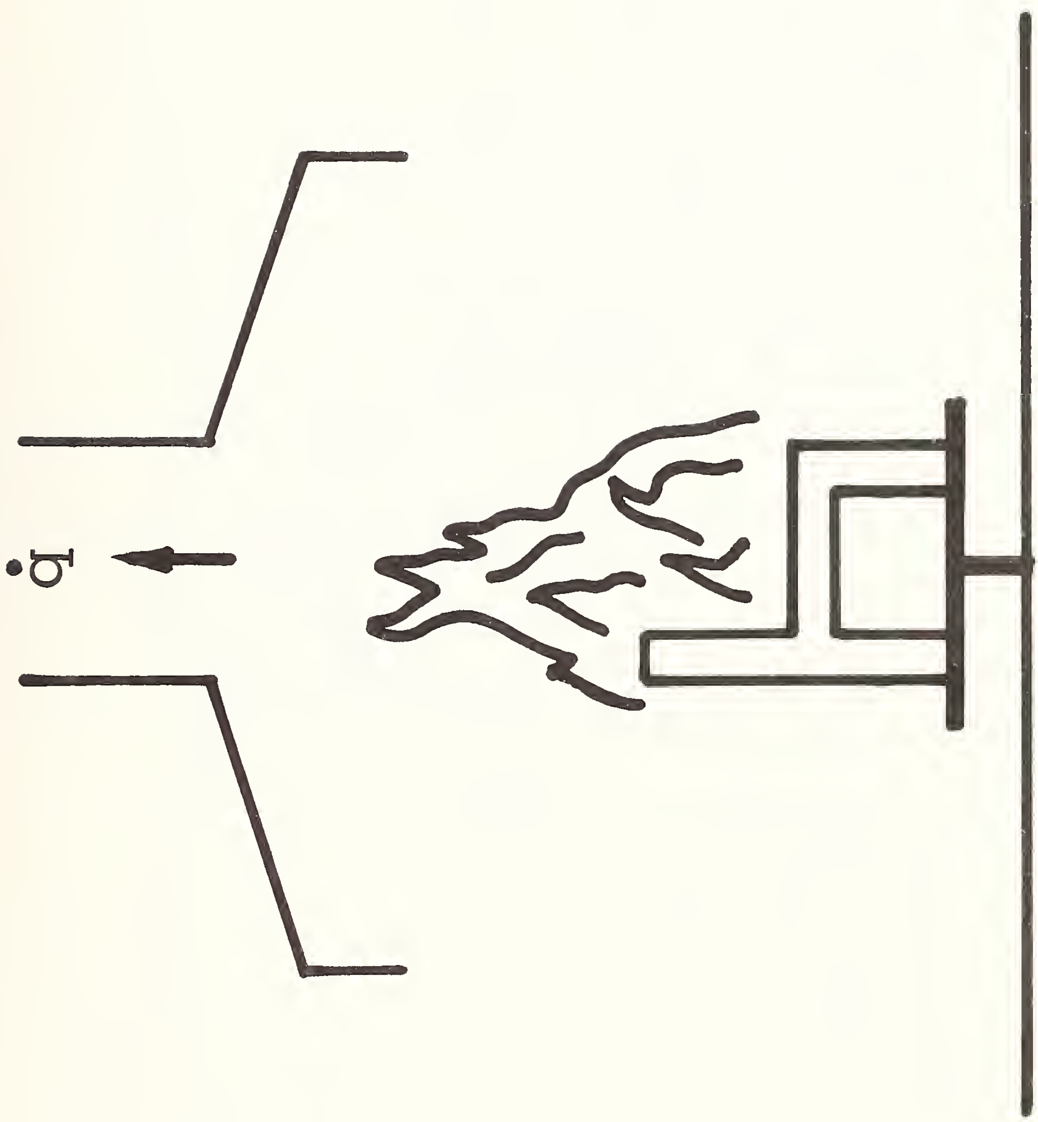
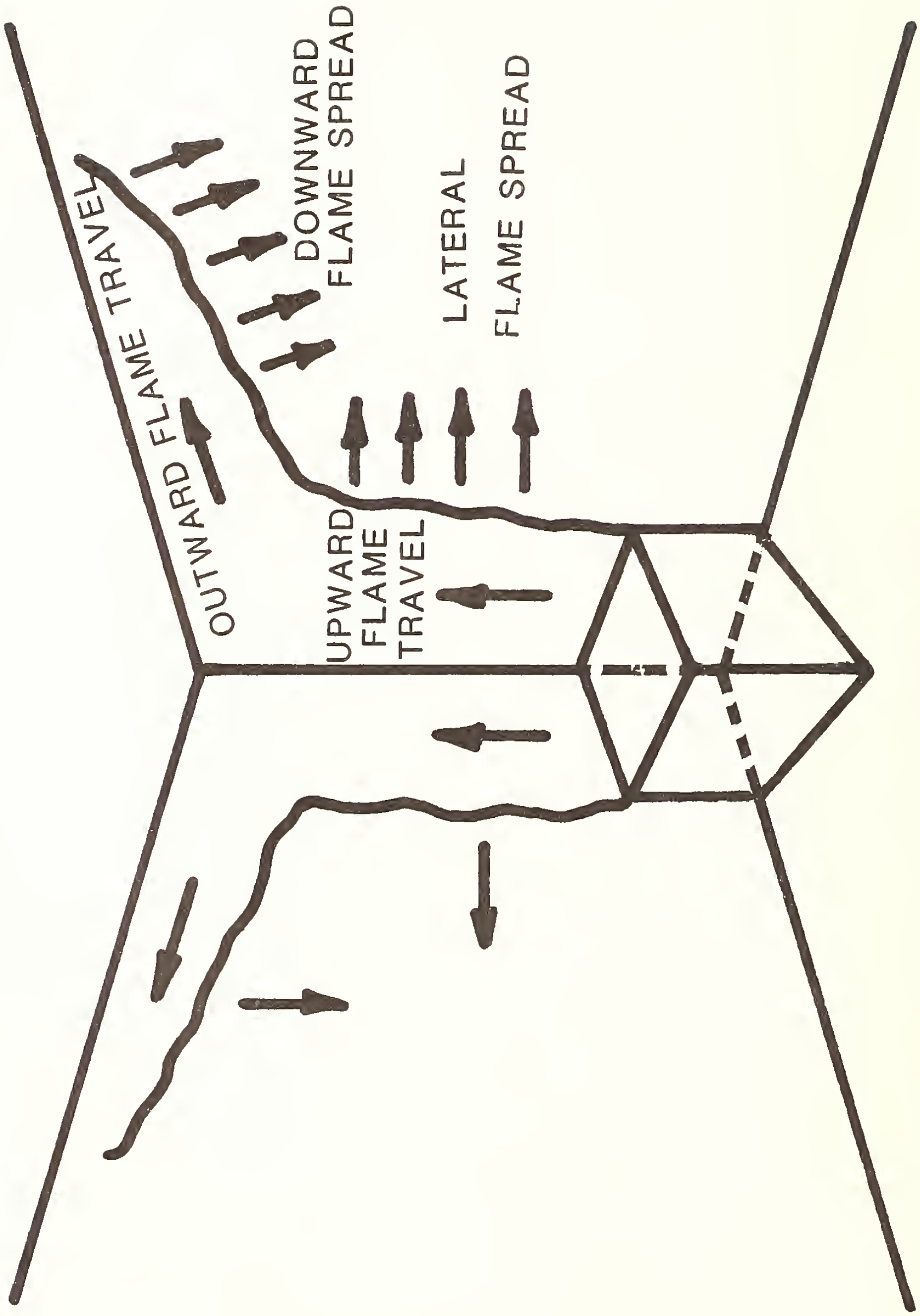


$$\Delta t = t_2 - t_1 = \frac{\dot{q}}{c_p \dot{m}}$$

ILL. 1



ILL. 2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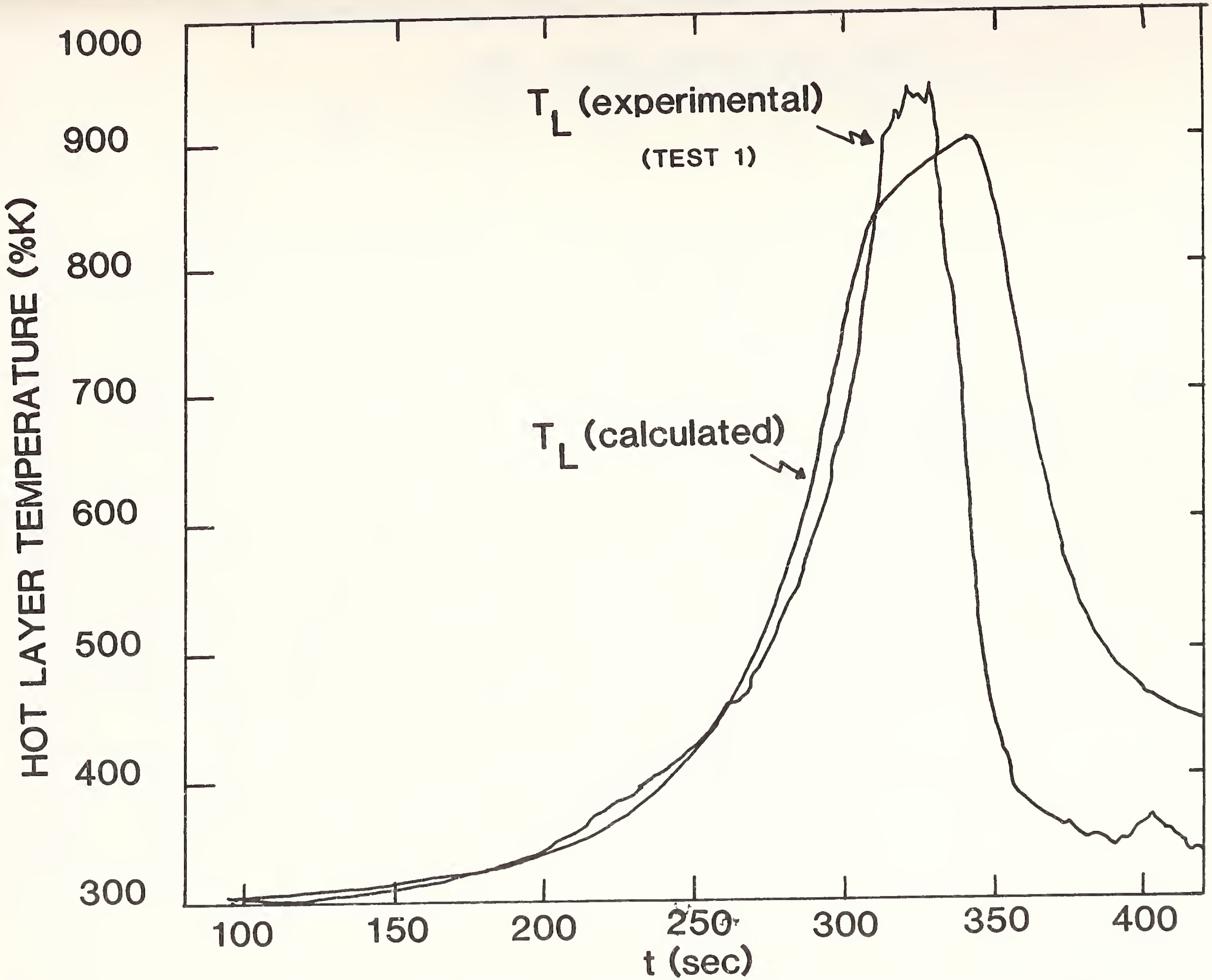
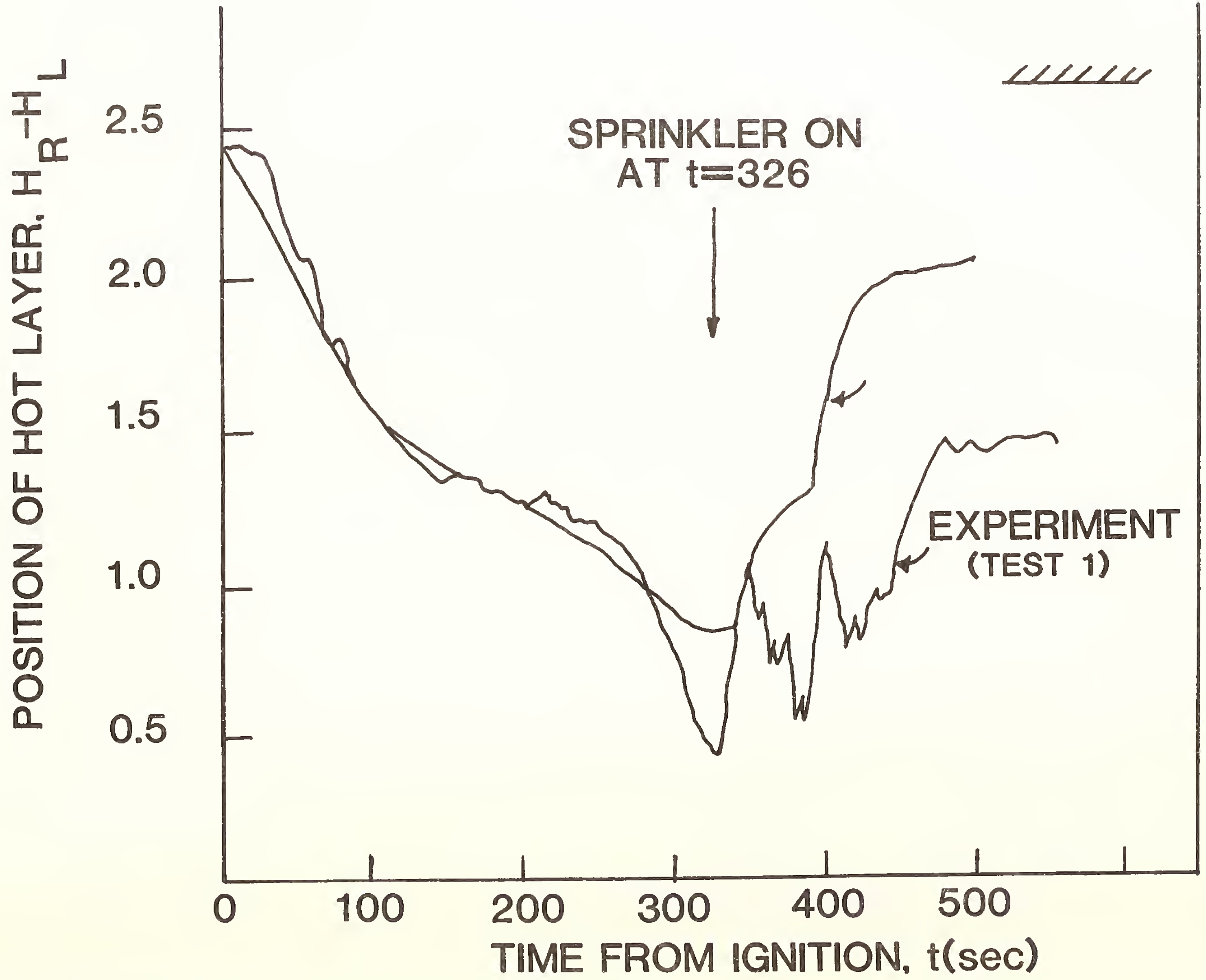
LATERAL
FLAME SPREAD
UPWARD
FLAME
TRAVEL

ILL. 3

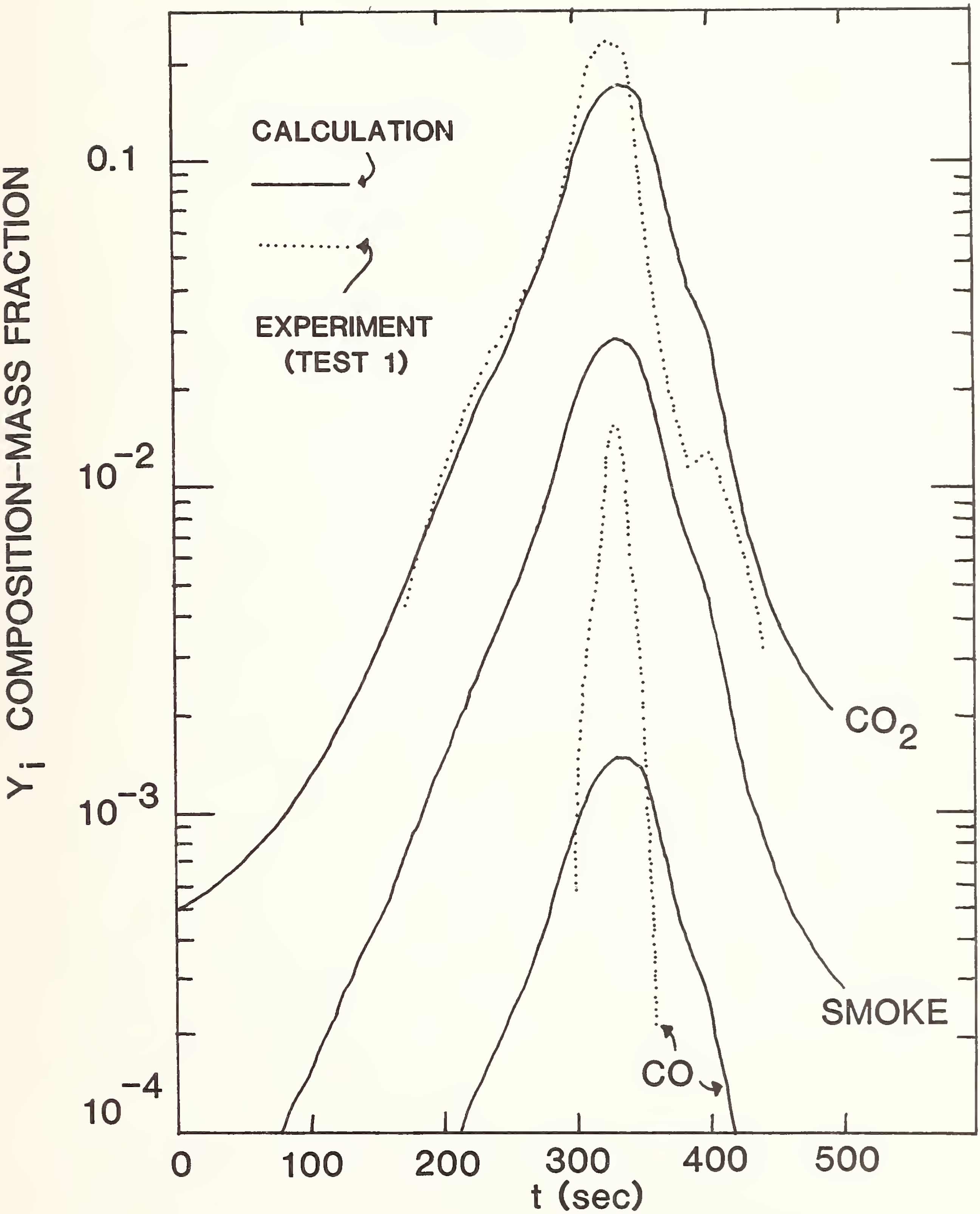


ILL.4 Experimental and Calculated Hot Layer Temperature – Harvard Model



ILL.5

Experimental and Predicted Hot-Layer Depth – Harvard Model



Experimental and Predicted Gas and Particulate Concentrations
Harvard Model

ILL.6

A Second Look at Fire Protection Code Criteria

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Building codes and fire codes have placed a great deal of emphasis on fire safety design criteria. Fire safety criteria in the codes are the accumulation of provisions based upon the role of judgment and gathering of historical and scientific data. And this approach has not been without considerable gain in the prevention of fires and reduction in the loss of life in buildings.

However, there is a problem. Often there is a range of uncertainty that develops when the original meaning of code provisions is lost in antiquity or no longer applies due to the evolution of innovative and creative alternative materials and design approaches. For example, means of egress criteria of the codes control the design, construction and arrangement of building elements required to provide a reasonable safe exodus from all buildings under hazardous situations. Except for rather extensive studies made in the last dozen or so years, the only support and justification for the specification-oriented code requirements related to: travel distance, occupant load factors, capacity of exits, number of exits, etc., can be found in an out-of-print document published by the NBS in 1935.[1] Furthermore, the people movement studies of the 30's may no longer be applicable to buildings in today's world.

Historically, it seems that a notorious fire accompanied with large loss of life and costly property damage usually precedes stringent code requirements and technical changes to our standards. Often this is followed by an overzealous attempt to protect buildings and occupants at the expense of sometimes overbearing and costly code provisions. Usually, these are add-on requirements which tend to make the code top heavy on a particular technical issue. A good example may be found in the evolution of requirements prohibiting certain types of nonmetallic, covered electrical wiring in plenum spaces in new building construction due to the concern of the fire toxicity problem.[2] In some instances this may be purposeful; however, such prohibitions should be tempered with allowances for the compensatory installation of a properly designed and installed fire extinguishing system.

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[1]National Bureau of Standards, Design and Construction of Building Exits, Miscellaneous Publication M151, 1935, NBS, Department of Commerce, Washington, DC.

[2]Toxic Hazard Evaluation of Plenum Cables, Richard W. Bukowski, P.E., Research Head, Smoke Hazard, Center for Fire Research, National Bureau of Standards, July 19, 1984.

Consider the rush in the 70's era by the model codes to establish criteria for smoke control and compartmentation in high-rise buildings. It seems ludicrous to expect undisciplined, transient occupants in a tall building to intuitively react to a fire situation by going to an area of refuge that is neither obvious to them or identified in any way. Smoke control criteria, on the other hand, includes natural and mechanical ventilation techniques. After being installed, these systems may be tested by using a variety of inconsistent techniques ranging from a casual inspection of the equipment to the use of smoke bombs, smoke generators or real smoke. Often this is done mechanically by some preconceived agreed-upon arrangement at the job site.

Occasionally codes incorporate judgmental values that may not necessarily be supported by modern scientific data or empirical evidence. Furthermore, some requirements may evolve around arbitrary and sometimes antiquated empirically-developed standards. Consider, for example, the use of the Standard Time-Temperature Curve introduced in 1918. This curve establishes the average furnace temperature as a function of time for all fire endurance tests. From this, fire resistance ratings are derived and used in all of the modern building codes and fire codes. Even though the fire endurance test has changed somewhat due to the introduction of new systems and assemblies, the test method and standard curve have been essentially the same for well over 60 years. Certainly the test standard should be examined since the construction methods, materials and fuel loads in buildings have changed extensively over the years.

Another concern is the use and application of fire resistance criteria in the codes. Requirements for fire resistance ratings range from one hour to four hours. Generally, lesser ratings are required for envelopment of hazardous areas or separation of dissimilar occupancies; whereas, the higher ratings are required for protection of major structural elements in buildings or for fire walls which may be required between contiguous buildings. This approach has some merit, however, the problem is "inconsistency."

Without current fuel load and occupancy hazard assessments, the requirements for fire resistance ratings will continue to be subjective in nature and not necessarily relate to modern scientifically-based data. Perhaps when accurate data is collected and analyzed, we may see that a more liberal reduction of fire resistance ratings can be given for five department interaction and fire fighting capacity in a community having a qualified fire department; or for sprinkler protection.

Another dichotomy is found in all codes in the application of fire ratings for walls and doors. It is difficult to justify, in the mathematical sense the use of 1-1/2-hour rated fire doors to protect openings in 2-hour rated fire walls. It is equally confusing to the layman that codes permit 1/3-hour fire-rated doors to protect openings in 1-hour fire-rated walls. Should not a simpler system apply to fire resistance ratings so that values are logical and consistent for the professionals who use the codes?

In the past, we have exploited vague and incomplete fire-loss statistics as the basis for justifying code requirements. This approach can be deceptive, inaccurate, and rationalized to support almost any hoped-for conclusion. It is a logical next step to discuss how some codes determine permissible building sizes. Historically, this has been done by categorizing buildings according to occupancy and construction classifications. Depending upon the combustibility of the building and relative occupancy hazard assessment, codes limit the building height and area. There is no uniform approach to the development of height and area tables in any of the model building codes. Unfortunately, some of the work done to explain permissible heights and areas was performed over 30 years ago based upon hazard assessments of occupancy factors extrapolated from old NFPA fire records, with adjustments for construction combustibility. Then through the selection of base numbers and some fudging over the years, height and area tables were developed in some of the codes.

Recognizing the lack of sophisticated fire data of years ago, it is apparent that the entire subject of building construction classifications and building size limitations must be studied to produce more scientifically-based results.

An interesting dilemma in the code application process is the reference to laboratory listed materials, assemblies and systems. Often a statement in a code will infer acceptance by the code official if laboratory "listed" materials are used. Frequently, the laboratory test method, the condition for listing and the end use of the produce are not in harmony. Regardless, some code enforcement officials will inadvertently relinquish their authority to a laboratory in deference to the listing, insofar as their interests are concerned.

Certainly it would be purposeful to reevaluate fire protection code criteria especially where modern scientific data does not exist to support long standing code requirements.

If technical requirements are found in the codes, they should make sense; otherwise, they should be changed or eliminated. This may suggest that a catharsis process be initiated. Historically and scientifically developed criteria should be analyzed to determine if the traditional reasons, rationale, and desired functions are valid and achievable.

The NCSBCS Task Force on Fire Protection was formed to constructively challenge the current state-of-the art of fire protection code requirements. Ultimately it is hoped that the task force will generate enough interest in this area to lead an effort to improve the codes and standard consensus process.

Let's expunge the codes of excessive, overbearing criteria and introduce viable alternative approaches which are innovative, creative, and affordable to produce desired adequate levels of fire safety in building design and construction.

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Non-Evacuation in Compartmented Fire Resistive Buildings Can Save Lives and It Makes Sense

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Compartmented fire resistive buildings are used for hotels, motels, apartments, condominiums, dormitories, hospitals, and other health care facilities. A review of numerous fires in these buildings has shown that:

- unless the fire is in your room or unit, you are safer if you stay in your room or unit rather than evacuate. This review showed that the majority of people who die from fire and smoke in compartmented fire resistive buildings die in the process of evacuation.

- evacuation of the fire floor in these occupancies increases the chance of death dramatically.

- self-closers for corridor doors are an important tool to contain a room fire or control the spread of a corridor fire.

Several fires in compartmented fire resistive buildings were reviewed. Not all of those that were reviewed were used in this study, only those where reasonably accurate conclusions could be drawn as to whether the victims had evacuated or not. These fires are listed in Table 1. The main reference sources were from articles in the National Fire Protection Associations bimonthly publication Fire Journal. The conclusions in some instances may conflict with the referenced article.

On February 10, 1981, at the Las Vegas Hilton, a fire occurred in an elevator lobby on the eighth floor around 8 p.m. The fire spread vertically on the outside of the building involving, in varying degrees, floors eight through twenty eight. Eight people died, five in the process of evacuation and three who were apparently taking an elevator down when it stopped at an involved floor. In the NFPA Fire Journal article it stated "There were no fatalities in rooms where occupants had kept their door closed and waited out the fire or waited to be rescued."[1].

On January 17, 1981, at the Inn on the Park in Toronto, a fire occurred in a second level meeting room around 2 a.m. Smoke spread to the upper levels by way of stairways, elevator shafts, and pipe chases.[2] Six people died, five due to evacuation. Four victims were found in a stairway and one in a corridor. The fire almost claimed twenty more victims in a stairway to the roof, but the people were able to force open a locked door to the roof.

On March 6, 1982, at the Westchase Hilton in Houston, a fire occurred in a guest room on the fourth floor about 2:15 a.m. The door to the room of origin didn't close when the occupants left. Twelve guests, all occupants of the fourth floor died. It was estimated that eight of these people died as a result of their attempts to evacuate.

On July 31, 1979, at about 3:25 a.m., at the Holiday Inn in Cambridge, Ohio, a fire occurred in a corridor connecting two buildings. Fire spread in the building corridors and up the open stairs. There were ten fatalities as a result of this fire. The NFPA Fire Journal article stated: "The NFPA Study at the time of the article was unable to locate any survivors who actually used the corridors for evacuation."[3] All those who died were occupants of rooms on the second floor of this two story building. Seven victims were found in the second floor corridor or in one of the stairs. Two were found in rooms with the doors open. One died four days later, but information on where the victim died was not given. This fire demonstrated the problems of evacuation with a corridor fire and the need for self closing room doors.

Shortly before 9 a.m. on May 23, 1982, at the Conrad Hilton Hotel in Chicago, a fire occurred in a guest room on the twenty-second floor. The door to the room of origin was left open. No self-closers were provided. Two victims were found in a room with an open door and one victim was found in the corridor.[4]

On December 13, 1977, a fire occurred at about 3 a.m. on the fourth floor of a dormitory at Providence College. Ten students died; two when they jumped from their room that was on fire and eight when they attempted to evacuate as the fire spread rapidly in the corridor on Christmas decorations. The corridor and a few rooms on one-half of the fourth floor were involved in the fire. On that half of the fourth floor where room doors remained closed, the rooms were clean and virtually undamaged. The corridor fire here, the worst possible fire for floor evacuation, was survivable in rooms with the doors closed.

On November 30, 1972, at the Baptist Towers Housing for the Elderly in Atlanta, a fire occurred in an apartment on the seventh floor around 2 a.m. The occupant of the unit of origin, upon discovering the fire, left her apartment, leaving the door open.[5] The fire subsequently spread to the corridor. Ten people died, nine on the floor of origin. Of these nine, eight were residents and one was a guard. Three victims were found in the corridor and one in an elevator. Five were found in rooms and four of them were probably in units with open doors.

On July 23, 1971, at the Howard Johnson Hotel in New Orleans, a fire occurred in a guest room on the twelfth floor at about 5 a.m. The fire spread to the corridor after the room of origin's door was forced open by a hotel guard. Six people died on the twelfth floor. Five were guests staying on the fifteenth floor. They used the elevator to evacuate, and they died when the elevator stopped at the twelfth floor. The sixth victim was the guard who attempted to fight the fire.[6] Had these guests not evacuated they would have lived.

On April 5, 1967, in a dormitory at Cornell University, a fire occurred in a basement lounge at approximately 4 a.m. Here, the effectiveness of the enclosed stairs was negated because doors were being wedged open or had been removed for shortening. Nine students died, seven victims were found in the corridors or in the first floor lobby, two were found in rooms with open doors.[7]

On April 14, 1981, at the Westport Central Apartments in Kansas City, MO, a fire occurred in the lobby at around 2 a.m. Two open stairs allowed heat and smoke to spread vertically. Eight people died. There was some question as to where the victims were found during search and overhaul. It is estimated that four died evacuating and four in their apartments.

On March 11, 1981, at the Orrington Hotel in Evanston, IL, a fire occurred in the third floor elevator lobby and corridor at approximately 9 p.m.[8] When the guests called the desk, the alarm was immediately transmitted to the fire department and guests were told to stay in their rooms. None of the eleven guests on the third floor became a victim of evacuation.

On December 8, 1961, at the Hartford Hospital in Hartford, CT about 2:30 p.m. a fire originating in a trash chute burst out of the chute onto the ninth floor. The fire spread in the ninth floor corridor due to combustible interior finish. Sixteen people died; seven patients, five guests, and four employees. Firemen on ladders were unable to reach the ninth floor ". . . but firemen at the top of the ladders gave instructions to people at the ninth floor windows, advising them to keep the doors closed, use wet bed clothing around the doors, and remain calm until they could be rescued. Those who acted on this good advice lived to escape unharmed. Where doors to patients rooms did not stay closed, the occupants perished."[9] The importance of non-evacuation and closed doors is seen here.

On July 11, 1982, at the Milford Plaza Hotel in New York City, a fire occurred in a room on the eighth floor at about 9 p.m. The room door was open, allowing heat, smoke, and fire to enter the corridor. Fortunately no one died in this fire. Afterwards, the New York City Fire Department Manhattan Borough Command critiqued this fire. One of their four conclusions following the critique was, "Occupants of hotel rooms, other than those in the room that is afire should be instructed to remain in their rooms, rather than self-evacuate and chance the atmosphere in the halls and stairways."[10] The New York City Fire Department's Manhattan Borough Command has developed fire safety guidelines for hotels. Their suggested instructions for hotel guests are:

> If the fire is in your room - leave
> If the fire is not in your room - stay

Of the 99 deaths that occurred in these fires, it is estimated that 81 died in the process of evacuation. Also of the 99 deaths, 75 occurred on the fire floor or floors.

The MGM Grand Hotel fire was treated separately because of its size and because it was unique in many respects.[11] Of the 61 that died in the high rise part of the building, 36 apparently died evacuating (they were found in corridors, elevator lobbies, stairs) while 25 were found in rooms. The 24 that died on the first floor were not counted since they were in a non-compartmented assembly occupancy. What shouldn't be overlooked are the thousands that survived the MGM Grand fire in the high rise portion even though total evacuation took about four hours.

The final figures in Exhibit #1 illustrate how deadly evacuation can be, particularly on the fire floor or floors. What is interesting is that most code officials or authorities having jurisdiction ask for evacuation of the fire floor and one or two above and below. Hopefully these figures show how wrong this procedure is.

Based on the above study, the following advantages of the non-evacuation concept in compartmented fire resistive buildings have been developed.

Reason #1 - The chance for survival is better if the fire is not in your room or unit.

There are no guarantees that, should a fire occur in a given fire resistive compartmented building, everyone will survive. But by non-evacuation the occupants chances for survival are much better based on the above study.

Reason #2 - This concept provides for uniform handling of all occupants, handicapped and non-handicapped alike.

This is one of the most powerful reasons for non-evacuation, it allows the problem of the handicapped to be addressed in a logical manner and it provides a uniform approach for all occupants. Since most elevators are returned to the first floor and use of the elevators is not recommended anyway, the handicapped are told to stay put.

Reason #3 - The room or unit offers many features for defense as opposed to the halls, stairs, or other alternatives.

These features are:

- The door between the corridor and the room or unit is an effective deterrent to smoke spread. This had shown to be important in many fires.

- Bedding, towels, etc. are available for sealing openings to retard smoke penetration.

- Running water is available to wet towels or sheets for sealing openings.

- Windows are available for fresh air, if necessary.

- A telephone is available to call the desk, the fire department, or other rooms.

All of these advantages are lost when someone leaves his or her room or unit. A key item to ponder here is that while people have an inherent fear of fire, they don't have an inherent fear of smoke. People often feel they can make it in a smoke filled corridor or stairway.

Problems that can be encountered in evacuation:

- o Flashover in a room with an open door can occur when you are in the hall. This is almost certain death.

- o Seeing and breathing in smoke filled corridors and stairs is very difficult.

- o People can become locked in stairways.

- o Going to the roof is a mistake, since not all stairs lead to the roof. The roof door will likely be locked.

- o It can be a long way down when you don't know where you are going. How many people will have trouble walking down 20 stories?

The evacuation mind set that we presently have, has spawned new approaches to evacuation. These take a variety of forms, such as a cable to lower you down the outside of the building, ladders to go from balcony to balcony, tubes to slide in, etc. Whether these new devices are any safer than the present exits is debatable, but if we can learn to stay put, then it won't be necessary to find out whether they are safer or not.

Reason #4 - Closed doors, either room or exit, retard smoke and fire spread.

In an article titled "The Analysis of a Tragedy" in the May 1983 issue of Fire Technology, Dr. Howard Emmons from the Division of Applied Sciences at Harvard University analyzed the Beverly Hills Supper Club fire and why so many people died in the Cabaret Room. Dr. Emmons presented an educated guess to answer the question. "For some 15 minutes after discovery, little smoke went down a 150 foot corridor from the Zebra Room (room where the fire was discovered) to the Cabaret Room (where the victims died), but then in a few minutes that corridor carried the fire the full length. Why?"[12] His theory is that the smoke and fire moved in that direction after exit doors were opened for guests to leave the Garden Room and the Cabaret Room. He points out, "The fire gases behaved just like the water in a water pipe. So long as the faucet is closed no water flows. As soon as a faucet is opened, water flows out. Thus, no flow occurred in the North-South Corridor as long as the north end doors were closed. However, when the doors were open, the fire gases went down the hall." The open exit doors were the valves that allowed the smoke and fire to spread.

One of the fires that was reviewed was the Pioneer Hotel fire in Tucson, AZ, December 20, 1970. Twenty-eight people died in a fire that started in a corridor shortly after midnight and spread because of combustible interior finish and open stairs. Reasonably complete information on the fire victims was not available from either the NFPA article nor sources in Tucson. Thus, the Pioneer Hotel was not included in the study. However, some very useful information was developed in discussions with Mr. Marshall Smyth, Smyth Consulting Engineering in Tucson. Mr. Smyth had been involved in a part of the Pioneer Hotel fire investigation, specifically that of flame spread on carpeting. This information pertained to Mr. Smyth's observations concerning fire spread in the corridors at the Pioneer Hotel, particularly the dead end corridors. He noticed that there was little fire extension into the dead end corridors with the room doors closed. He also noticed that the fire burned down to and into rooms with open doors. This lack of burning into dead end corridors with closed doors he compared with trying to blow smoke into a bottle full of air; with a bottle full of air very little smoke enters. Mr. Smyth's observations seem to be consistent with Dr. Emmons water pipe idea and his thoughts on the Beverly Hills Supper Club.

How can building and fire officials put this information to practical use in controlling smoke and fire spread particularly in compartmented buildings? They can do this by having people stay in their rooms with the doors closed. This is particularly important on the fire floor to retard fire spread.

Dr. Emmon's water pipe idea is even more interesting when one observes how the exits for compartmented fire resistive buildings are generally designed. Dead end corridors are discouraged as being unsafe. They may be unsafe with the present evacuation mind set, but they are probably safer in the non-evacuation mode. Since the dead end corridors are discouraged, it is usual to have exit stairways at the ends of the corridors. In reality this provides a large chimney at each end of each corridor. With doors to the exit stairs open, particularly on the fire floor, the valve is opened and smoke spreads. There seems to be an impression that by putting an exit sign over the door to the stairway (chimney) that smoke will not enter the stairway. However, smoke still follows the laws of physics and enters the stairway anyway, with or without the doors open. However, the open stairway door accelerates the smoke spread via the stairs. The non-evacuation technique would keep these doors closed as much as possible.

Reason #5 - Closed room and exit doors, allow smoke control systems to work properly.

Stairway pressurization systems as an example, are designed to keep a stairway smoke free with the door to the fire floor and a limited number of other doors open. When too many doors are opened, the stairway is no longer pressurized. If the pressurized stairway in a 40 story building is designed to have the door to the fire floor and three others opened, who decides which doors can or cannot be opened? The simple solution is non-evacuation. Leave the pressurized stairwells to the fire department. They have self-contained breathing apparatus. If they open too many doors, the smoky stairwell won't bother them.

Reason #6 - This concept provides for uniform reaction by occupants whether they receive early or late notification.

When occupants become aware of a fire is when they become aware. At that point their fire clock starts. However, they have no idea when the fire's clock started. When their fire clock starts they are never going to have less information than they do then. They don't know where the fire is, whether it is just starting, approaching flashover, or has burned out. They should be prepared to defend in place. Many people place a great deal of reliance on early notification by sophisticated alarm systems. Will the alarm systems work when they are needed? Did they in fact ever work? This is a critical point not only for the building occupant but also for the building and fire official.

John Sharry, Fire Chief at Lawrence Livermore Laboratory, former chief consultant for the NFPA's Life Safety Code wrote an article entitled, "Real World Problems with Zoned Evacuation." John said,

> ". . . Of the estimated 400 systems personally tested by the author over the past 12 years, none operated properly the first or even the second time, even though in most cases the systems had been "pretested" by the contractor."[13]

Mr. Sharry's experience points out the need for building and fire officials to insist on exhaustive testing of alarm and communication systems when they are installed and on a periodic basis, so that building occupants can receive notification to defend in place as soon as possible.

Reason #7 - This concept provides for uniform reaction to an accidental or incendiary fire.

Is the cause of a fire important when a building occupant learns of a fire? Probably not, but many people have said that if there is an accidental fire and they have a chance to get out, they are going to leave. How will they know it is accidental? They won't. What they should be aware of is that if there is a life threatening fire in one of these occupancies, the chances are good that the fire is incendiary. The losses examined show that to be true. This means the fire will likely start fast and grow to the limits of its container very quickly. That fire growth can be controlled with closed doors, and the fire deaths reduced with non-evacuation.

Reason #8 - This concept eliminates occupant reliance on inaccurate or incorrect information from building personnel.

When a building occupant calls the desk or manager to report a fire, should they expect to get accurate information? If there is a fire, the switchboard is probably lit up like a Christmas tree. Confusion and stress is what will be happening. How can the operator possibly know what is happening and how bad it is. For example, at the Westchase Hilton fire, the first alarm, both automatic smoke detection and guest calling, came from the eighth floor. The fire was on the fourth floor.

Reason #9 - This concept is in harmony with the accepted fact that in high-rise buildings, total evacuation is impractical.

In the past a distinction has been made between a high-rise building and a low-rise building. The high-rise building is generally one where:

1. There are floors beyond the reach of fire department aerial equipment. This means that evacuation and fire fighting on the upper floors has to be done internally.

2. There is a potential for significant stack effect.

3. Evacuation is impractical. This is due to the physical problems of a walk down many flights of stairs and that of exit stair crowding since exit capacity is designed to handle a single floor. In exit design, if the occupancy of individual floors is equal or similar, you can have a two story, twenty-two story, or sixty-two story building, each with identical exit stairs.

Because of these limitations on evacuation due to building height, when a fire occurs, total evacuation is impractical and non-evacuation makes practical sense. For example, it took four hours to totally evacuate the MGM Grand Hotel.

Reason #10 - This concept provides a uniform approach to low and high-rise buildings.

All high-rise buildings are also low-rise buildings. Since non-evacuation makes sense in high-rise buildings, it also makes sense in low-rise compartmented fire resistive buildings. The validity of this reasoning was demonstrated in the fires reviewed. The Holiday Inn, Providence College, and the Cornell University fires were in low-rise buildings. Similar results are seen when comparison can be made between high-rise and low-rise buildings. The Westchase Hilton was 13 stories, the Providence College dorm was 4 stories. Each had a fire on the fourth floor, each had 8 people die attempting to evacuate.

Reason #11 - This concept eliminates questions about the fire department's response and manning.

What is the fire department's manning? How long will it take them to respond? Have they preplanned for a fire in this building? Will the weather be a factor? How high will the fire departments aerial equipment reach?

None of these items is a concern when the non-evacuation approach is taken. Non-evacuation can help the fire department by leaving the exit stairs available for their use. Also, if the fire department can direct their initial efforts to fire fighting, the smoke and heat generator can be stopped sooner.

One volunteer fire department has found this approach make a lot of sense in a six story fire resistive building specifically for the elderly. This fire department likes this approach due to staff shortages they experience in the daytime.

Reason #12 - This concept provides for greater employee safety by not having employees respond to evacuate occupants or fight the fire.

Often hotels, apartments or other similar buildings will have their employees respond to the suspected fire floor to do a variety of jobs. These response plans are often drafted in conjunction with or at the direction of the local authority having jurisdiction.

Some of the activities that an employee may be expected to do are:

- o Assist occupants to safety, with special attention to aged, infirm, or otherwise incapacitated persons.

- o Search rooms to be sure all occupants have escaped.

- o Extinguish or control the fire, using available first aid equipment.

One assumption that seems to underlie these items is that the fire will be small and non-threatening. Another is that employees can do all of the above without self-contained breathing apparatus since maintenance of and training in the use of self-contained breathing apparatus is not something that hotels or apartments should be doing. Having employees do these things is not realistic, particularly with the high chance of incendiary fires. The chance for employee injury is substantial and unnecessary. Non-evacuation addresses this problem very nicely.

Reason #13 - This concept handles the problem of a limited night staff.

All of the above problems are compounded by limited staffing on the evening and night shifts. If we assume a residential occupancy has three shifts a day with the following hours:

Day shift	- 8 a.m. - 4 p.m.
Evening shift	- 4 p.m. - midnight
Night shift	- Midnight - 8 a.m.

The 14 losses that were examined occurred as follows:

Day shift	2	14.3%
Evening shift	3	21.4%
Night shift	9	64.3%
	14	100.0%

As can be seen the greatest chance for a multiple death fire in these occupancies occurs when the most problems exist for the limited staff. Some of these problems are:

- o Guests are asleep with their security locks locked. The pass key won't work.
- o There will probably be only 1 to 3 staff people available. Do they use the buddy system or go alone on the search and rescue mission? Someone has to stay at the desk to answer phones, etc.
- o With no breathing apparatus, they are expected to go to the fire floor where the greatest chance of being killed is, and basically put their life on the line to evacuate guests who are already safe in their rooms. Also someone has to stay at the desk to answer phones, etc.

The non-evacuation concept provides an easy solution to these problems.

Reason #14 - This concept provides a uniform response to new and existing compartmented fire resistive buildings.

Does the building you are staying in, living in, or reviewing for code compliance comply with the latest codes? How old is it? These are questions that can't be answered by occupants just by looking around. Also, building code and fire officials cannot always get improvements made because of retroactive features of some codes. However, when the non-evacuation approach is considered the differences because of age become less significant and new solutions to problems become available.

Reason #15 - This concept provides a uniform approach in sprinklered and nonsprinklered buildings.

Buildings with automatic sprinkler systems have an unblemished record as far as life safety is concerned. Non-evacuation fits like a glove. Non-evacuation in nonsprinklered buildings makes sense for all the other reasons mentioned.

Reason #16 - This concept should reduce false alarms necessitating building evacuation.

Compartmented fire resistive buildings such as college dormitories can experience many prank alarms just "to see everyone get out in the cold at 3 A.M." The nonevacuation concept should reduce or eliminate these kinds of false alarms.

Reason #17 - It's simple.

In fire resistive compartmented buildings a lot of money has been spent making them fire resistive. These buildings have been divided into tens, hundreds, or sometimes thousands of compartments, the overall fire load has been divided into many smaller fire loads. Many barriers have been put in to limit the spread of fire and smoke. With all that has been done, it doesn't make sense to eliminate these advantages by telling people to evacuate. The present evacuation mind set is probably a hold over from the combustible hotel buildings of many years ago and from fire drill training in grade school. The construction of these buildings has changed but the evacuation approach hasn't.

In looking at some recent fires in combustible buildings, the same non-evacuation approach may be the way to go here also. In the Dorothy Mae fire in Los Angeles, another corridor fire, the Los Angeles Fire Department seemed quite positive in saying that if the 24 people that died"... had stayed in their rooms, they'd still be alive."[14]

TIPS ON APPLYING THE NON-EVACUATION CONCEPT

One question that needs consideration is how can the non fire oriented public tell the difference between a fire resistive and a combustible building? This is not a difficult problem. Walk on the floor. Listen to the sound and the feel of the floor. A concrete floor will be firm, and a wood joist floor will be springy. The sound will be different and it shouldn't be hard to teach the general public how to tell the difference.

Being mentally prepared to defend in place is important since precious time is not spent wondering what to do. An excellent idea in restricting smoke spread into a room or unit is to use duct tape to seal openings. Duct tape can be torn easily, is readily available and it can be packed as a regular travel item like a toilet kit.

If you are in a compartmented fire resistive building when a fire occurs, check the hallway for smoke by using a security peephole, don't open the door. If there is no smoke, stay alert, stay put and keep checking. If there is smoke in the corridor, seal the air gap around the corridor door and other openings as necessary with duct tape, wet towels, or wet sheets. Stay put, stay alert, and wait for direction from the Fire Department. After the fire, tell the Fire Investigators what you did to survive. It is important that code writers be made aware of how people survive as well as how they die.

IN SUMMARY, LESSONS LEARNED

Although no warranties or guarantees can be made that, should a fire occur in a compartmented fire resistive building, there will be no injury or loss of life, the studies and statistics related here support these conclusions:

1. In a fire resistive compartmented building, unless the fire is in your unit, you are safer if you stay in your unit rather than evacuate.

2. Evacuation of the fire floor increases the chances of deaths dramatically.

3. Self-closers for corridor doors are an important tool to help contain a room fire or control the spread of a corridor fire.

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Table 1

COMPARTMENTED FIRE RESISTIVE BUILDING FIRE DEATHS
COMPILED BY
TRAVELERS INSURANCE CO. ENGINEERING DIVISION
FIRE PROTECTION UNIT

		TOTAL DEATHS	DEATHS ON THE FIRE FLOOR	APPARENT DECISION OF VICTIMS	
				EVACUATE	NON-EVACUATE
1.	Las Vegas Hilton Las Vegas, NV	8	8+	5(3)	-
2.	Inn On The Park Toronto, ONT	6	-	5	1
3.	Westchase Hilton Houston, TX	12	12	8	4
4.	Holiday Inn Cambridge, OH	10	10+	10	-
5.	Conrad Hilton Chicago, IL	4	4	4	-
6.	Providence College Providence, RI	10	10	8(2)	-
7.	Baptist Towers Atlanta, GA	10	9*	7	2
8.	Howard Johnson New Orleans, LA	6	6*	5	-
9.	Cornell University Ithica, NY	9	-	9	-
10.	Westport Central Apt Kansas City, MO	8	-	3-5	5-3
11.	Orrington Hotel Evanston, IL	-	-	-	-
12.	Hartford Hospital Hartford, CT	16	16	16	-
13.	Milford Plaza New York, NY	-	-	-	-
	TOTAL	99	75	81	11
14.	MGM Grand Las Vegas, NV	61 Highrise (24 1st Floor)		36	25
		160	75	117	36

+ Multiple floor fire * Guard death

4/18/84

Telephone Connected Early Warning and Communication System

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Totel Systems Inc.
Stratford, CT

ABSTRACT

This paper describes a new development in telephone engineering that provides two vital fire fighting functions - annunciation of smoke detectors by individual location, and one way voice communication to remote sections of buildings by zone or all-call using existing standard telephone equipment.

This development creates an opportunity for advanced fire systems features to be put in place quickly and at low cost since most structures already have complete telephone system wiring and standard station line telephones throughout the building.

THE PROBLEM

The fire sensing and warning problem we set out to solve is typified by an urban high rise hotel structure. The building is in place, structurally sound, difficult to rewire, and filled with combustible materials and human occupants in small somewhat soundproofed rooms. The rooms are often left vacant usually treated with a casual attitude.

The problem is compounded by several typical fire hazards: many people, many smokers, complicated electrical wiring, arsonists, poor security control, fast burning furnishings, air systems that may spread smoke, high rise evacuation concerns, panic possibilities, and increasing legal liabilities.

There are 11,500 fires reported in hotels each year according to the AHMA Fire Safety Commission and NFPA. Some of them have been major disasters with significant loss of life. Smoke detectors have been legislated in hotel rooms in most places. Sprinkler systems are being forced in new construction. In spite of this, few codes require that room smoke detectors be annunciated. Vacant rooms are often fire problems - 40% of hotel fires are smoldering cigarette ignitions - often after a guest leaves. 20% are arson - 15% are electrical.

Voice communication for evacuation and or emergency information is also left to the hotel discretion in some cities.

The guests in the MGM Grand fire reported that the worst problem for them as individuals, was not knowing what to do and not having any information. Even so, few cities require actual voice systems in guest rooms.

The BOCA code requiring "audible voice communication" throughout the building is interpreted in some cases to require a speaker or other means to advise room occupants of emergency situations. In other cases, hallway speakers are deemed adequate.

THE DEVELOPMENT

Recognizing that the telephone system in a hotel is:

A. already in place
B. maintained well year after year
C. standard in its electrical characteristics, and
D. individually wired and identified at a central point

My company, Totel Systems Inc., primarily Steven Churchill, inventor, assembled and developed the electrical components capable of these two functions as well as several enhancements, in a system known as the Versatel III.

The system has three major parts:

A. Circuit card or telephone line card for connection to the standard telephone "Tip and Ring" wire of each telephone (located in the PBX equipment room with associated power supplies, etc.).

B. A "sender" device for connection to the room smoke detector's auxiliary relay contacts and located in the room telephone terminal.

C. A communication center providing manual activation of phones by zone or all call, display of detector activation by room #, live voice microphone, and display of answered calls.

The sender is a small circuit mounted in the telephone terminal in the guest room. The circuit is installed on the terminals of the standard telephone wire in the room. The telephone wires are replaced on the original terminals. The telephone is not affected in anyway by the existence of this circuit which produces a very low level loop current operating on 10-15% of normal loop current. The auxiliary contacts (normally open) of any smoke detector are wired to the same telphone terminals.

The sender circuit can, in some cases, provide a supervisory signal so that the complete circuit including the smoke detector's (normally closed) trouble relay can be connected to a second set of terminals. In this case, the circuit provides a constant signal of "ok" condition.

When the smoke detector is in the "alarm" mode, the sender provides a higher level of loop current on the telephone wires.

In the telephone equipment room, a receiver circuit and a voice interrupt circuit card is connected across each telephone pair.

This circuit can sense the "ok" and the "alarm" loop current condition. It is also relay connected so that the hotel management or fire fighting personnel (or an automated system) can remove the telephone sets from normal use and immediately ring them in large number; usually by floor or zone, or even all at once.

The same circuit card permits the one way voice message either recorded or live, to be put on to all telephone lines in the zone.

Finally, latching relays on the circuit card await the "off hook" and later "on hook" switch signal from the room phone to indicate completion of the call and return that phone to normal use.

PRESENT STATUS OF THE DEVELOPMENT

The circuits of the Versatel III are fully developed and in regular use in many locations.

The one way voice system has been available for several years and Totel has installed 60 systems. Others are also making some equipment of this type.

The sender circuit and the combination of detector annunication and voice communication was introduced in 1983. There are several systems in place and there are others making telephone connected smoke detector systems.

No one else is making a combined system with all of the features explained in this paper.

Some examples of present use include:

The Hyatt Regency, Dallas, Texas: 980 rooms with specially designed security center. The emergency communication system is provided with a custom made display showing all wings or sections of the hotel in color coded zones. The Sheraton Bal Harbour, Florida: 680 rooms with voice communication and smoke detection communication in a test location in Florida.

INSTALLATION AND USE

The Verastel III is installed in the telephone equipment room. Room senders are installed in the telephone terminal in the room. No extra wiring is needed between the equipment room and the guest room. Installation, therefore, can be made without closing the hotel, drilling through walls and floors, or redecorating the hallways.

The Command Center is located in the telphone operator's center or security center. Wiring from the PBX room is required to the command center for these functions - display, activation, and voice communication.

Typical use of the system is as follows:

When a smoke detector goes into alarm, a signal is initiated from the room. The signal is picked up and indicated by audible signal and blinking visual light indicating the room number.

The telephone operator or security officer calls the room or sends a security officer to the room if necessary.

The fire fighting people may elect to advise guest of the situation. If so, the push buttons marked by zones or floor are activated. The telphones in the zone are immediately rung if on hook. Existing calls are "lost" and outsiders are disconnected.

The recorded voice message is immediately played to all phones in a one way message. If a live message is desired, the microphone switch turns off the recording and enables a live message.

The zone that is activated is displayed by red lights for each phone and a room number of each phone. As telephones are lifted and, if replaced after the message is heard in a normal manner, the light is extinguished indicating a completed call.

Unanswered calls or incomplete wiring results in continuation of the illuminated light.

FEATURES

Using existing wiring and existing standard station line telephones, the Versatel III:

A. signals smoke detector alarms by individual location
B. supervises the circuit and power to the detector
C. provides push button or automatic intercept of large numbers of telephones
D. rings phones as part of alarm signal
E. interupts existing telephone calls

F. provides a recorded one way emergency voice message to the intercepted phones (usually by floor or zone)
G. provides the possibility of an override live voice for additional detailed message
H. supervises outgoing calls and displays answered/unanswered calls by line/number
I. returns each telephone to normal use as soon as it is hung up.

FUTURE

As this system becomes more widely accepted and understood, fire codes will adopt a more rigorous requirement in both areas - detector annunciation and voice communication. These fire safety areas have been taking a "back seat" to sprinkler systems but are more and more recognized as needs for people oriented operations such as hotels. The sprinklers surely save property and can save lives by holding down the spreading of a fire, but, if smoke detectors report by number on each smoldering fire, it will be possible to avoid the flame at all and the attendant fire alarm and sprinkler activation.

Voice evacuation and communication systems are needed to avoid panic, help people to help themselves, and evacuate in an orderly manner if required.

The use of telephone wiring will expand. The telephone wiring is an existing "computer network" that will be put to use now without awaiting fiber optic or other LAN developments.

Totel's computer (now used for automatic wake up and other features) will be linked to the present electromechanical relay operated system thereby providing memory and printed reports of safety events; time and location, calling activity, etc. The computer will then also enable a cross reference for room occupancy, important since an unanwered call may be due to an injured or handicapped party in a certain room. This must be distinguished from a vacant room.

The computer version of the product may then lead to a "smart" hotel room telephone with features like: energy control, maid status, message waiting, telephone director, and many more.

CLOSING REMARKS

James G. Gross

We have had a most interesting and informative day. I have a number of impressions I would like to share and discuss with you but, due to the lateness of the hour and fullness of the day, I'll keep my remarks short.

However, I would like to mention a couple of observations that really hit home. Although we had three subjects that we were going to deal with, it turned out that computers and their application were an important part of almost all of the presentations. This certainly tells us how important is the subject of computers and automation in construction. From the questions and interest raised by the audience related to fire protection engineering, as well as the promise suggested by two papers that dealt with modeling and understanding fire development and smoke promulgation, it suggests that we will see the day in the near future when the science of fire protection engineering will approach that of structural engineering, where we can well predict the performance of structures under given loads and, indeed, the loads imposed by man and nature are well characterized.

I've learned a lot today. Each paper had a few jewels of information in it for me. I want to thank the speakers for being with us and presenting their views. I also want to thank the audience who participated actively in the discussion to provide additional insight into the subjects at hand.

We will publish the proceedings as soon as we can. Most of the papers are in hand; and with the help of the rest of the authors, we hope to have all of them soon. The proceedings will be mailed to everybody registered for the conference. This publication also will be made available to others interested in building technology and the regulatory process.

I want to thank our moderators, Rick Howell and Art Cote, for the excellent job of keeping us on schedule and controlling the high quality discussion. I want to thank the Economic Development and Technical Innovations Committee of the National Governors Association, which provided support for this meeting by publicizing this conference, and the National Fire Protection Association for their active support. I want to thank the National Conference of States on Building Codes and Standards, its President, Dick Wolfe, and Bob Wible, Executive Director, for the opportunity to work together in the development and presentation of this conference.

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- Automation of the Building Code Compliance
- Microcomputer Design Tool to Aid Construction Professionals to Comply with the Florida Model Energy Efficiency Code
- Automated Checking of Simply-Supported Prismatic Reinforced Concrete Beams for Compliance With Code Requirements
- Emerging Engineering Methods Applied to Regulatory Fire Safety Needs
- Survey of the State of the Art of Mathematical Fire Modeling
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- Non-Evacuation in Compartmented Fire Resistive Buildings Can Save Lives and It Makes Sense
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