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Background to the Development Process Automated Residential Energy Standard (ARES)

In Support of Proposed Interim Energy Conservation Voluntary Performance Standards for New Non-Federal Residential Buildings

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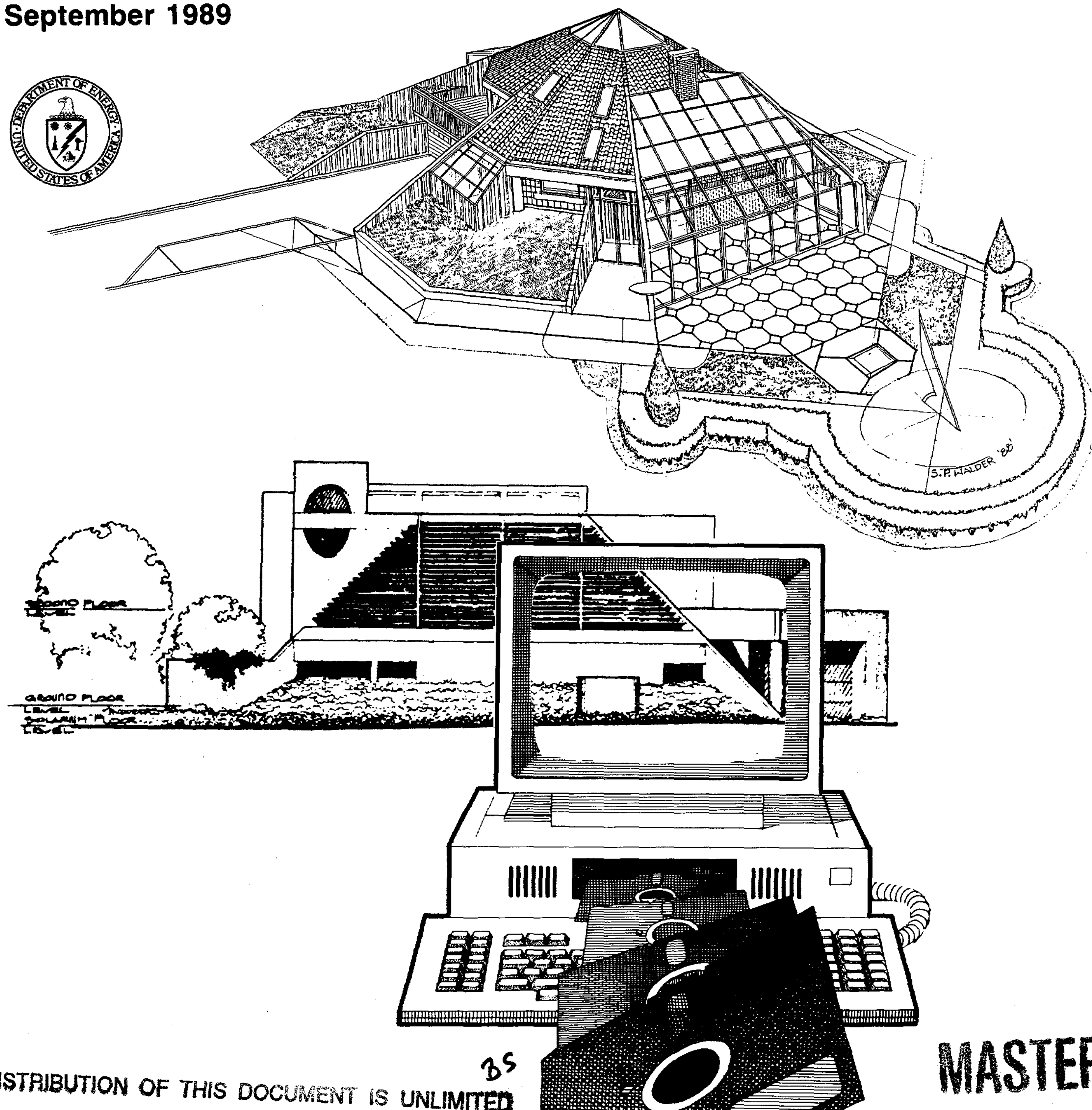

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David Conover of the National Conference of States on Building Codes and Standards provided invaluble expertise and insight throughout the development process. Joe Huang of Lawrence Berkeley Laboratory conducted the numerous computer simulations that form the basis for the energy analyses in the standard.

Michael R. Brambley and, previously, Raymond Reilly and Allen Lee served as project manager for the Voluntary Residential Standards Project at Pacific Northwest Laboratory (PNL). Victor Lortz wrote the software which embodies the proposed Standard and was primary author of the accompanying User's Guide. Z. Todd Taylor provided overall guidance and technical support for the analysis of the standard and assisted in preparation of the software User's Guide.

The software for this proposed voluntary standard has been used by the U.S. Department of Housing and Urban Development (HUD) in developing proposed new HUD mandatory standards for new manufactured housing. HUD funded work at PNL that was used jointly in HUD's new standard and in updates to the proposed DOE Voluntary Residential Standard.

PREFACE

The Energy Conservation for New Buildings Act of 1976, as amended, 42 U.S.C Section 6831 et. seq. requires the U.S. Department of Energy (DOE) to issue energy conservation standards for the design of new residential and commercial buildings. The standards will be mandatory only for the design of new federal buildings and will serve as voluntary guidelines for the design of new non-federal buildings.

The original recommendations for the non-federal residential standards were produced by the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE) Special Projects Committee No. 53 under contract to Pacific Northwest Laboratory (PNL). Those recommendations were published in four volumes entitled Recommendations for Energy Conservation Standards for New Residential Buildings. DOE modified the original recommendations to accommodate an optional, more flexible economic analysis procedure. DOE also directed PNL to produce additional technical documentation for the software that embodies the standards and to assess the economic and environmental effects of the standards.

The final standards are documented in six publications in support of the Proposed Interim Energy Conservation Voluntary Performance Standards for New Non-Federal Residential Buildings:

- ARES 1.2 User's Guide (Automated Residential Energy Standard) - Explains the use of the ARES program to develop location-specific energy conservation requirements.
- Technical Support Documentation for the Automated Residential Energy Standard (ARES) - Explains the data and algorithms used by the ARES program to optimize energy-related features of new residences.
- Background to the Development Process for the Automated Residential Energy Standard (ARES) - Explains the background and philosophy of the standard development process.
- Technical Support Documentation for the Automated Residential Energy Standard (ARES) Data Base - Documents the assumptions and procedures used to develop the residential energy consumption data base in ARES.
- Description of the Testing Process for the Automated Residential Energy Standard (ARES) - Describes the process used by the development committee to initially test the ARES computer program.
- Economic Analysis - Describes an assessment of the likely impacts of the new standards on the nation's economy.
- Environmental Assessment - Describes an assessment of the likely impacts of the new standards on new home habitability, on institutions associated with residential construction, and on the economy in general.

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1.0 INTRODUCTION

Congress has required the U.S. Department of Energy to develop, test, and issue energy conservation standards for the design of new residential and commercial buildings. The standards will be mandatory only for the design of new federal buildings. The standards will be voluntary for non-federal buildings and will be published as guidelines for use within the private sector.

This report documents the development and testing of a set of recommendations generated to serve as a primary basis for the Congressionally-mandated residential standard. This report treats only the residential building recommendations. Recommendations for commercial building standards have been developed under separate projects, and are reported in other DOE publications (DOE/NBB-0051/2 et. al.). This report (issued in four volumes), was prepared by the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE), Special Project Committee 53 (SP-53), and documents the technical recommendations for the new standard. The recommendations were prepared under contract to Pacific Northwest Laboratory (PNL). The recommendations are based, in part, on the results of research tasks conducted expressly for this effort by other contractors to PNL. Where appropriate, the work of these contractors is referenced in these documents. The recommendations for a new residential energy standard were designed to complement the format of the ASHRAE 90 series of energy standards. It is intended that these recommendations be submitted to ASHRAE to serve as one input to its periodic upgrading of its energy standard. ASHRAE will conduct its own independent development, review, and consensus acceptance process before issuing a revised residential standard. This volume of the report (Volume III) documents the development processes that resulted in the recommendations and includes: the project background, objectives and scope, the organizational structure through which the project objectives were pursued and the team selected, and the technical process leading to the generation of the recommendations.

1.1 BACKGROUND

ASHRAE Standard 90-75, "Energy Conservation in New Building Design" was published over ten years ago. The initial impetus to write an energy conservation standard was a joint effort of the National Conference of States on Building Codes and Standards (NCSBCS) and the National Bureau of Standards (NBS) in 1973, which resulted in the NBS document "Design and Evaluation Criteria for Energy Conservation in New Buildings." In February 1974 ASHRAE accepted the responsibility of writing a national voluntary consensus standard based on the NBS document. As a result, ASHRAE Standard 90-75 was approved by the ASHRAE Board of Directors in August 1975. Since that time, several energy-related activities have been undertaken jointly by ASHRAE and the federal government which have resulted in significant advances in energy conservation technology and standards development. Standard 90 was revised and published in May 1980 as ANSI/ASHRAE/IES Standard 90A-1980. It contained revised Sections 1 through 9 of Standard 90-75, with work continuing to revise Sections 10 and 11 (designated 90B) and Section 12 (90C).

ASHRAE Special Project Committee 41 (SP-41), utilizing a Technical Evaluation Committee, was formed in 1982 to assist the U.S. Department of Energy (DOE) in developing an energy conservation standard for commercial buildings as mandated by Congress, and for a revision of Standard 90A-1980 for commercial buildings. In the meantime, the ASHRAE Standards Committee moved to split Standard 90 into two parts - 90.2 (residential) and 90.1 (non-residential). The recommendations of SP-41 were presented to Standards Project Committee (SPC) 90A-1980/1975R in December 1983 for consideration and possible inclusion in the revised standard. The SPC for energy conservation in residential buildings, SPC 90.2P, was approved for formation by the Standards Committee in January 1984 and held its first meeting in June 1984. In the fall of 1984, ASHRAE was requested by PNL to submit a proposal to form a Technical Evaluation Committee (TEC) to provide recommendations for a voluntary residential energy standard for DOE as mandated by Congress. Where appropriate, this TEC would also assist in the update of ASHRAE 90.2P for residential structures. The contract for this work was finalized on April 1, 1985, and the project was designated as SP-53 by ASHRAE.

1.2 JUSTIFICATION FOR UPGRADING THE RESIDENTIAL ENERGY STANDARDS

Numerous factors justify the development of new residential energy standards. Improvements in energy technology, analysis tools, and the understanding of building energy consumption characteristics offer opportunities for improving existing standards. The increasing capability to integrate economics into energy conservation design provides a sound basis for a new standard. And, the need for flexibility and ease of use at the codification and user levels influence the design of a new standard. The research described herein drew on these advances providing the foundation for a standard that is responsive to new technology and state-of-the-art procedures. In particular, the following is a list of the major features, characteristic of either the current or anticipated environment in standards technology, that were considered in this project:

The new standard should provide for multiple compliance paths. With multiple paths, the end user selects from a number of procedures that range from those that are simple and relatively inflexible (highly prescriptive) to those that provide a significant degree of design latitude but entail a more sophisticated set of user operations (highly performance oriented.)

The requirements of the standard should be dictated by economics. That is, the process for arriving at the requirements of the standard should be carefully delineated and embody an explicit economic analysis procedure to provide cost-effective levels of energy conservation.

The standard should be generated using state-of-the-art procedures in energy use analysis. The energy analysis procedure selected to support standards development should be based both on its ability to accurately model residential energy use patterns, and the range of building design conditions that can be simulated by the procedure.

The standard should be designed to expedite and simplify the codification process. A simplified process is required for acceptance by both code agencies and end users. In particular, the following phases of standard codification were considered in the design of the work to be conducted under this plan:

- the implementation process (the process a code agency must go through to convert a standard to code),
- the compliance process (the process end users follow to demonstrate compliance with the code), and,
- the compliance check process (the process the local code agency follows in checking for compliance.)

The standard should encourage a wide range of energy conservation measures. For example, energy measures such as innovative glazing should be encouraged by making explicit the procedures for receiving credits for the use of such a measure.

The standard should be comprehensive in its coverage. To the extent practicable, the standard should be designed to address equitably the wide range of common residential unit types, such as site-built single family and multi-family homes and manufactured homes, common construction materials, including light frame and heavy mass materials, and the major foundation types such as basements, crawl spaces and slabs.

The precise requirements of the standard must be capable of utilizing local information. The standard should provide a set of procedures with some data (typically energy data) provided. The exact energy requirements of the code resulting from the standard should be determined using appropriate local data (typically cost data) provided by the codifying agency.

The standard should accommodate new technologies without major structural revisions. Such a standard could be modified to allow the end users to gain credit for new methods of saving energy. Updating the standard should not require the existing procedures to be modified. Rather, the references to new materials and methods would be added as modules to the then current standard.

The standard should contain equipment sizing requirements. Such a capability should be provided in recognition of the important role equipment sizing plays in end use energy consumption.

1.3 OBJECTIVES

This project was designed to develop and analyze recommendations for an energy conservation standard for new residential buildings. The recommendations are intended to be used as the basis for DOE's voluntary energy conservation standards mandated by Congress, and may be used by ASHRAE as the basis for updating Standard 90. The work conducted under this project was based upon the following initial set of objectives:

- the standard resulting from this work should contain a number of alternate paths to demonstrate compliance;
- the energy requirements generated by applying the standard developed from this work should be economics based. That is, they should be derived from cost-benefit criteria;
- the work should utilize explicit and technically defensible energy data and a cost-benefit procedure authored or selected by the Technical Evaluation Committee (SP-53);
- a code agency adopting the standard developed from this work should have the option of establishing the energy requirements by inserting appropriate local cost data. The other information necessary to establish the compliance requirements, and the procedures to demonstrate compliance, should be contained in the standard;
- the recommended standard should contain procedures for the local code jurisdictions to readily check for compliance;
- the procedures developed should encourage the use of new and innovative technologies by either providing explicit credit for their use or providing a mechanism for easily updating the standard to give proper credit to new technologies; and,
- the standard should contain equipment sizing guidelines and/or requirements. Particular attention should be given to the regional performance of heat pumps. In formulating the methodology for a new residential energy standard the TEC proposed to take into account the following associated issues:

- the current status, and anticipated developments, in building materials and equipment technology and construction practice;
- the current and projected capabilities of design practice, taking into account the availability of new design and analysis tools;
- the approach and format utilized by other existing or proposed national, state and local energy standards;
- the significance of indoor air quality issues and the nature of indoor air pollutants;
- opportunities to encourage the use of renewable energy sources, including, but not limited to, daylighting, solar and geothermal systems and subsystems; and,
- the problems of enforcement by building code officials.
- the ability to encompass a wide range of residential unit types and construction materials; and,
- the incorporation of examples of the standard's application.

1.4 SCOPE

The project covers new residential buildings including single family, multifamily, and manufactured housing (HUD-code mobile homes). The influences on energy use by the design of the building envelope, mechanical systems and the service hot water system are considered. Regional climate effects are included as well as regional variations in the criteria that dictate a cost-effectiveness based energy standard, such as local energy costs. An important consideration in formulating the standard was providing for regional equity. That is, the standard should not penalize one or more portions of the country because of climate, custom or economic singularity.

2.0 PROJECT ORGANIZATION AND DEVELOPMENT PROCESS

This section provides details related to project management and the process for developing standard recommendations. The basic outline for conducting the project was detailed in a project plan prepared in July 1985 by PNL and ASHRAE SP-53 for the U.S. Dept. of Energy. The project was managed through a series of 17 major meetings of the committee, in which research was planned, the conceptual approach for standard development was refined, and direction was provided for energy consumption analysis, cost estimating, economic analysis procedures, development of a microcomputer model to contain the standard, and development of a format for the final project documentation. The activities of the committee are recorded in the meeting minutes. In addition to the major project meetings of the full committee, numerous smaller meetings were convened to plan and review specific research projects, to analyze results from these projects, and to develop specific recommendations for portions of the standard that were subsequently reviewed by the entire committee. A record of the technical issues raised and the committee's positions on the issues is contained in Section 4.0 of this document.

2.1 OVERVIEW OF PROJECT ORGANIZATIONAL STRUCTURE

Figure 2.1 presents the overall organizational structure for this project. Funding for the SP-53 committee activities was provided by the DOE through PNL and ASHRAE. PNL provided overall project management on behalf of DOE. Technical support to the committee was provided by a combination of Technical Advisers, research groups conducting technical analysis, and software developers. The research activities preformed as part of this effort are summarized in Section 2.3. Subcontracting was coordinated by PNL.

2.1.1 DOE Project Direction

Jean Boulin, Chief of the Architectural and Engineering Systems Group (AESB), Building Systems Division, and Stephen Walder, a senior engineer with (AESB) were the project's government's technical representatives (GTRs). They will review the technical study and utilize the information generated by the project in developing a proposed interim energy conservation standard for DOE issuance.

2.1.2 PNL Project Manager

The PNL Project Manager had overall project management responsibility on behalf of DOE. The Project Managers for PNL, were Allen Lee and Raymond Reilly, with assistance from Todd Taylor. They were responsible for the following:

- maintaining close liaison with DOE through formal and informal reports, reviews, and personal contacts;
- (together with ASHRAE and DOE) identifying the project objectives and approaches;
- ensuring the coordination of all project participants;
- establishing reporting requirements and monitoring the progress of all participants for conformance to scope, schedule, and costs;
- developing Requests for Proposals and statements of work for contract research. In this regard the Project Manager evaluated proposals, selected contractors, managed the work, was responsible for schedules and budgets and the technical analysis of deliverables, and coordinated TEC and subcontractor communication;
- issuing the Final Project Plan and for reviewing and finalizing all documents prepared for DOE;
- (together with ASHRAE) maintaining quality assurance; and,
- (together with ASHRAE) developing the final report.

2.1.3 ASHRAE Responsibilities

ASHRAE was responsible for performing the following tasks:

- contracting with and managing the TEC;
- providing monthly reports to PNL by the eighth of each month. The reports summarized the work conducted to date, problems encountered, budget and

schedule issues and other matters related to performance of ASHRAE responsibilities;

- circulating project documents, specifically the minutes of TEC meetings;
- coordinating with ASHRAE headquarters and with related ASHRAE committees, such as the Standard 90.2P and 62 committees, and other committees involved in residential envelope, equipment and air quality issues;
- managing the logistics of TEC meetings including scheduling, planning, and obtaining reservations, meeting rooms and accommodations for committee members;
- (together with PNL and DOE) identifying the project objectives and approaches;
- (together with PNL) maintaining quality assurance; and
- (together with PNL) developing the final report.

2.1.4 TEC Responsibilities

The TEC was responsible for performing the following tasks:

- developing the procedures, techniques and recommendations for the energy conservation standard;
- reviewing existing standards to assure that the recommended format reflects current practice and maintains a reasonable degree of consistency with existing practices and procedures;
- identifying, with the PNL Project Manager, the research necessary to achieve the project objectives, and assisting in the preparation of statements of work for RFPs for contract research, providing technical assessments of research results and utilizing the findings for developing recommendations for the standard;
- providing expertise in the review of construction data and costs, computer input and output related to energy performance analysis, cost assumptions, and air infiltration and indoor air quality analysis;
- suggesting appropriate climate data, building types, HVAC equipment characteristics, and cost data for inclusion in the standard;

- developing an economics procedure that formed the basis for generating the standard's requirements; and
- assuring that the recommendations are regionally equitable in terms of benefits and costs.

2.2 DESCRIPTION OF RESEARCH PROJECTS

A significant amount of research was required to develop the technical basis for the new energy standard. The research included background studies providing information serving as the basis for refining the approach to standard development, and research to develop the new residential energy standard. The following is an itemization of the research conducted with particular attention given to the background research:

2.2.1 Subcontracted Research

Profile of the Code Promulgation Process

A profile of the codification-implementation-compliance process was constructed by David Conover of the National Conference of States on Building Codes and Standards. This project provided a framework for the development of standard-related materials that are useful to code agencies, and brought cognizant representatives from the code regulatory industry into the process of reviewing the work conducted under this program. Further, the project accomplished the additional goals of:

1) identifying potential users of the standard and the anticipated type of use;
2) profiling how the standard would be implemented by these users;
3) identifying the problems that may be encountered with the proposed format and approach;
4) identifying and characterizing the and users of the codified standard and the compliance checkers;
5) identifying the problems these end users and code officials may have with the proposed format; and

6) identifying a cross-section of code agencies for continuing review of the SP-53 work.

Energy Data Base Development

The TEC, in association with PNL and Lawrence Berkeley Laboratory (the PNL subcontractor for energy analysis work), determined that a new database of energy information was required to form the technical foundation for the standard. The consensus was that the DOE-2 energy analysis program should be used for this analysis. The project included the following tasks:

1) developing of a climatic breakdown of the energy information compatible with the format and approach of the standard;

2) identifying the data to be developed; and,

3) conducting the required simulations using DOE-2.;

Equipment Efficiency Studies

An analysis of mechanical equipment available in the marketplace, its cost and performance characteristics was conducted by ADM Associates, Inc. A careful review of the preliminary results was undertaken and the results were found to be inconclusive. The TEC recommended that the work be terminated and the results discarded.

Air Infiltration Analysis

Studies were undertaken related to the impact of air infiltration on energy use. After some initial analysis, conducted by W. S. Fleming and Associates, this work was abandoned and the approach to quantifying infiltration was based on existing ASHRAE procedures.

2.2.2 TEC Developmental Work

In addition to the responsibilities listed above, the TEC undertook specific tasks required in the development of the standard. These are described below:

Development of the Format for a New Residential Energy Standard

A detailed profile of a proposed new residential energy standard was constructed identifying the format and structure of the new standard, the procedures for using the standard, the supporting technical information, and the process for codifying the standard. Tasks conducted as part of this research included the following:

1) delineating the process for arriving at the compliance information, including the need for data (energy and economic);

2) identifying the appropriate energy analysis procedure or data base of existing energy information to serve as the basis of the standard requirements;

3) developing pro forma statements for identifying appropriate sources of energy and economic data. These statements served as the basis for the research projects;

4) describing the elements of the multiple path approach including the number of paths and the procedures for their use. This task required construction of a scenario of how an end user would demonstrate compliance using each of the paths;

5) identifying the appropriate vehicle(s) for housing the standard (hard copy, microcomputer, etc.) and the process to be followed in codifying the standard; and

6) identifying additional research required to develop the technical basis for the characterized standard.

Identification of Economics Procedure

The committee developed the economics procedure to be used in the standard. This task consisted of the following:

1) identifying the algorithms that characterize the economics procedures followed in selecting cost-effective energy conservation measures;

2) delineating the values for the economic information to be defaulted in conducting the economic analysis (such as, discount rate, energy escalation rates, etc.); and,

3) identifying default costs for conservation measures and energy.

Development of Compliance Documentation Materials

The TEC was responsible for the design of the forms and other materials used to calculate and demonstrate compliance with the standard.

Regional Variation in Mechanical Equipment Performance

The project assessed the impact of climate on the performance of mechanical equipment in terms of seasonal efficiencies (with specific emphasis on heat pumps.) A procedure was developed for adjusting rated performance based upon geographical location (see Position Paper #2-4 in Section 4.0 below).

2.2.2 PNL Project Research

To support the standard development activities PNL conducted the following work:

Development of a Microcomputer Program to Contain the Standard

The committee decided to depart from current standard formats in opting for a standard contained in an electronic microcomputer format. The program developed is intended to be used by codifying bodies in setting local standard values. The program, developed at PNL, contains all the materials needed to generate the explicit standard requirements. The development of the program was closely coordinated with the TEC to assure that the procedures and information selected by the committee are accurately reflected in the results generated by the program. The output of the program includes all the information required to document and support a multiple compliance path approach with additional supporting explanatory material provided in a user's manual.

Indoor Air Quality Studies

A study was conducted outlining the impacts of the recommendations for a new energy standard on indoor air quality. This study, the results of which will appear in the Environmental Assessment (EA) to be prepared by PNL, consider the impact of the standard on levels of radon and related gases, formaldehyde, moisture and combustion gases.

2.2.3 ASHRAE Research

During the project ASHRAE initiated a contract with the National Association of Home Builders (NAHB) to collect residential building cost data for the thermal envelope and HVAC equipment, and for fuel and electricity. This project was in support of the revision of ASHRAE SPC 90.2. These data were also made available to the TEC and used to develop the default cost data base for the thermal envelope.

3.0 TECHNICAL APPROACH

This section presents the technical framework for development of the residential conservation standard. The framework provides the background for meeting the objectives stated in Section 1.3. The fundamental concept adopted to meet the objectives of this new standard is consumer cost-benefit. The determination of the levels of conservation required by the standard needed to be driven by their economic value to the consumer. The diversity of economic conditions nationally and regionally required that the standard be flexible in a manner that could accommodate a range of possible conditions. The standard can be described as consisting of four parts: 1) General Characteristics providing an overview of the features of the standard; 2) Multiple Paths, outlining the procedures to be followed in using the standard; 3) Energy Analysis, delineating the process for arriving at the amount of energy saved by conservation strategies; and 4) Economic Analysis, describing the methodology for defining levels of cost-effectiveness in energy conservation. In the sections that follow, each of these components is discussed in detail and the issues addressed by the TEC are outlined. While a general approach to standard development is presented, the TEC considered alternative approaches as work progressed. In many cases the need to conduct the research is described.

3.1 GENERAL CHARACTERISTICS OF THE STANDARD

The Standard consists of a series of procedures rather than a set of prescriptions. That is, it is the responsibility of the codifying agencies to employ the Standard procedures to identify the precise local requirements to be codified. This flexible format is unique among current energy standards and provides the ability to accurately reflect changes in time sensitive parameters such as costs. Further, the need to update the Standard is reduced, since at any time current information can be inserted and new standard levels developed. The ability of the Standard to be fine tuned appropriately places the control of the requirements in the hands of the codifiers of the Standard, who are generally in the best position to consider the technical and political ramifications of the requirements. In contrast to the local determination of the cost information, the Standard contains an explicit set of energy data and an economics procedure developed as part of this effort. As will be discussed below, the committee felt that determination of this information was appropriately within the purview of the TEC. To identify the levels of conservation to be required under the code, the codifying agency inserts energy cost and construction cost information into the procedure. Some of the economic information required to operate the economic analysis, such as discount rates and escalation factors, are provided in the procedure as default or fixed values. In general, the criteria used to develop the materials included the following:

- The procedures developed were based upon information currently available and in the public domain. That is, they embodied current knowledge of energy and economics analysis methodology, standards promulgating procedures and performance of residential structures.
- The Standard resulting from this work is designed to allow consideration of a wide range of energy features.
- The application of the Standard is intended to be regionally equitable. That is, its application will create equal burdens or benefits across regions and residential unit types, sizes, and configurations.

3.2 MULTIPLE COMPLIANCE PATHS

The Standard allows the end user to select from a multiple number of paths to demonstrate compliance. The paths are distinguished by the degree of freedom provided in selecting unique combinations of energy features, and the level of difficulty in demonstrating compliance. In general, the greater the degree of design freedom, the higher the level of difficulty in use. As a first step in delineating the compliance paths for a specific location, a "target" is established. The target represents the energy cost associated with a home designed with what are found to be cost-effective energy features for that location, type of home, and type of mechanical equipment. In other words, the energy target provides a basis for assigning relative values to energy conservation features in each of the compliance paths. The paths are as follows: 1) a set of prescriptive packages of conservation measures, 2) a point system, and 3) a whole residential unit energy performance approach. The end user, in demonstrating compliance, selects only one of these paths.

The three compliance paths (packages, points, and whole unit performance) were selected for two basic reasons: 1) they typify the range of possible alternative paths in terms of the degree of flexibility they provide the end user; and 2) there is prior experience with their use in existing energy standards (notably in the State of California Energy Standards.) The salient features of each path are described briefly below:

- Energy Packages - For each house type in each climate region, sets of energy packages with specified levels of energy conservation measures (ECMs) are precalculated. The user can select one of these prescriptive packages as the simplest route to demonstrating compliance with the code requirements.
- Energy Points - Using a baseline set of conservation measures, points are assigned to a wide range of energy conservation measures. The end user selects a unique set of energy measures, and using the procedures described in the Points Compliance section, determines the corresponding number of points. The total of the points for the proposed measures (Design Points) is then compared to a predetermined allowable total (Target Points) to demonstrate compliance.
- Whole Unit Performance - A procedure is provided for demonstrating compliance by documenting that the proposed design will have a level of energy use not greater than the same home equipped with the basic energy conservation package specified in the Energy Packages approach. In using this path the user has the freedom to select from a range of energy analysis tools to demonstrate equivalency as long as the selection of tool and the procedure for conducting the analysis comply with guidelines outlined in the Standard.

3.3 ENERGY ANALYSIS

The committee considered two options with regard to the source of the energy data required in conducting the cost-benefit analysis as follows: 1) specifying the energy analysis procedure and requiring the codifying agency to perform the energy calculations; or 2) precalculating an explicit matrix of energy data for practically every conservation measure available to the user. It was the committee consensus that developing an explicit data base of energy information would simplify the task for the users of the Standard (e.g. code officials) and that the project had the resources and technical expertise to conduct such work. Additionally, there was considerable concern that the users with more limited technical and financial resources would be unable to develop a defensible base of energy information. Further, since the use of any energy analysis procedure is subject to interpretation of input data, there was a danger that each user of the Standard might create a unique data base of energy information, potentially undermining the regional equity of the Standard. The generic types of analysis procedures available to perform energy analyses and thus generate a data base include: degree day, bin methods, microcomputer simulation or main frame computer simulation. These procedures, as well as existing energy data bases developed from one of these procedures, were considered by the TEC in developing the energy data base. In selecting either an energy analysis procedure to generate the energy data base or an existing data base for the Standard, the following criteria were considered:

- The flexibility of application of the procedure or data base. That is, the range of energy related conditions that can be addressed and displayed in a data base. The scope of conditions that may need to be covered include ranges of building size and shape, conventional energy conservation measures (insulation, glazing, etc.), heating and cooling conditions, a wide range of climate variables, solar features, internal heat gain, infiltration, equipment efficiencies, high mass construction and innovative energy technologies.
- The relative and perceived level of accuracy of the energy procedure or data base.
- The use of the procedure or data base in other ongoing and planned energy activities. This criterion considers the need to be compatible with other related initiatives reducing confusion on the part of the end user and codifying agencies.
- Acceptance of the procedure or data base by the engineering and scientific community as being current and up to date.
- Ability to use the procedure or data base within the scope of effort and time constraints of the TEC (SP-53) work.

- The compatibility of the results of the energy analysis procedure or data base with issues of standard format and economics analysis.

Based upon these criteria a matrix (see Table 3.1) was created that summarizes some observations of the suitability of each of the generic energy analysis procedures available to develop the energy data base. The committee found that the procedure that best met the above stated criteria was a public domain main frame simulation model and selected the DOE-2 program. A subcommittee was appointed to develop the input data for data base development and monitor the work of the PNL subcontractor. The energy analysis work was conducted by Lawrence Berkeley Laboratory (see LBL Technical Support Document).

Table 3.1. Evaluation of Generic Energy Analysis Procedures

Analysis Procedure	Degree Day Method	Bin Method	DOE 2.1 Data Base	Micro-Computer Sim.	Main Frame Sim.
1. Level of perceived credibility	0	0	+	+	+
2. Compatibility with other major energy programs	0	-	+	0	0
3. Engineering Society acceptance as state-of-the-art	-	0	+	+	+
4. Economy of Use	0	0	+	0	-
5. Compatibility of output with proposed Structure	-	-	+	+	+
6. Relative Accuracy	-	0	+	+	+
7. Flexibility/New Technology					
a. Passive Solar	-	-	0	+	+
b. Superinsulation	0	0	0	+	+
c. Thermal Mass	-	-	+	+	+
d. Other New Technologies	0	0	+	+	+

key: + above average rating
0 average rating
- below average rating

3.4 ECONOMIC ANALYSIS

The committee felt that while the specific economic information that drives the cost-benefit analysis should be determined locally, the procedure should be delineated by the committee. The local inputs include, but are not limited to, local construction and energy costs. The following criteria were considered in developing the economics procedure:

- The results should be reasonable given a wide range of possible economic conditions;
- The perspective of the home buyer should be of paramount importance;
- The type of economic procedure selected should be appropriate to standards setting; and,
- The range of parameters considered should be comprehensive (e.g., discount rates, escalations.) A detailed discussion of the economic analysis procedure and the technique for optimizing the selection of ECMs is provided in Section 4.0 (position papers 3-1 and 3-2).

4.0 TEC POSITION PAPERS

During the course of the project numerous position papers were developed to document TEC decisions and methodologies leading to the final recommended standard. Some of the position papers, particularly those developed early in the process, represent conceptual strategies, and give few details of the final work products. Others, which were developed subsequent to the planning stages, are more complete discourses. To provide complete documentation, all papers are included in this document. As shown in Table 4.1 below, the papers have been separated into nine general categories for this report. The papers appear in this order in the Appendix to this volume.

Table 4.1. List of Position Papers

Philosophy of Development (Category 1)

Paper #	Title
1-1	Baseline Methodology for Standard Development
1-2	Mandatory and Minimum Requirements
1-3	Equivalency Among Paths
1-4	Treatment of Alternate Energy Sources
1-5	Indoor Air Quality

Energy Analyses (Category 2)

Paper #	Title
2-1	Selection of Design Tools for Creating Energy Database
2-2	Prototype Selection
2-3	Location Multipliers
2-4	Regionalized Equipment Efficiencies

Table 4.1., cont'd.

Economics (Category 3)

Paper #	Title
3-1	Economic Analysis for a Residential Energy Conservation Standard
3-2	Economic Analysis Procedures in Microcomputer Program
3-3	Creation of Cost Data Base

Thermal Protection (Category 4)

Paper #	Title
4-1	Ceiling Insulation
4-2	Wall Insulation
4-3	Floor/Foundation Insulation
4-4	Door Insulation
4-5	Thermal Mass
4-6	Attic Radiant Barrier Systems
4-7	Roof Absorptivity
4-8	Glazing and Sash Materials
4-9	Movable Insulation
4-10	Air Infiltration
4-11	Pipe Insulation
4-12	Sealing and Insulation of Air Distribution Ducts in HVAC Systems

Solar Space Conditioning (Category 5)

Paper #	Title
5-1	Solar Space Conditioning
5-2	Internal Shading Devices
5-3	External Shading Devices

Table 4.1., cont'd.

System Design (Category 6)

Paper #	Title
6-1	Design Load Calculations
6-2	Sizing of Space Heating and Cooling Equipment
6-3	Control and Zoning of HVAC Systems

Ventilation (Category 7)

Paper #	Title
7-1	Mechanical Ventilation for Comfort

Domestic Hot Water (Category 8)

Paper #	Title
8-1	Domestic Hot Water Efficiency Requirements
8-2	Flow Reducers on DHW
8-3	Thermosyphon Heat Losses in Domestic Hot Water Systems
8-4	Instantaneous Water Heaters
8-5	Passive and Active Solar Water Heating

Format of Standard (Category 9)

Paper #	Title
9-1	Package Methodology
9-2	Development of Points Compliance Path
9-3	Philosophy of Performance Path
9-4	Certification of Analysis Tools
9-5	Solar Hot Water in Performance Path

APPENDIX

ASHRAE TEC SP-53 POSITION PAPERS

APPENDIX

ASHRAE TEC SP-53 POSITION PAPERS

This appendix contains the individual position papers developed by the ASHRAE Technical Evaluation Committee for Special Project 53. The papers represent documentation of the opinions and collective judgments of the committee, the resources used in developing recommendations for the new standard, and many details of the final recommendations.

The reader is cautioned that the papers were produced by a number of persons in disparate locations at various stages of the development process and were not designed to provide a fluid and continuous history of the process. The need to reproduce memoranda, graphics, and other existing works without devoting excessive time and effort resulted in formats that are not entirely consistent from paper to paper. Rather than reorganize all the papers, each is included here in its near-original state. Because some papers have their own numbering systems, each should be viewed as an individual document. No position paper ever makes reference to the tables or figures of any other position paper or to the body of this volume. The pages of each paper are numbered and captioned separately to assist the reader.

CONTENTS

<u>CONTENTS, cont'd.</u>

Thermal Protection (Category 4)

Solar Space Conditioning (Category 5)

System Design (Category 6)

CONTENTS, cont'd.

Ventilation (Category 7)

Domestic Hot Water (Category 8)

Format of Standard (Category 9)

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #1-1

Title: BASELINE METHODOLOGY FOR STANDARD DEVELOPMENT

Statement of Issue: How should baseline methodology be used in the development of standards?

Resolution: A software based standard which embodies a seven-step baseline methodology will be developed.

Discussion:

To develop a consistent standard requires a baseline methodology derived from processes representing the basic objectives of the standard. For this standard, SP-53 agreed on a number of objectives. Some of these were related to approach while others had to do with format and acceptance of the standard. Those which relate to approach were used to created the baseline methodology. These six objectives were:

1. To utilize local data wherever available;
2. To cover a wide range of energy conservation measures;
3. To use technically defensible energy analysis techniques;
4. To create a standard that is economics based;
5. To provide a simple means of identifying compliance; and
6. To expedite and simplify the codification process.

It was then decided that the best way to fulfill these objectives was to embody the methodology of the standard in a computer program. In this way, the standard remains flexible and responsive to local conditions and jurisdictional requirements, but it still maintains a consistency and equivalency in methodology. In other words, the process and philosophy of the standard doesn't change with each computer run, but the required levels of conservation may.

This process of setting energy dollar goals for different housing types in various jurisdictions is called the "baseline methodology".

This methodology should produce results that do not limit design options and assure that products are available to meet the Standard's criteria. The basic philosophy should be to specify a set of energy conservation measures (ECMs) that are economically viable to demonstrate that there is at least one approach which is cost effective. The "equivalent" approaches will also meet the energy target, but there is no measure of cost effectiveness associated with them. Since the analyses are done on a generic basis, it is sufficient to show that there is at least one combination of ECMs that is cost effective; this will identify the energy target. Thus, variations in ECM levels from those creating the goal can be thought of as "equivalent" approaches to energy conservation.

The steps in the methodology are:

1. Select a generic design which represents one of the three prototypes (single family detached, single family attached, and manufactured housing). (For information on generic designs and prototypes, see position paper #2-2 on prototype selection.)

2. Select fuel and equipment types for heating and cooling. To provide for equality among various fuel types, energy dollar goals are separately derived for each fuel and equipment combination.

3. Select climate, and enter local fuel costs and other economic data as available. This fulfills the objective of responding to local conditions in the development of the standard.

4. Select climate minimum levels of ECMs (energy conservation measures) which are to be allowed. This will allow the coverage of a wide range of options without requiring any ECM to bear the conservation burden to the exclusion of others.

5. Configure generic design with mandatory measures and other fixed assumptions such as thermostat settings and window management. This correlates the design with models previously run on DOE-2.1 to create the database on energy savings for the ECMs. The database fulfills the objective of using technically defensible energy analysis techniques in the development of the standard.

6. Using the energy savings deltas from the revised data base and the equipment characteristics, combinations of ECMs are analyzed to find the most cost effective set. The definition of cost effective is based on total conditioning energy dollars for the combination of ECMs. Calculation of the energy dollars is done with the economic methodology as described in the position paper on Economics (#3-1). This fulfills the objective of creating a standard that is economics based.

7. Adding the base domestic hot water system energy dollars to the conditioning dollars provides the compliance goal for the building prototype/fuel/equipment category selected in steps 1 and 2. This goal is the basis for identifying equivalence among the different paths (see position paper #1-3 on Equivalence). Standardization of the process and identification of the energy dollars goals provides the mechanism to allow for ease in compliance checking.

These steps, when embodied in the computer program, represent the philosophy selected to develop the standard. By doing standard development with a computer program, the final objective of refining the Standard to particular localized conditions is accomplished. Furthermore, the format and approach create an opportunity for more effectively conducting plan review and field inspections on new construction.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #1-2

Title: MANDATORY AND MINIMUM REQUIREMENTS

Statement of Issue: Should a standard contain minimum and/or mandatory levels of thermal performance, and if so how are they defined.

Resolution: The standard will establish minimum levels of thermal performance for components of a residential building. No component may utilize a level of thermal performance below these minima. Generally, a building constructed with all components at minimal levels would not meet the standard; therefore, some components must be provided above the minimum to meet an energy target. All of the paths will provide flexibility in selection of the combination of components that will reach the energy target.

Mandatory requirements will be established for items that must be included regardless of compliance path. Components identified as mandatory will have minimum levels of performance. No trade-offs will be considered on mandatory items, even if levels are above minimum.

Discussion:

Various factors will influence the decision as to minimum levels. Among those factors are comfort, "state-of-the-art" insulation levels, level of retrofit difficulty, and economics.

The establishment of minimums therefore becomes one of the most difficult decisions in the development of a standard. If the standard is intended to optimize the economics of an energy conservation measure (ECM), then it could be argued that if all factors are correct, the minimum requirement and the maximum requirement are identical (the optimum). Therefore, the consideration of minima may revert to one of the other criteria ("state-of-the-art", comfort, or retrofit difficulty). This would place the ultimate evaluation of economics in the hands of the user because the energy target would be based on optimum economics as established by the variables in an economic formula.

Mandatory requirements are those in which the available variables are limited and where the optimal economic criterion was used for their establishment. That is, no credit could be given for upgrades because any upgrade would not meet the economic parameters used in the standard development.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #1-3

Title: EQUIVALENCY AMONG PATHS

Statement of Issue: How is equivalency among the different paths handled?

Resolution: The standards process should provide energy cost equivalency among the compliance paths for each combination of equipment and fuel types. Equivalency means that a design which complies under the prescriptive path could be shown to comply through either the points or the performance paths. Similarly, a design complying under the points path would also be in compliance if the performance path were used.

Discussion:

To develop a residential energy standard based on the inclusion of cost effective economic energy conservation measures (ECMs), as SP-53 is tasked to do, requires that a number of steps be completed in sequence. The major objective after the decision to allow three different compliance paths is how to assure equality among the different paths. The concept of equality is based upon an energy cost target derived from the application of cost effective measures to one or more generic residential designs with a specific fuel type/equipment type for heating and cooling. This target (in terms of energy dollars) requires that a large number of energy use simulation analyses be made for each of the different ECMs and each of the different generic house models.

Once this data base of energy requirements exists, then an economic analysis can be performed to identify cost effective levels of each ECM. For example, by comparing the energy savings from different insulation levels with the differential costs associated with adding the next level, the insulation level with the highest return is determined. After the level for each ECM is identified, then the combination of ECMs which is cost effective must be determined. This is done by adding the ECM with the highest return to the generic model and calculating its economic effectiveness. Then, the ECM with the second highest return is added to the model. The energy consumption of the modified design is calculated and the economic effectiveness is determined. This process is continued for all the ECMs until the economic effectiveness is no longer positive (i.e., the return from the combination of measures is less than the return from the previous combination of measures). At this point the energy cost of the generic model with the additional measures having the highest return becomes the energy cost target for that fuel/equipment type combination in that particular climate zone.

Equivalency among and within the compliance paths is based on a similarity in energy cost with the target. It is important to note that once the energy cost target is established for a generic group of structures, the economic requirement for cost effectiveness is no longer required. That means that designs equivalent to alternative paths are not necessarily cost effective. However, there does exists at least one design, the design used to identify the energy cost target, which satisfies the energy consumption requirements and is a cost effective implementation of the standard.

Since the economic criteria are removed in developing the alternative paths, there needs to be some minimum levels for the major ECMs to assure that reasonable energy efficiency and thermal comfort will result from a design. These minimum levels would be developed from existing standards and analyses which "equalize" the energy effects of the different house components. Based upon a maximum energy consumption, values of insulation, infiltration, etc. will be determined so that no one component is responsible for a majority of the energy savings. This alleviates the situation where a designer might trade off all of the ceiling insulation for solar hot water and high efficiency equipment. That design might meet the energy target, but it probably would be uncomfortable to live in. Thus, the target constrained by some minimum levels of certain ECMs represents the requirement for equivalency which must be satisfied when creating the compliance approaches for alternative paths.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #1-4

Title: TREATMENT OF ALTERNATIVE ENERGY SOURCES

Statement of Issue: How should the standard treat alternative energy sources such as woodstove energy, photovoltaic energy, wind energy, biomass, and geothermal energy.

Resolution: None of the alternative energy sources mentioned above shall be included as a basic option in the standard.

Discussion:

Woodstoves and wood furnaces save energy by burning wood, a nondepletable energy source. The amount of energy saved depends upon the kind of wood, the design of the wood stove or furnace, and the frequency of use. The user oriented aspect of this option precludes its use in the standard.

Photovoltaics is the technology of converting sunlight directly into electrical current using solar cells. Photovoltaics are not included in the standard because they are not generally cost competitive with conventional energy sources. However, photovoltaics are included as an option in the performance path.

Wind energy, generating electricity using wind power, is not to be included in the standard as an option because its effectiveness depends upon microclimatic conditions, information not available in the development of the standard. In addition, few products exist today for residential application.

Biomass energy or energy released from the decomposition or burning of organic material, shall be excluded from the standard because it is a user dependent option with little current potential for commercialization.

Geothermal energy, the energy which can be extracted form the earth's interior, shall not be included in the standard as basic option because of the complexity in determining its energy savings potential. This option, however, can be included under the performance path.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #1-5

Title: INDOOR AIR QUALITY

Statement of Issue: How should the Standard deal with indoor air quality issues?

Resolution: Because the purpose of this Standard is only to govern the use of energy, it will not explicitly insure the quality of indoor air. It will defer to other applicable standards in this area. However, no mandatory requirement of the Standard will reduce the air exchange rate of a house below 0.4 ACH, and no ECM will be required for which the only available material is known to be hazardous. Additionally, the Standard will include an appendix describing radon-preventing construction techniques.

Discussion:

Because this is an energy standard, it will not be concerned with the health and safety aspects of indoor air quality, except to explicitly defer to other applicable standards. However, many components of new home construction that impact energy conservation clearly impact indoor air quality as well. The areas of major concern are constructions that restrict the exchange of indoor and outdoor air, and constructions that may contain materials that emit potentially harmful gasses. Additionally, foundation construction may be a concern in areas where soil radon content may be high.

Though this standard does not explicitly insure quality of indoor air, it should in no way hinder builders' efforts to meet existing air quality standards. Therefore, the standard will be designed to reduce the calculated air exchange rate of a new home to no less than 0.4 ACH. Furthermore, no ECM will be required for which the only available materials are known to seriously aggravate air quality problems.

The prevalence of radon leakage into homes and the associated health problems are increasingly well-known. Though this standard is not responsible for this concern, it is prudent to provide information where possible. Therefore, the Text of the Standard will include an appendix describing construction techniques that minimize the risk of radon buildup in houses and suggesting mitigation techniques if radon levels are found to be high after construction. Though not part of the Standard, this appendix will provide useful information in locations where radon is known to be prevalent.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #2-1

Title: SELECTION OF DESIGN TOOLS FOR CREATING ENERGY DATABASE

Statement of Issue: A process needs to be identified which allows a consistent set of energy data for the various energy conservation measures to be developed. The technique must include an accurate computer simulation model of building energy use which is readily available.

Resolution: The DOE-2.1C computer program was selected to create the energy data base for the SP-53 residential standard because of the significant previous experience with the program and because of its relative widespread acceptance as the public domain energy analysis program.

Discussion:

The first step in the development or refinement of an energy standard involves calculating the energy requirements of a typical structure in a given location. The overall energy use then becomes an energy target which forms the foundation of the standard and is the basis for identifying equivalency among the various compliance paths. The process of selecting a design tool or energy analysis methodology to create a data base of energy use from which these targets are developed, required the development of a set of criteria that must be met by the options considered. Those tools meeting the criteria were then evaluated on applicability to the SP-53 project. Once a tool was selected, a number of additional issues were identified which had to be resolved before the data base could be created and used within the Standard.

Criteria for the design tools were identified as:

- Public Domain - tool must exist in the public domain with the source code available for review if necessary.
- Well Documented - tool must have good documentation both on its use and on the algorithms used in the energy calculations.
- Flexible - tool must be flexible and able to easily handle a number of building designs and types of equipment.
- Handle Envelope Dominated Buildings - tool must be capable of accurately evaluating the dynamic heat transfer characteristics of both lightweight and massive building envelopes (in particular, those constructions typically found in low-rise residential structures).

- Sensible and Latent Loads - tool must be capable of analyzing the sensible and latent loads within a space and of also modeling the impact of those loads on typical residential HVAC systems.
- Variety of Climates - tool must provide for different climates and model the impact of dry bulb and wet bulb temperatures, wind speed, and solar irradiation on the interior conditions of a building. In conjunction with the capability of handling envelope dominated structures, hourly climate data must be available in the proper format for the tool to cover the multitude of locations required within the study.
- Validated and Accurate - tool must be validated with measured building energy requirements and should have been demonstrated to be reasonably accurate for a wide variety of building designs.

Based upon these criteria, the following design tools were considered for use in developing targets:

- DOE 2.1 (versions A, B, C)
- BLAST 3.0
- TARP
- CIRA
- SERIRES

Other tools may meet the criteria, but they were not identified to the committee when the selection was occurring.

From this list, DOE-2.1 was selected as the design tool to be used in the targets development process. Reasons for its selection include:

1) It meets the criteria;
2) It is the most widely used of the tools on the list;
3) It provides a better simulation of latent loads and equipment performance than do others; and

4) It has previously been used to create a substantial data base of information on the energy impacts of a variety of residential energy conservation measures (ECMs).

Reason 4 provided the most compelling argument for the selection of DOE-2.1 since this would substantially reduce the number of analyses required to complete the data base and then create energy targets. This was true at the time of selection although it was later found that a large number of inconsistencies in the existing data required that the data base be recreated.

The selection of DOE-2.1 raised a number of issues which had to be resolved before the data base could be completed and the development of the Standard could progress. First was the issue of multiple versions of DOE-2.1. There are currently three versions of DOE-2.1 available: version 2.1A which was used to create most of the residential data base, version 2.1B which includes daylighting calculations and was used to create the data base for manufactured housing, and version 2.1C which fixed most of the bugs found in 2.1B and provides some enhanced algorithms not used in 2.1B. A more detailed description of the differences between 2.1A and 2.1C is found in the attached memo from Stephen Byrne at LBL dated 2/6/86. Differences between 2.1B and 2.1C are primarily in the calculation of the diffuse solar radiation. This difference may affect the energy calculations by less than 10% but does not affect the internal consistency of either version. There are other differences between the two versions but they affect parts of the program not used in the modeling of residential structures. There are gaps in the existing data base and some information was generated with a different version of DOE-2.1 than was used for the majority of the calculations. The question arises as to the compatibility of existing results and of future results. Are the differences in energy use and delta loads significant enough to require a complete recalculation of the data base? Analysis to date indicates differences of plus or minus 10% in heating and cooling loads between 2.1A and 2.1C with 2.1B results lying somewhere in between. This 10% deviation is in the absolute loads. Deviations in delta loads, which are the values used in the data base, should be significantly smaller since each version is internally consistent in the approach used to calculate energy use. This would mean that deviations in delta loads among the different versions might be as small as a couple percent, so the problem of using different versions is minimal.

It should also be noted that differences in costs for ECMs will typically vary by 10 to 50% depending upon region and ECM. Also, the selection of economic cost effectiveness criteria (period of analysis and payback requirements) may introduce an additional difference of 60% in climate ECM level selection. Using the scalar approach, the ratio of the heating scalar to the materials scalar can vary from 13.6 to 8.3 depending upon the term of the mortgage and whether a 2 year to positive cash flow or 7 year crossover criterion is selected. This means that the dividing lines for insulation levels or other ECMs may move up to 60% on a heating degree day basis. This variation, along with the uncertainty in first costs, will more than mask the discrepancies of 10% in energy calculations. Since the combination of energy and dollars is used to identify cost effectiveness, the variability in energy calculations among the different versions of DOE-2.1 does not appear to pose a significant problem, nor does it require recalculation of the data base information.

Although it was initially recommended that future runs be made with DOE-2.1B for consistency with the existing data base, the data base was completely redone using DOE-2.1C. Even though there was a large amount of data on ECM energy use, there were a number of modeling inconsistencies identified in the existing data that cast doubt on its overall consistency and accuracy. For this reason, all ECMs were again analyzed with DOE-2.1C using a standard set of input assumptions agreed upon by the SP-53 Committee. At that time, problems with the DOE-2.1 analysis of underground heat transfer were also solved by merging the results of a finite difference model into the new DOE-2.1C runs.

Another issue which had to be resolved was what to do about systems and ECMs which are not currently modeled in DOE-2.1. As the current version of DOE-2.1 constantly changes, some of these features will be included, but some will not. Two questions were addressed:

1) How to resolve compatibility between the data base and an item modeled with future versions of DOE-2.1; and

2) How to provide delta load estimates for systems and ECMs which may never be directly modeled within DOE-2.1.

The first question on compatibility is directly related to the multiple versions discussed on the previous page. It is recommended that future runs be made with the most recent version of DOE-2.1 available at the time. For consistency with the data base, a sensitivity run should also be included to provide a point of comparison between new results and original runs from version 2.1C. This sensitivity run would consist of the typical design analyzed in a climate like St. Louis with the same input file as was used for 2.1C. When the cost effectiveness of an ECM is determined, those ECMs which are within the deviation indicated by the sensitivity run of being cost effective will need to be further analyzed. This provides the advantage of significantly reducing the climates and ECMs which might need to be rerun to obtain accurate conclusions.

The second question is much more difficult to resolve since results from the DOE-2.1 runs are used to provide points for different ECMs and to do the performance analysis. Without DOE-2.1 results, new systems and ECMs can not be integrated into the standard. For ECMs and systems not directly modeled (e.g. radiative barriers or evaporative cooling), it is suggested that an effective U-value or overall system COP be utilized within the DOE-2.1 model to arrive at some conservative estimates of energy savings. These numbers will not represent the full savings achieved with the implementation of such an ECM, but should be reasonable enough to assign points or provide credit within a performance analysis. Unfortunately, with any new ECMs, the code and standards groups will be faced with the dilemma of modeling within the current version of DOE-2.1 or not providing any credit for its use. The modeling may not be exact, but can usually be handled in some fashion within DOE-2.1 to allow credit for new ECMs and their use within the standard.

Another issue raised by the selection of DOE-2.1 to create the data base is how to translate these numbers into a dynamic standard which accounts for variations in local climate, materials costs, and fuel costs? Any large scale simulation program such as DOE-2.1 is too cumbersome, time consuming, and expensive to be an explicit part of a dynamic standard. The answer to this problem was a regression approach. By doing statistical analyses on the multitude of DOE-2.1 runs, regression equations were derived which adequately account for climatic variations. When combined with the selected economic data, cost effective levels can be calculated for all the ECMs covered in the latest version of the DOE-2.1 data base. This approach was implemented into the ARES computer program and is used in the creation of the dynamic Standard.

TO: Robert Busch
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FROM: Stephen Byrne
Building Energy Analysis Group 90-3125
Lawrence Berkeley Laboratory
Berkeley, CA 94720

SUBJECT: Differences between DOE-2.1A and DOE-2.1C

DATE: February 6, 1986

As per your request, I have enclosed a list of several of the differences between versions 'A' and 'C' of the DOE-2.1 program. This list was originally developed at the request of Allen Lee at Pacific Northwest Laboratory. Although there have been many improvements in the code, I've identified here only those that will affect our residential database work in support of the ASHRAE standards activities. The major differences fall into two categories:

Algorithm Improvements:

(1) The calculation of the fraction of diffuse and direct solar radiation has been changed to make use of more current research.

(2) The custom weighting factor calculation has been improved to more accurately handle the split between radiative and convective heat gain from lights.

(3) New system performance curves have been implemented to more accurately model part load effects in residential air conditioners.

(4) Numerous bug fixes have been made, making the latest version (DOE-2.1C) the most accurate and up-to-date.

Enhanced Modeling Capabilities:

(1) The natural ventilation control strategies have been enhanced to allow more accurate modeling of the opening and closing of windows by building occupants.
Note: This enhancement exists in the LBL development version only and will be included in the next public release.

(2) The rate of natural ventilation is now a function of exterior wind speed, rather than a fixed input value. This more accurately models the effects of climate.
Note: This enhancement exists in the LBL development version only and will be included in the next public release.

(3) Many additions have been made to the sunspace model, allowing sensitivity studies of orientation, thermal coupling with living space, etc.

(4) Trombe walls have been added with features similar to the sunspace model.

(5) The occupant control of window draperies can now be modeled as a function of exterior conditions (e.g. solar gain), rather than with a predetermined schedule.

(6) Exterior shading of windows and walls can now more accurately handle the effects of diffuse solar radiation by modeling the fraction of the sky seen by the shaded surface.

(7) The Sherman-Grimsrud method of calculating infiltration rate has been added, improving the climate dependence of infiltration.

(8) The calculation of custom weighting factors can now account explicitly for the effects of interior partition walls.

In addition, we are currently making use of research done by LBL and others on building/earth heat transfer in order to improve the foundation modeling capabilities of DOE-2. This is ongoing work that we anticipate will become part of a future release of the program. If you have any further questions, please contact me.

copies to:
Allen Lee, Pacific Northwest Laboratory
Robert Pratt, Pacific Northwest Laboratory

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #2-2

Title: PROTOTYPE SELECTION

Statement of Issue: In past work, 9 prototypes have been used to describe typical residential buildings. How many prototype designs are required in the SP-53 work to cover the applicable structures?

Resolution: Based on the results of sensitivity analyses, it was decided that only three prototype designs were required to categorize residential buildings for the purposes of this standard. These are: single family detached structures, single family attached structures, and manufactured housing structures.

Discussion:

Much of the initial work in categorizing residential structures was detailed in the Affordable Housing project[(a)] also known as the Slide Rule Data Base. This work used 9 prototypes or typical designs to cover most residential structures less than four stories in height. These nine prototypes were:

- Single Story Detached Dwelling
- Split Level Detached Dwelling
- Two Story Detached Dwelling
- End Unit Townhouse
- Mid-Unit Townhouse
- End Unit Apartment
- Mid-Unit Apartment
- Single Wide Manufactured House
- Double Wide Manufactured House

For each of these prototypes, a typical design was created with an average floor area, shape, and construction characteristics. Differences in floor area within a prototype were corrected with multipliers while no adjustment was made for differences in shape or aspect ratio. Results of analysis using the Slide Rule Data Base indicated that energy savings for any particular ECM

(a)U.S. Dept. of Energy, Affordable Housing Through Energy Conservation - Technical Support Document, DOE/SF/00098-1, November 1983.

seemed to be linear with size (on a square foot, linear foot, or air change basis). However, ECM savings were not necessarily linear with ECM level, that is, insulation savings were not consistent on a Btu per R-value basis. The conclusion drawn from these results was that each ECM was relatively independent of the others, and as such each ECM could be considered separately without analyzing all the combinations of ECMs which included it. This conclusion was valid for reasonable combinations such as R-19 wall & R-30 ceiling or R-11 wall & R-39 ceiling, but not with R-0 wall & R-39 ceiling. In fact, the R-0 level did not correlate well with other levels.

The issue facing SP-53 was that use of 9 prototypes made it difficult to easily implement the standard in a package and points approach. With each prototype requiring a separate set of packages and points tables, the standard would become quite cumbersome and lose the simplicity desired. If possible, it was desired to reduce the number of prototypes by identifying groups of prototypes which were energy and economically equivalent. If groups had the same energy deltas (within 5 to 10%), and the same shape of energy savings curve, then one prototype could be used to represent that group. Since previous results had indicated linearity on a per unit basis (sf, ft, or air change), it was decided to normalize all ECMs to a per unit basis. Then a sensitivity analysis was done on the prototypes and ECMs in four climates: Atlanta, Denver, Miami, and Minneapolis. This covered the range of heating and cooling climates found in the 45 cities of the data base.

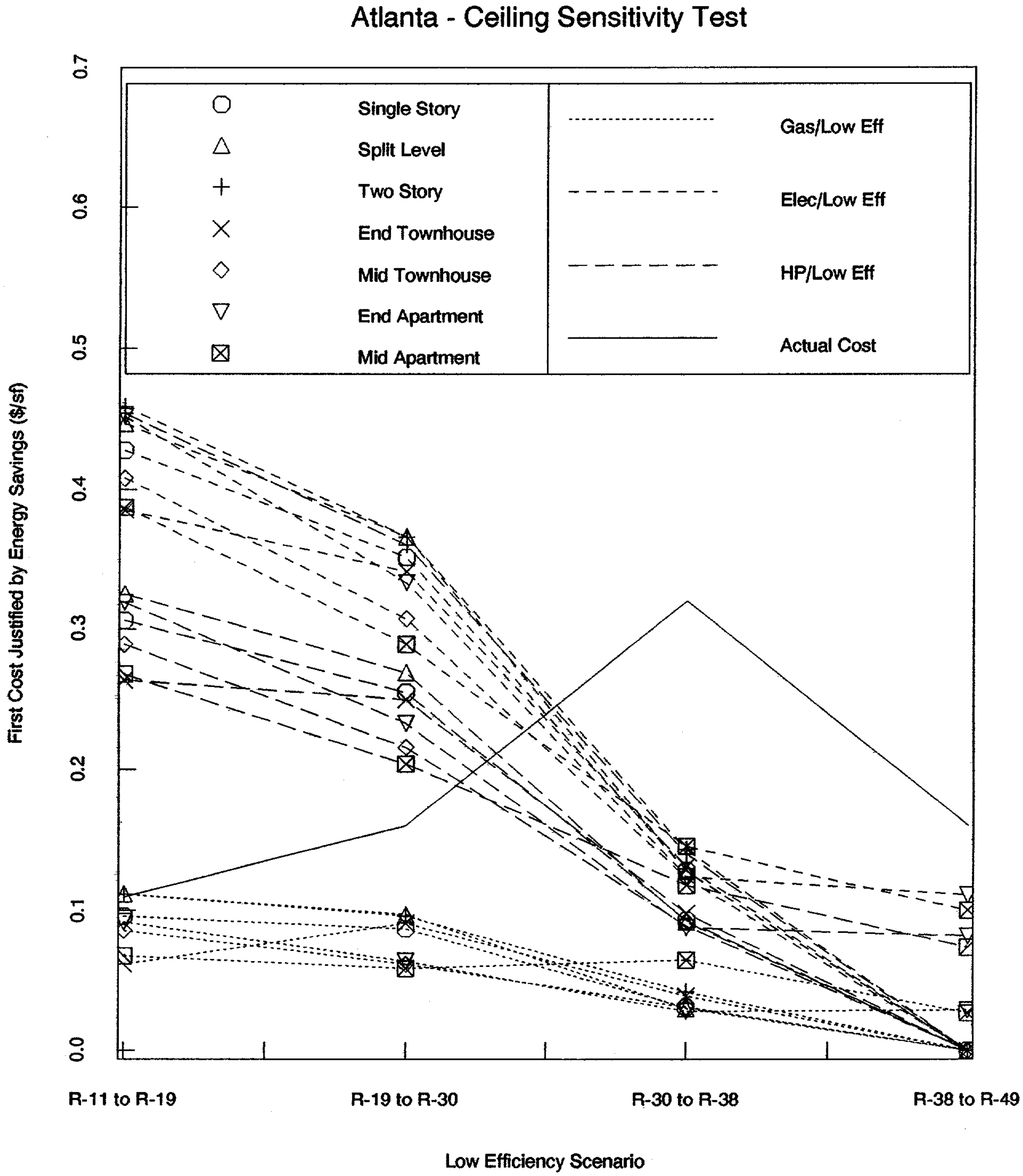
Only those ECMs which were affected by envelope size and prototype description were included in the analysis; for example, equipment efficiency was not included since it is independent of prototype design and envelope size. The analysis consisted of identifying the cost effective levels of the affected ECMs for two different equipment efficiencies (low and high) and for three combinations of heating and cooling equipment: heat pump, electric resistance heat and DX cooling, and gas furnace and DX cooling. The hypothesis was that if a set of prototypes indicated the same cost effective level of an ECM for all of the equipment type/efficiency combinations, then that set could be represented by a single prototype. Since the standard is economics based, then only the discrete cost effective levels were of interest in identifying equivalency. This provided the criteria for deviation within a group. Analysis of the sensitivity results indicated that seven of the prototypes could be separated into two groups. The single family detached designs of one story, split level, and two story all had the same cost effective levels of the ECMs and had similar shapes of the energy dollar per unit versus ECM level curves. In a similar fashion, the single family attached dwellings of end and mid-unit townhouse, and end and mid-unit apartment were identified as an equivalent grouping (see graphs at end of paper).

Both of these groups were checked to make sure there were no anomalies in the cost data within a group, that is the addition of a given level of ECM had the same cost for all designs within a group. Both groups also met this criterion so it was concluded that the seven designs could be represented by two prototype groups for the purposes of developing and presenting the standard.

Analyses of manufactured housing indicated an energy equivalence between the two types, but there was a lack of ECM cost equivalence. Particularly in the addition of ceiling insulation, there was a difference in construction requirements between the single-wide and the double-wide. This results in different costs for each ECM level so it is difficult to combine them into one prototype for the economic optimization process. However, the two designs can be represented as one prototype in the energy analysis and thus within the data base.

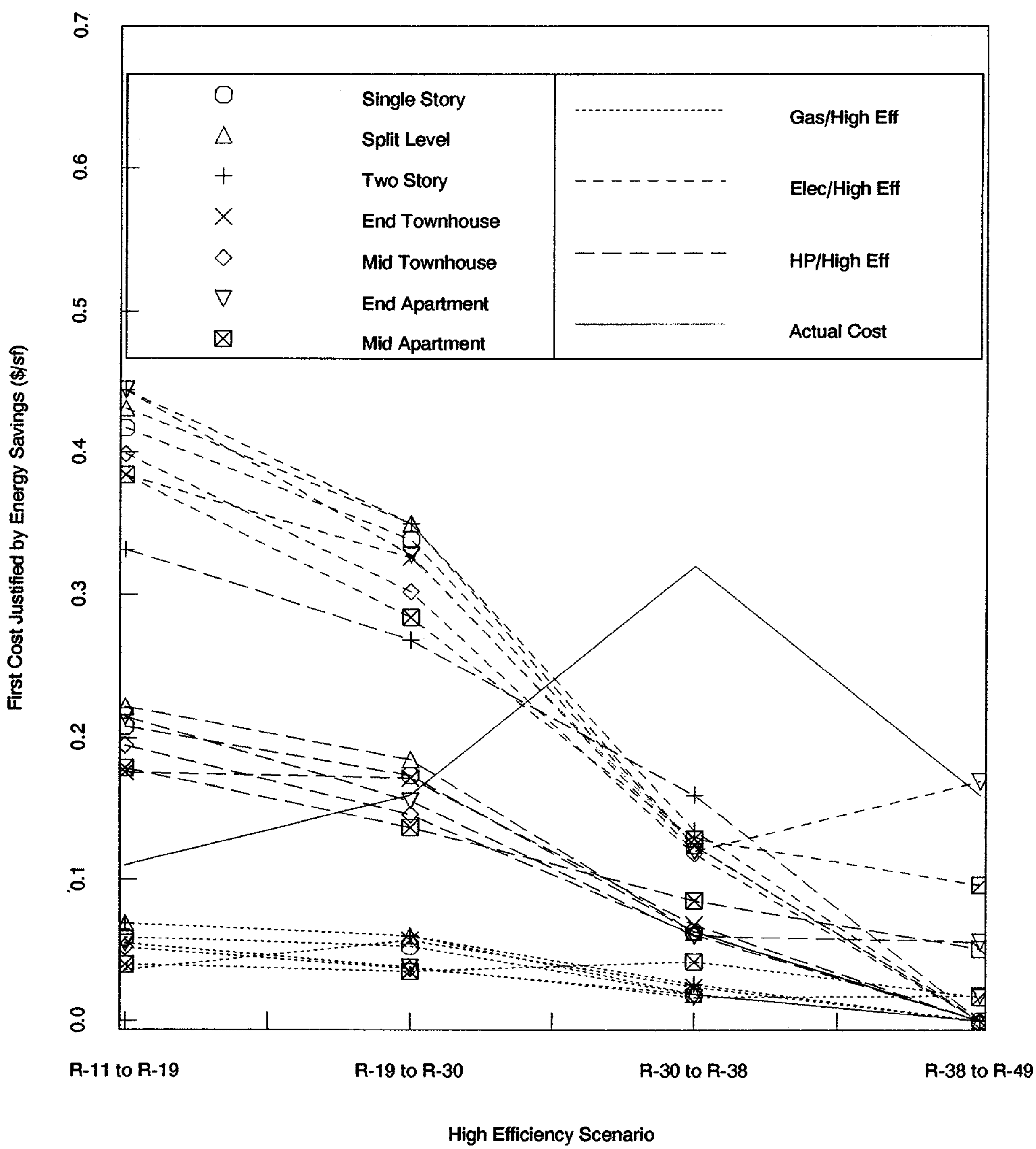
For the majority of the standard, it will be sufficient to utilize three prototypes to represent residential structures: single family detached, single family attached, and manufactured housing. Only in the economic optimization process is it necessary to differentiate between single and double wide manufactured housing.

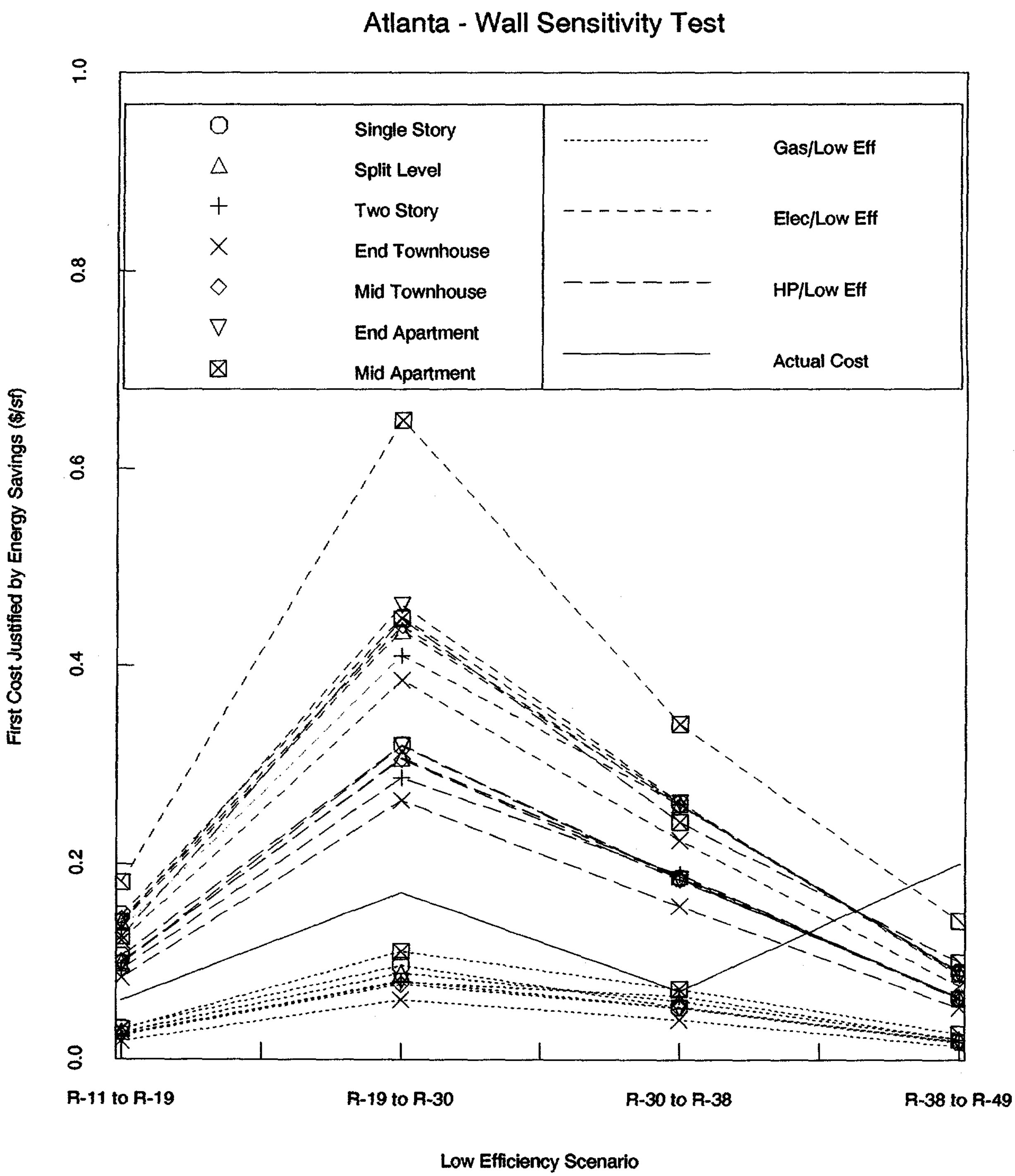
To check on the effects of changes in size and aspect ratio, an analysis was completed in the fall of 1985 for SP-53. The analysis included three climate areas: Atlanta, Miami, and Minneapolis. Heating energy consumption on a per square foot basis was constant over the range of aspect ratios and floor areas (1080 to 2600 sf) considered. Cooling was not constant with less consumption per square foot as the floor area increased. This was due to the constant internal loads for all floor areas considered. However, as the assumption on floor area only impacts the base load in the point system, and comparisons are made between two designs of the same floor area, this deviation will have little effect on the equivalency among paths. The conclusion was that by using the parallel compliance approach, floor area could be used to characterize a design and to determine base loads. All other ECMs will scale with the size of the component where the ECM is applied. As long as each ECM is used on a per unit basis, the methodology is applicable to designs of any size and aspect ratio (limit on size to below 5000 square feet).

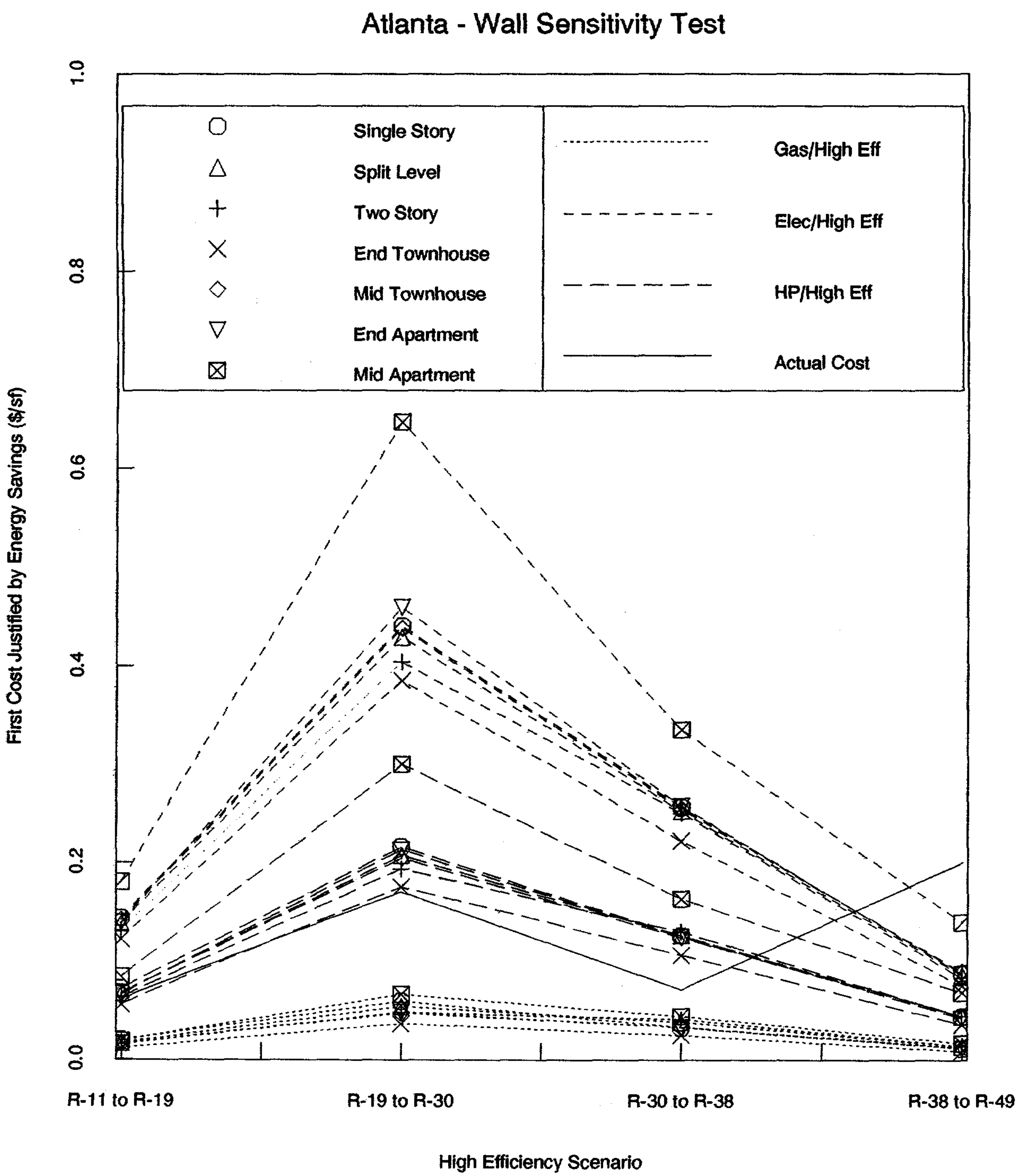


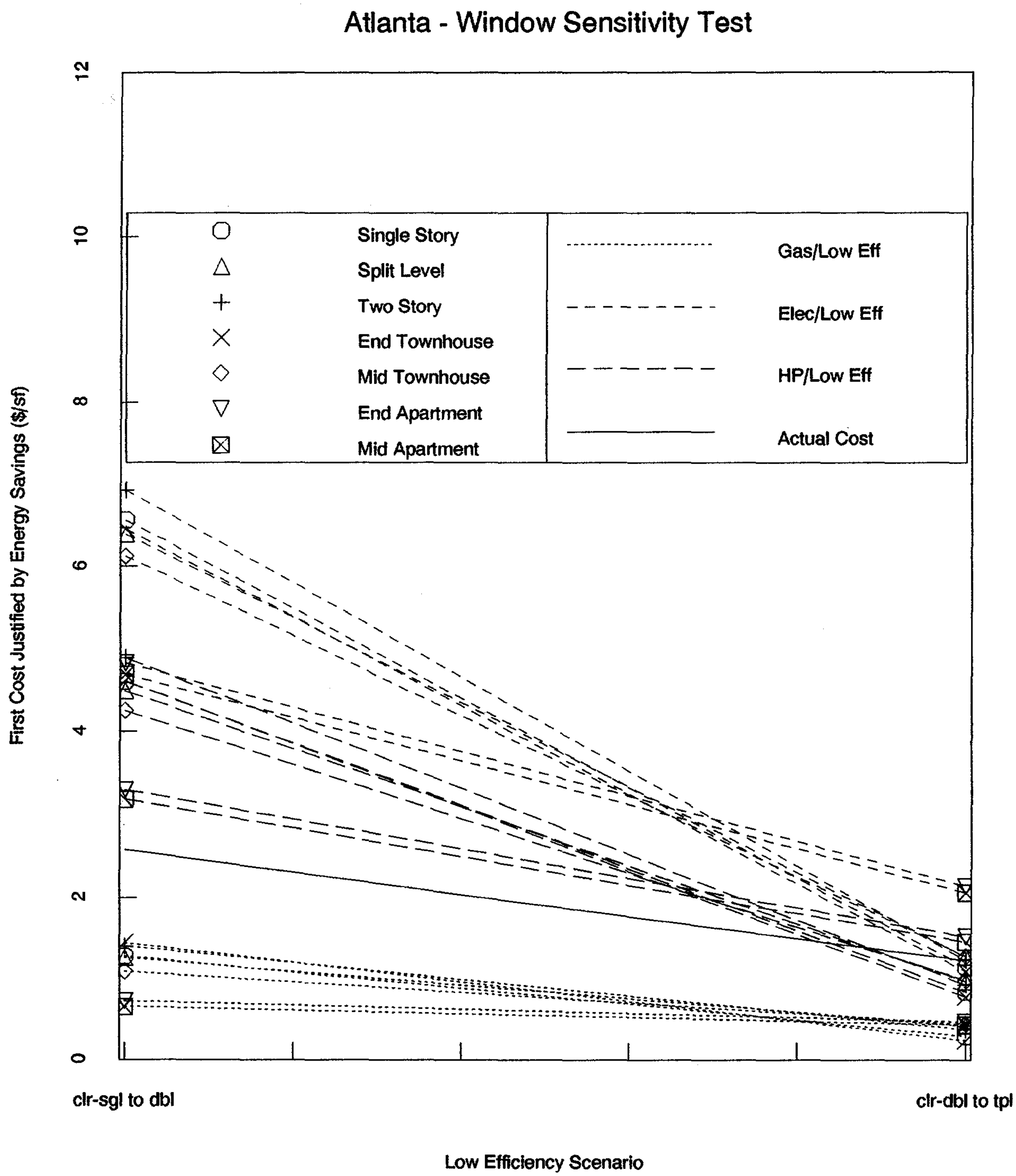
Atlanta - Ceiling Sensitivity Test
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/Low Eff
Elec/Low Eff
HP/Low Eff
Actual Cost
First Cost Justified by Energy Savings ($/sf)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
R-11 to R-19
R-19 to R-30
R-30 to R-38
R-38 to R-49
Low Efficiency Scenario

Atlanta - Ceiling Sensitivity Test

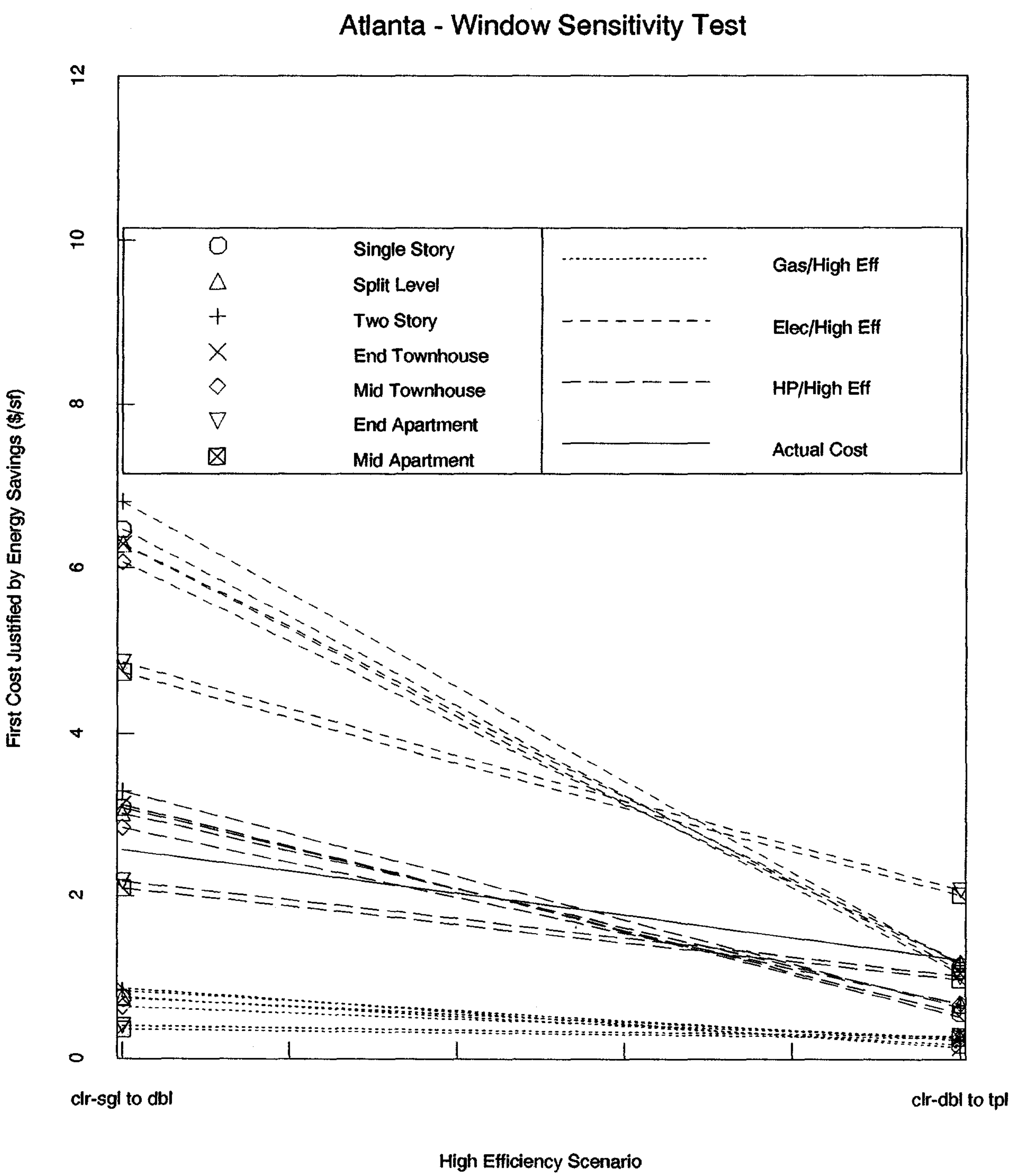



Atlanta - Wall Sensitivity Test
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/Low Eff
Elec/Low Eff
HP/Low Eff
Actual Cost
First Cost Justified by Energy Savings ($/sf)
0.0
0.2
0.4
0.6
0.8
1.0
R-11 to R-19
R-19 to R-30
R-30 to R-38
R-38 to R-49
Low Efficiency Scenario

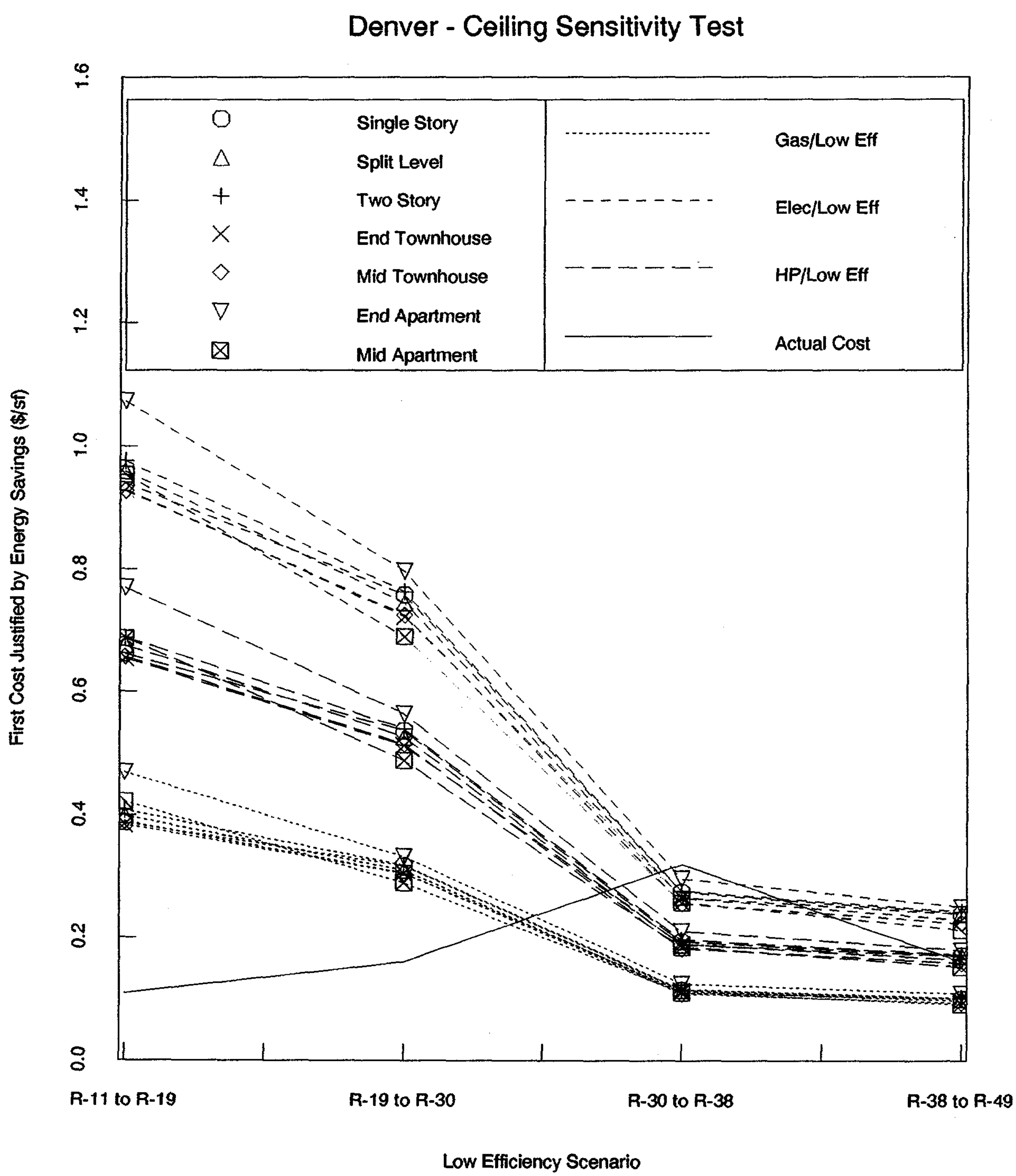

Atlanta - Wall Sensitivity Test
1.0
0.8
0.6
0.4
0.2
0.0
First Cost Justified by Energy Savings ($/sf)
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/High Eff
Elec/High Eff
HP/High Eff
Actual Cost
R-11 to R-19
R-19 to R-30
R-30 to R-38
R-38 to R-49
High Efficiency Scenario

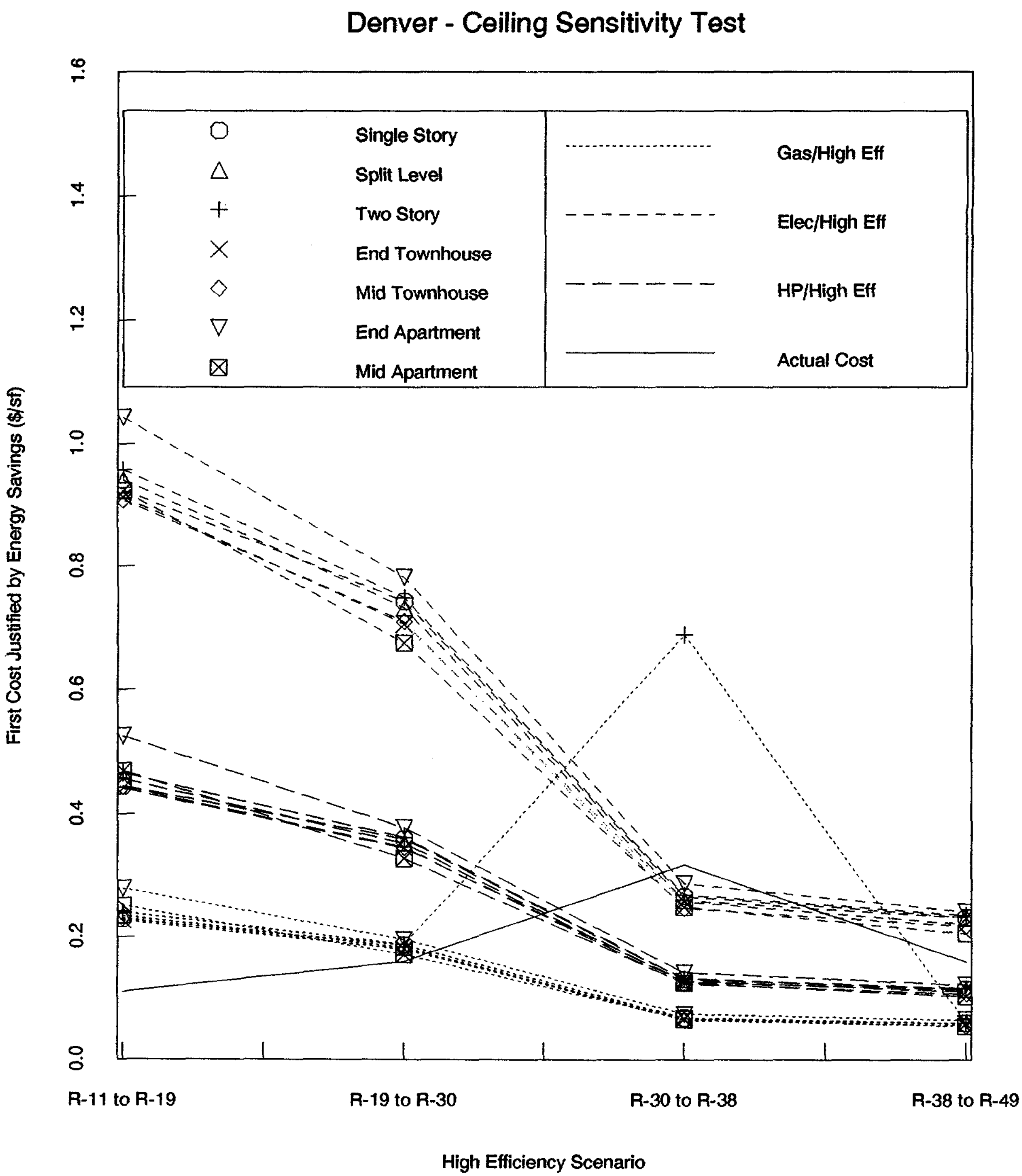


Atlanta - Window Sensitivity Test
First Cost Justified by Energy Savings ($/sf)
0
2
4
6
8
10
12
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/Low Eff
Elec/Low Eff
HP/Low Eff
Actual Cost
clr-sgl to dbl
clr-dbl to tpl
Low Efficiency Scenario

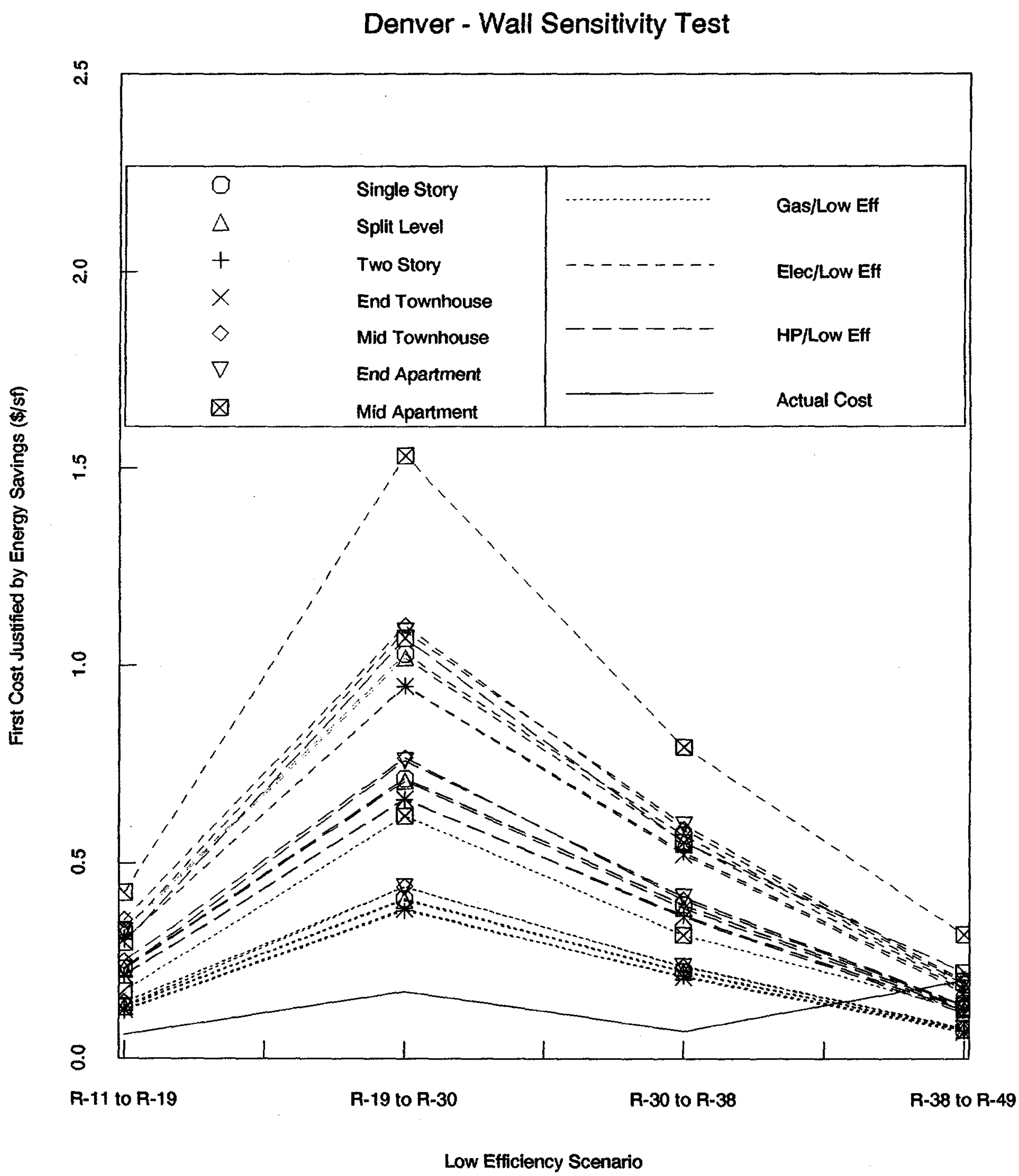


Atlanta - Window Sensitivity Test
First Cost Justified by Energy Savings ($/sf)
0
2
4
6
8
10
12
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/High Eff
Elec/High Eff
HP/High Eff
Actual Cost
clr-sgl to dbl
clr-dbl to tpl
High Efficiency Scenario

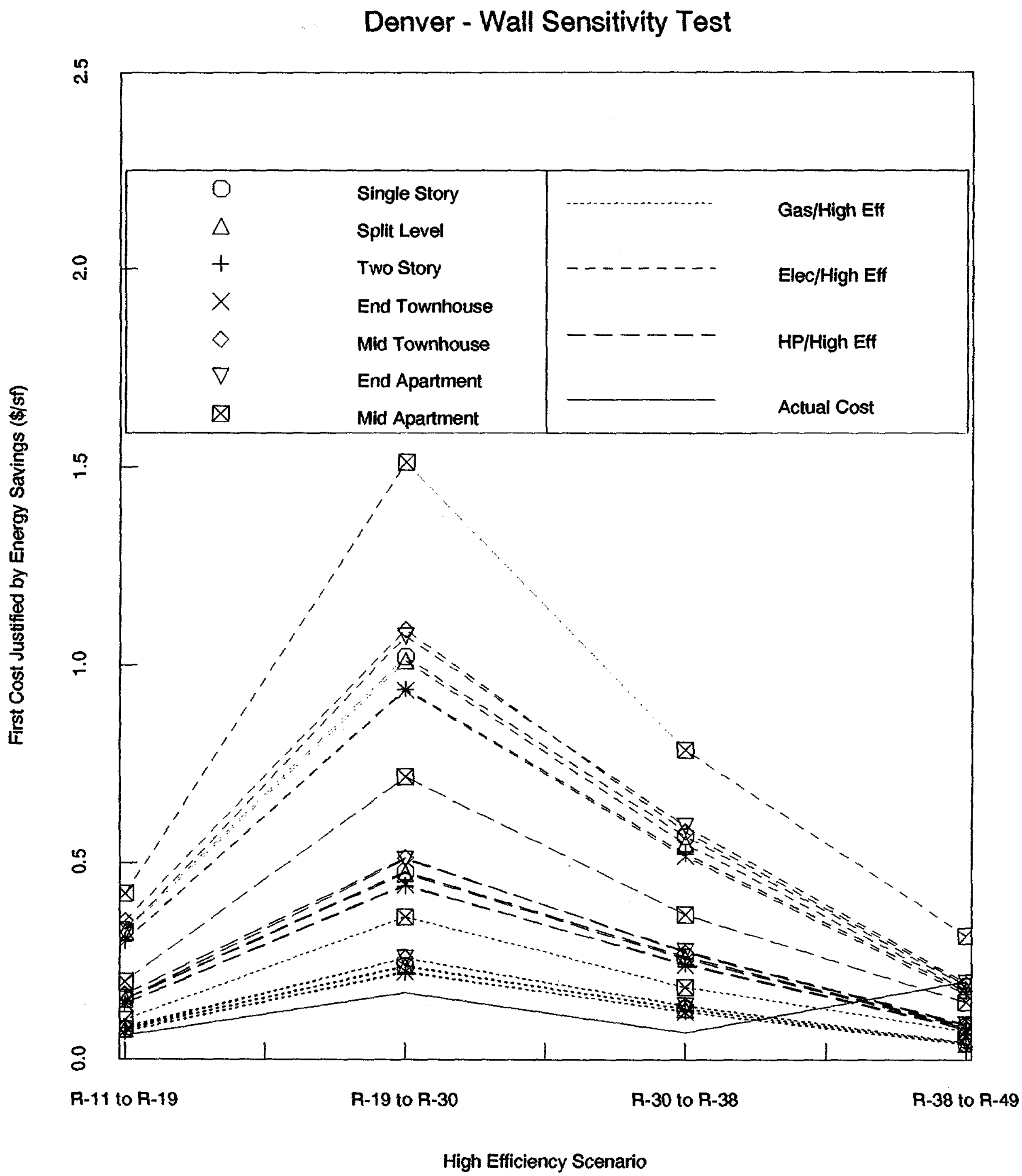

Denver - Ceiling Sensitivity Test
First Cost Justified by Energy Savings ($/sf)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/Low Eff
Elec/Low Eff
HP/Low Eff
Actual Cost
R-11 to R-19
R-19 to R-30
R-30 to R-38
R-38 to R-49
Low Efficiency Scenario



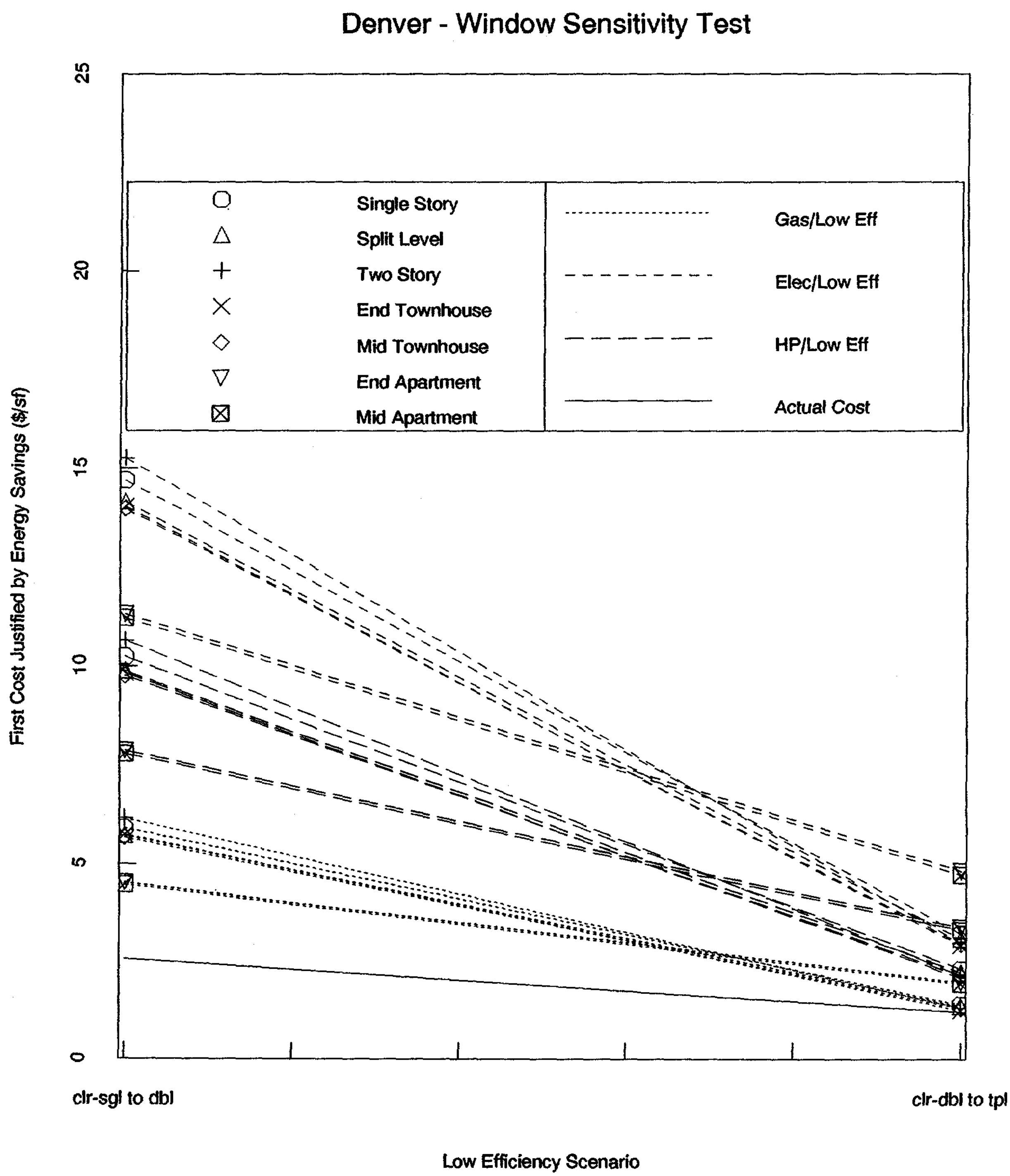
Denver - Ceiling Sensitivity Test
First Cost Justified by Energy Savings ($/sf)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/High Eff
Elec/High Eff
HP/High Eff
Actual Cost
R-11 to R-19
R-19 to R-30
R-30 to R-38
R-38 to R-49
High Efficiency Scenario



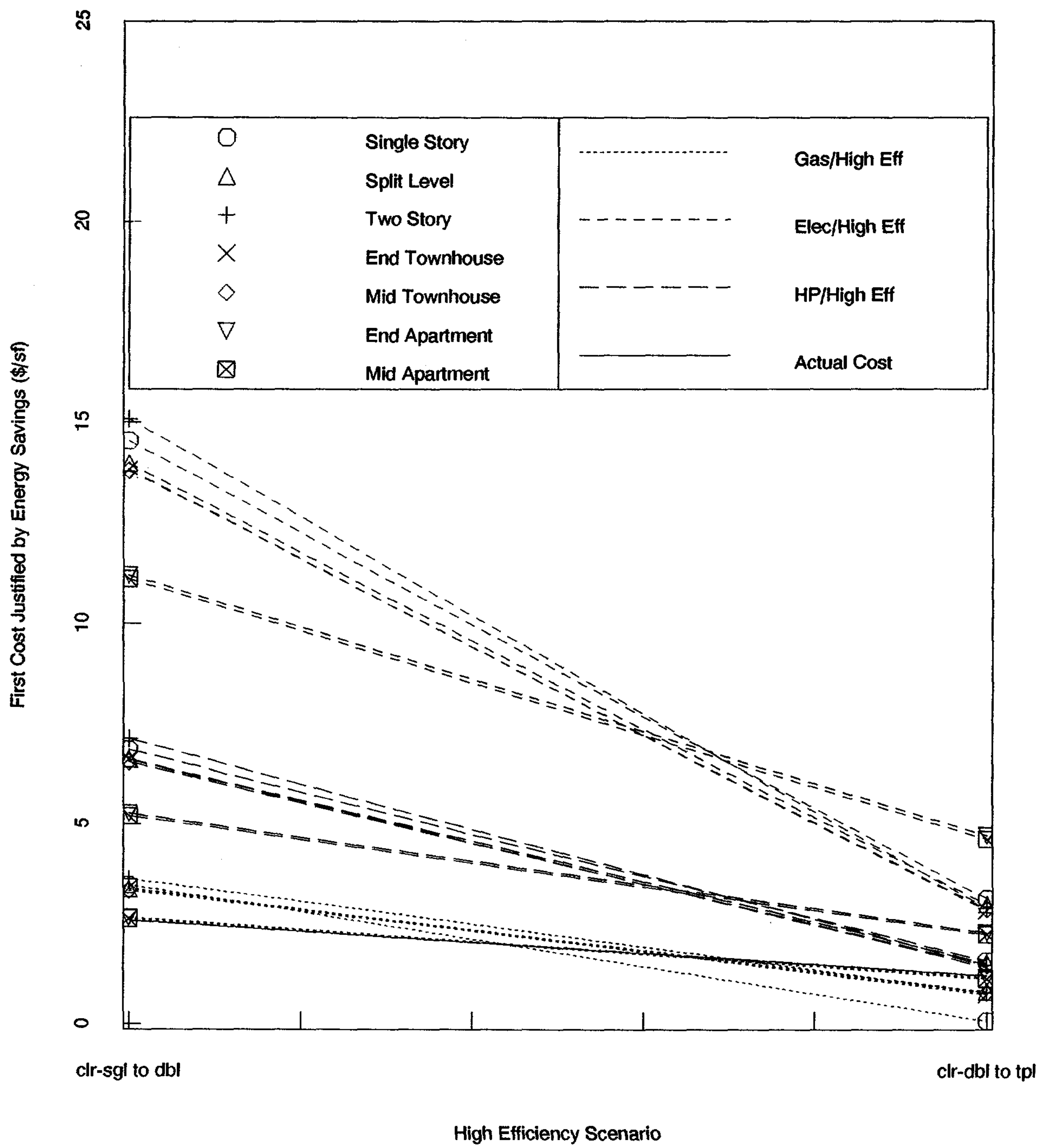
Denver - Wall Sensitivity Test
First Cost Justified by Energy Savings ($/sf)
0.0
0.5
1.0
1.5
2.0
2.5
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/Low Eff
Elec/Low Eff
HP/Low Eff
Actual Cost
R-11 to R-19
R-19 to R-30
R-30 to R-38
R-38 to R-49
Low Efficiency Scenario

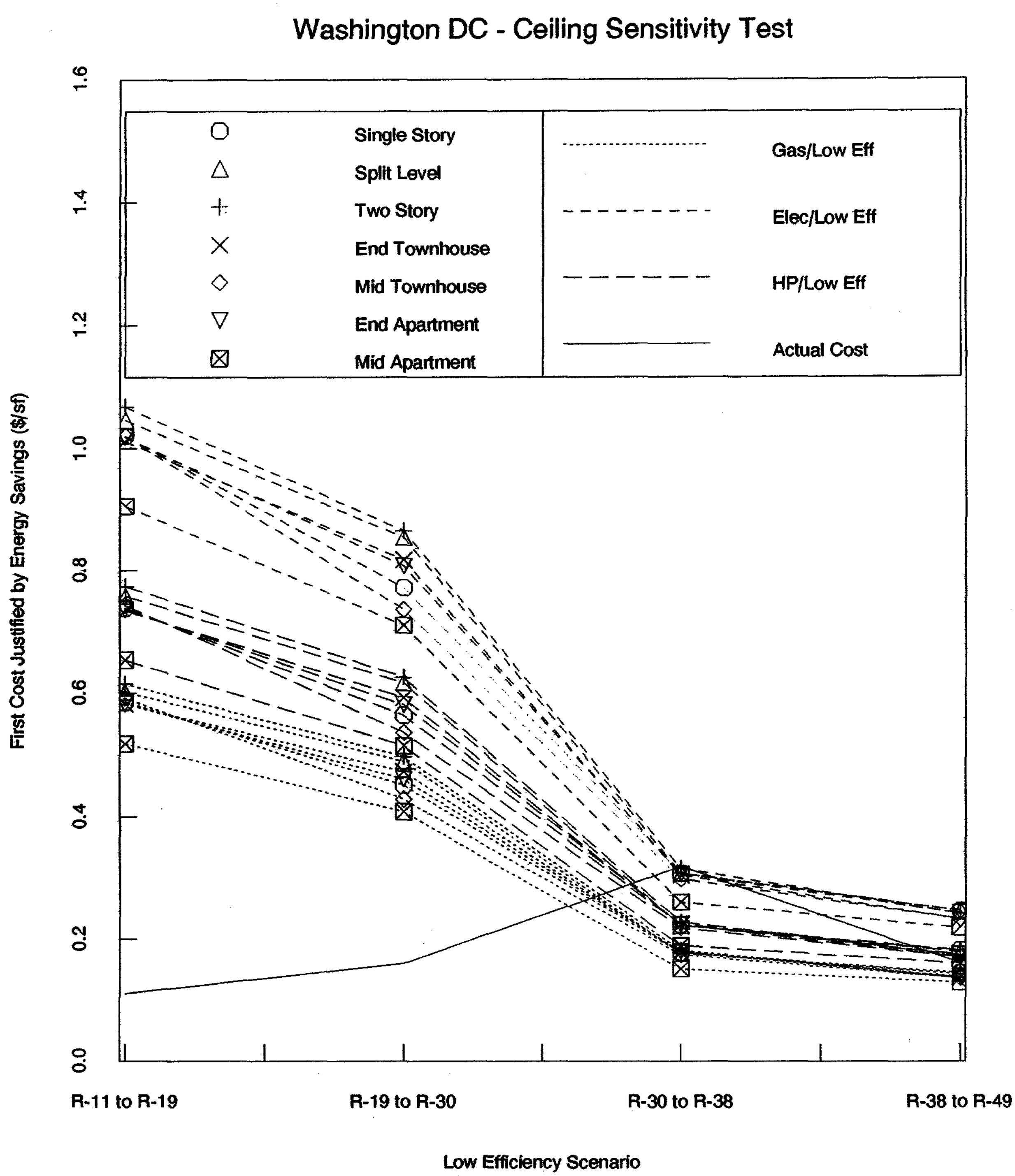


Denver - Wall Sensitivity Test
First Cost Justified by Energy Savings ($/sf)
0.0
0.5
1.0
1.5
2.0
2.5
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/High Eff
Elec/High Eff
HP/High Eff
Actual Cost
R-11 to R-19
R-19 to R-30
R-30 to R-38
R-38 to R-49
High Efficiency Scenario

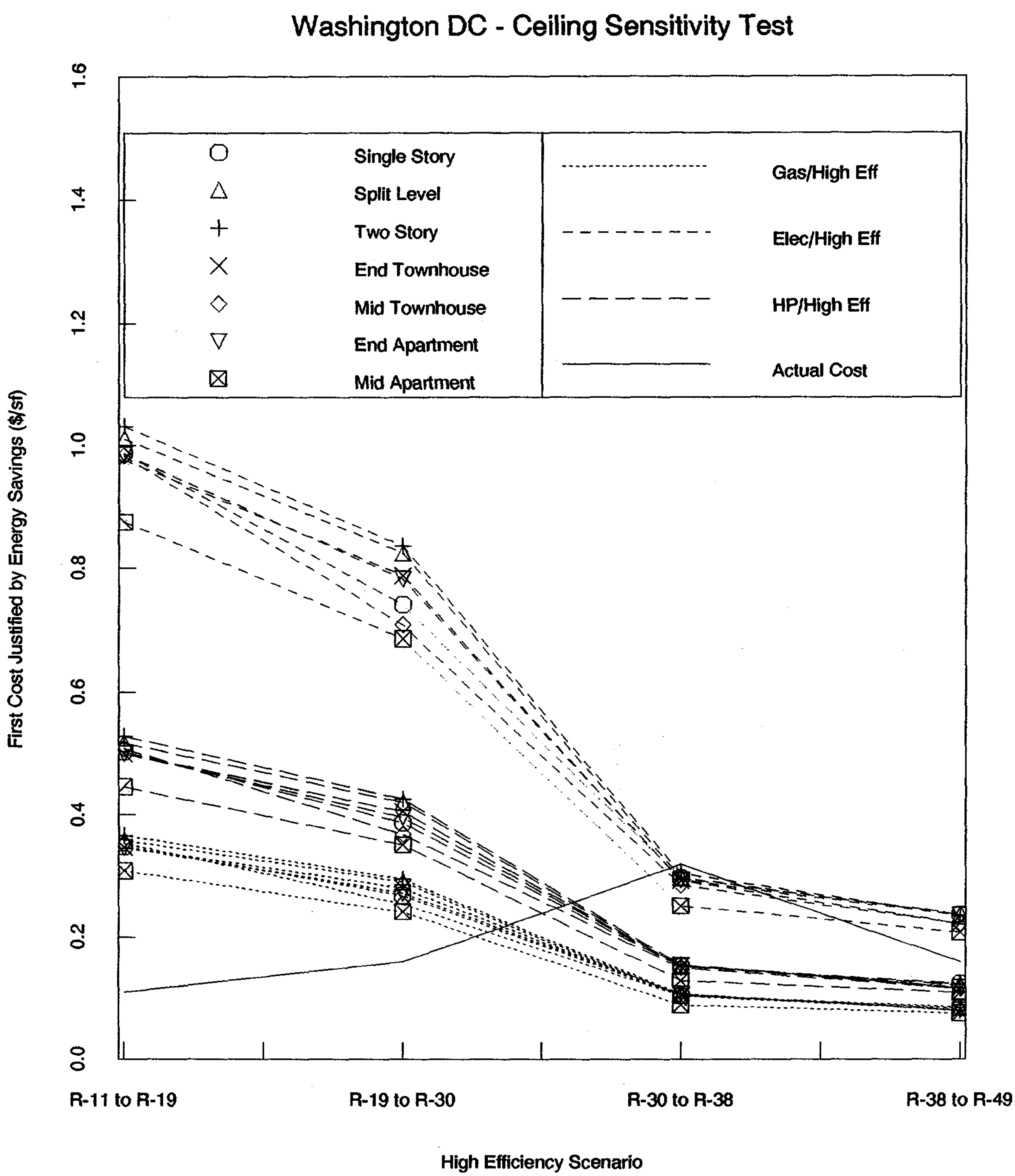

Denver - Window Sensitivity Test
First Cost Justified by Energy Savings ($/sf)
0
5
10
15
20
25
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/Low Eff
Elec/Low Eff
HP/Low Eff
Actual Cost
clr-sgl to dbl
clr-dbl to tpl
Low Efficiency Scenario

Denver - Window Sensitivity Test

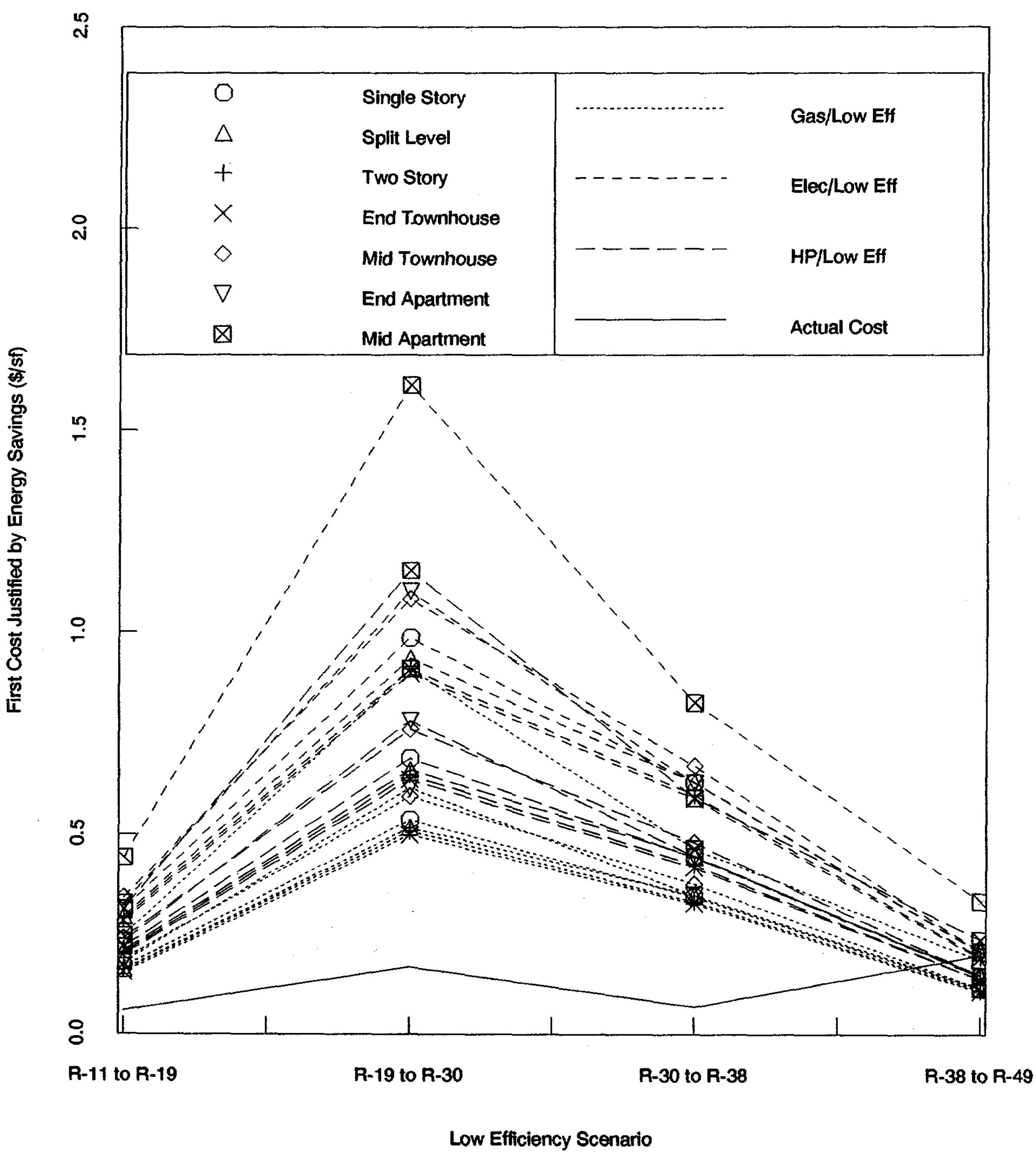


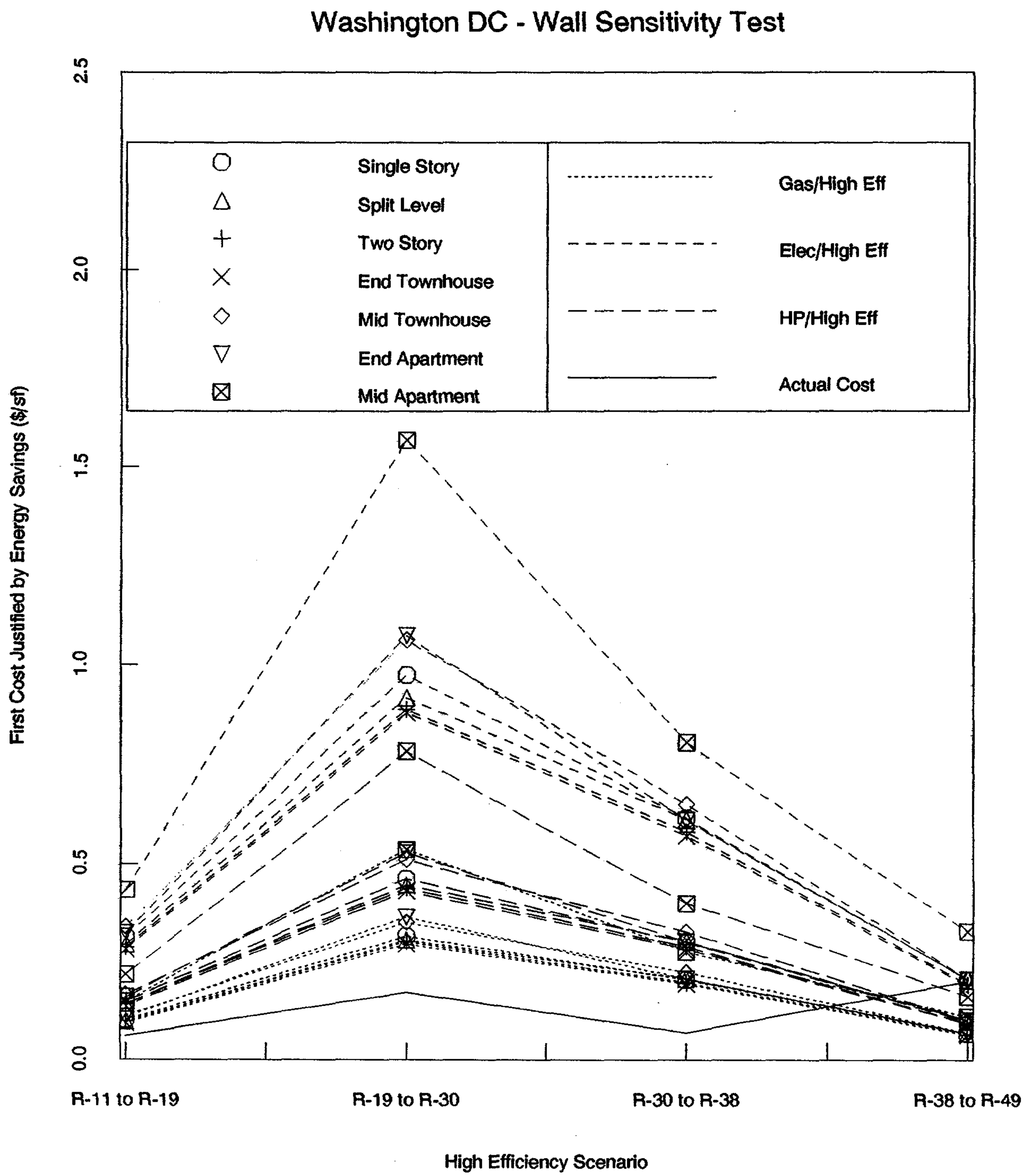


Washington DC - Ceiling Sensitivity Test
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/Low Eff
Elec/Low Eff
HP/Low Eff
Actual Cost
First Cost Justified by Energy Savings ($/sf)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
R-11 to R-19
R-19 to R-30
R-30 to R-38
R-38 to R-49
Low Efficiency Scenario

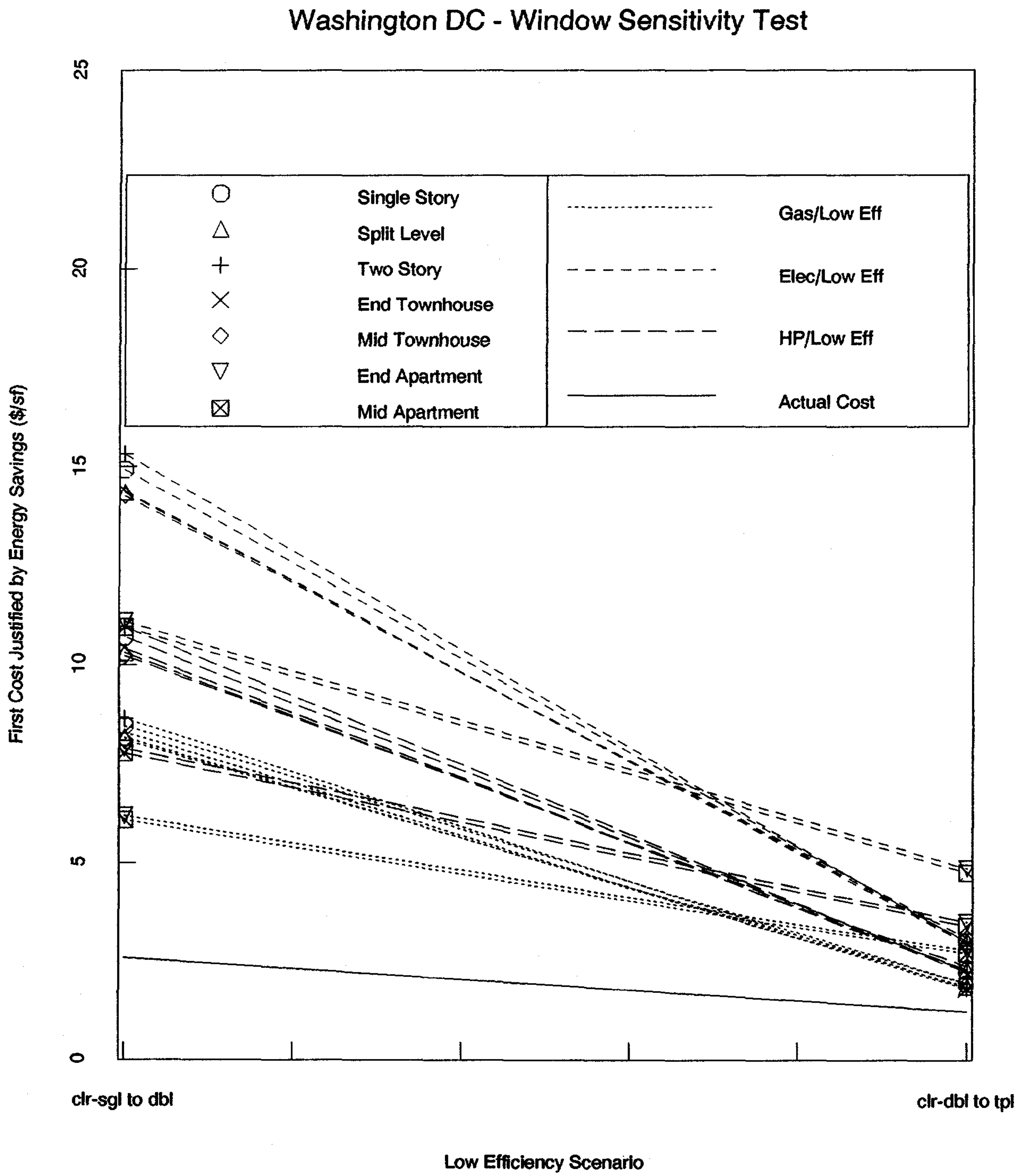

Washington DC - Ceiling Sensitivity Test
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/High Eff
Elec/High Eff
HP/High Eff
Actual Cost
First Cost Justified by Energy Savings ($/sf)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
R-11 to R-19
R-19 to R-30
R-30 to R-38
R-38 to R-49
High Efficiency Scenario

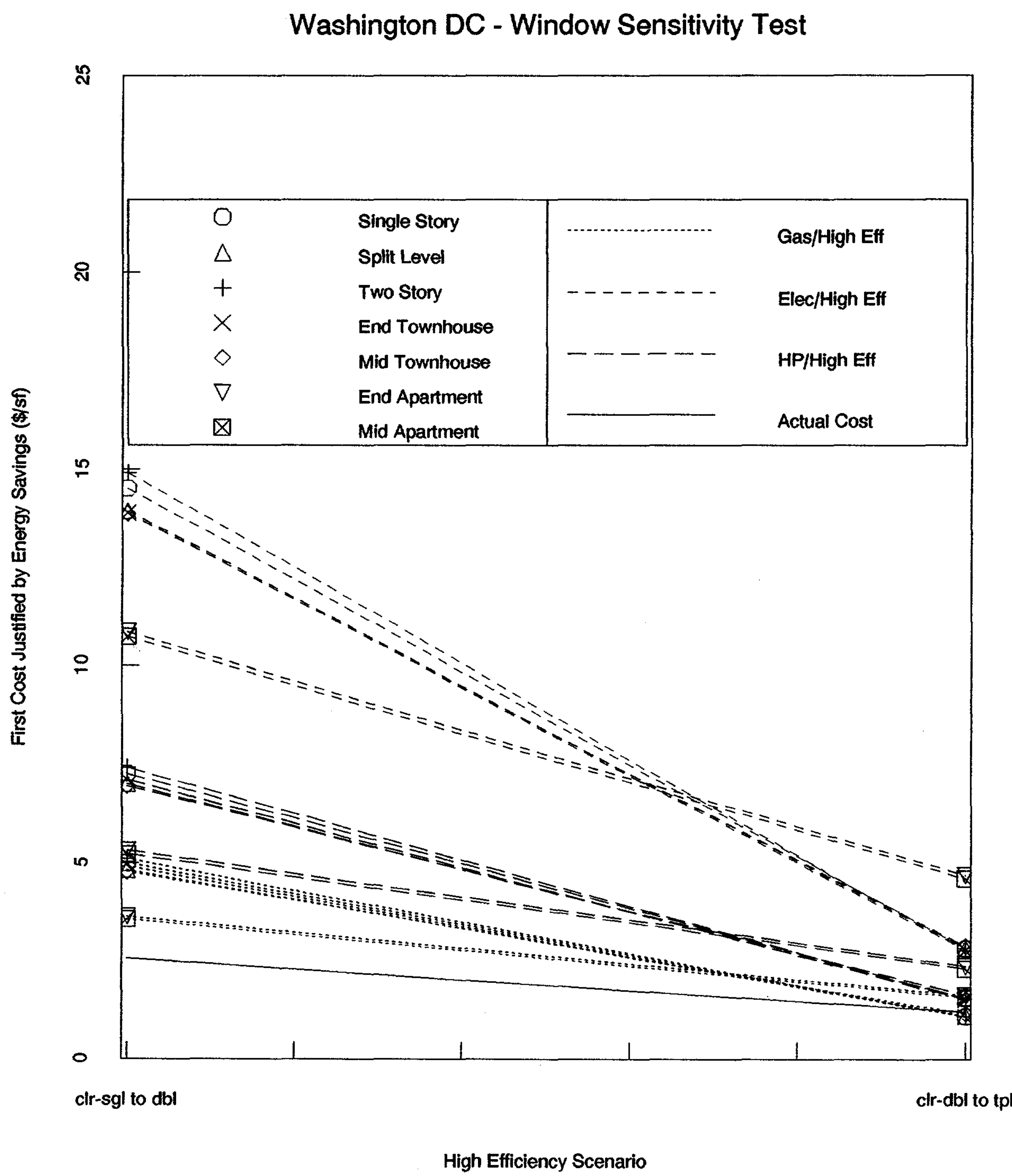
Washington DC - Wall Sensitivity Test

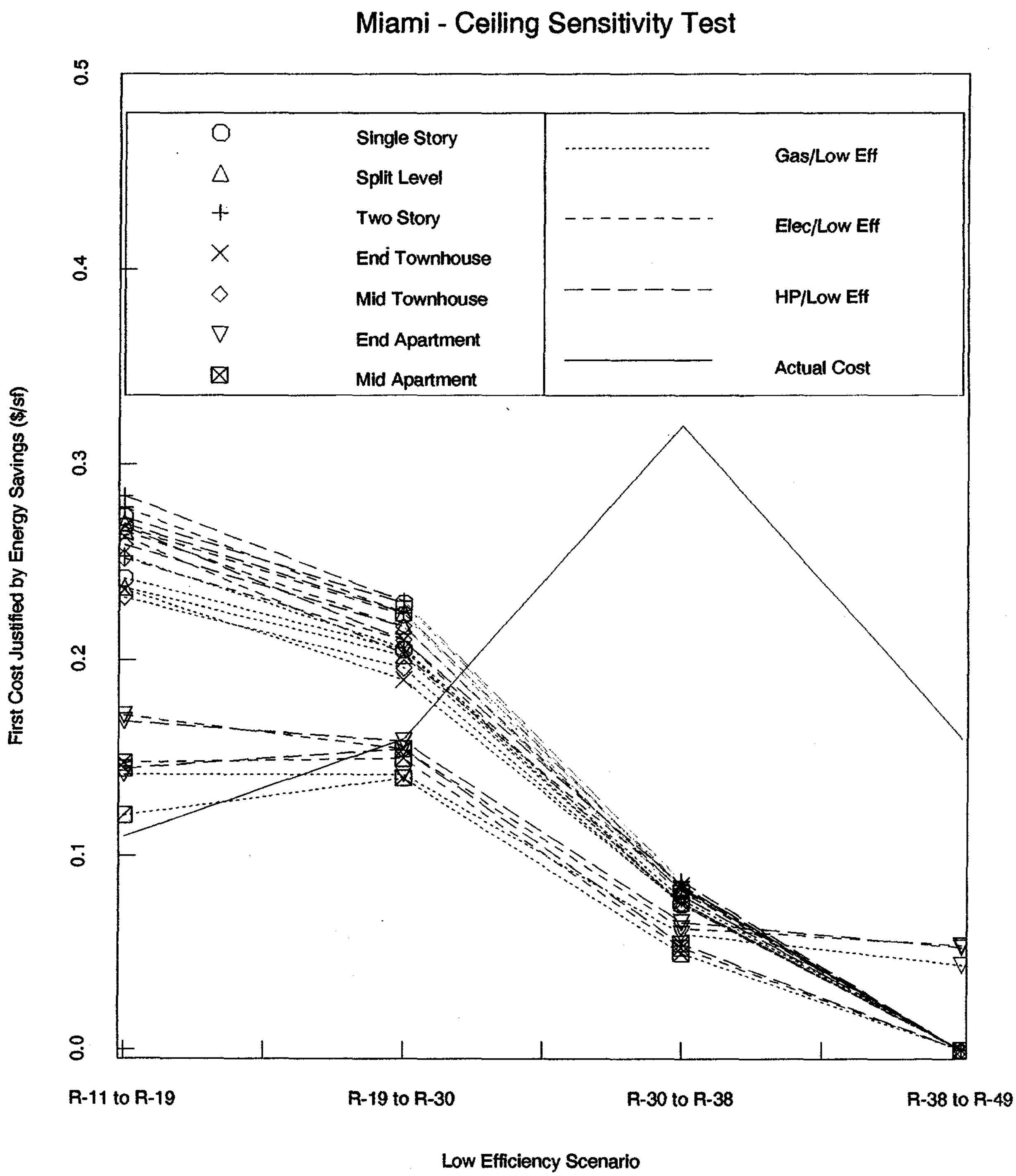




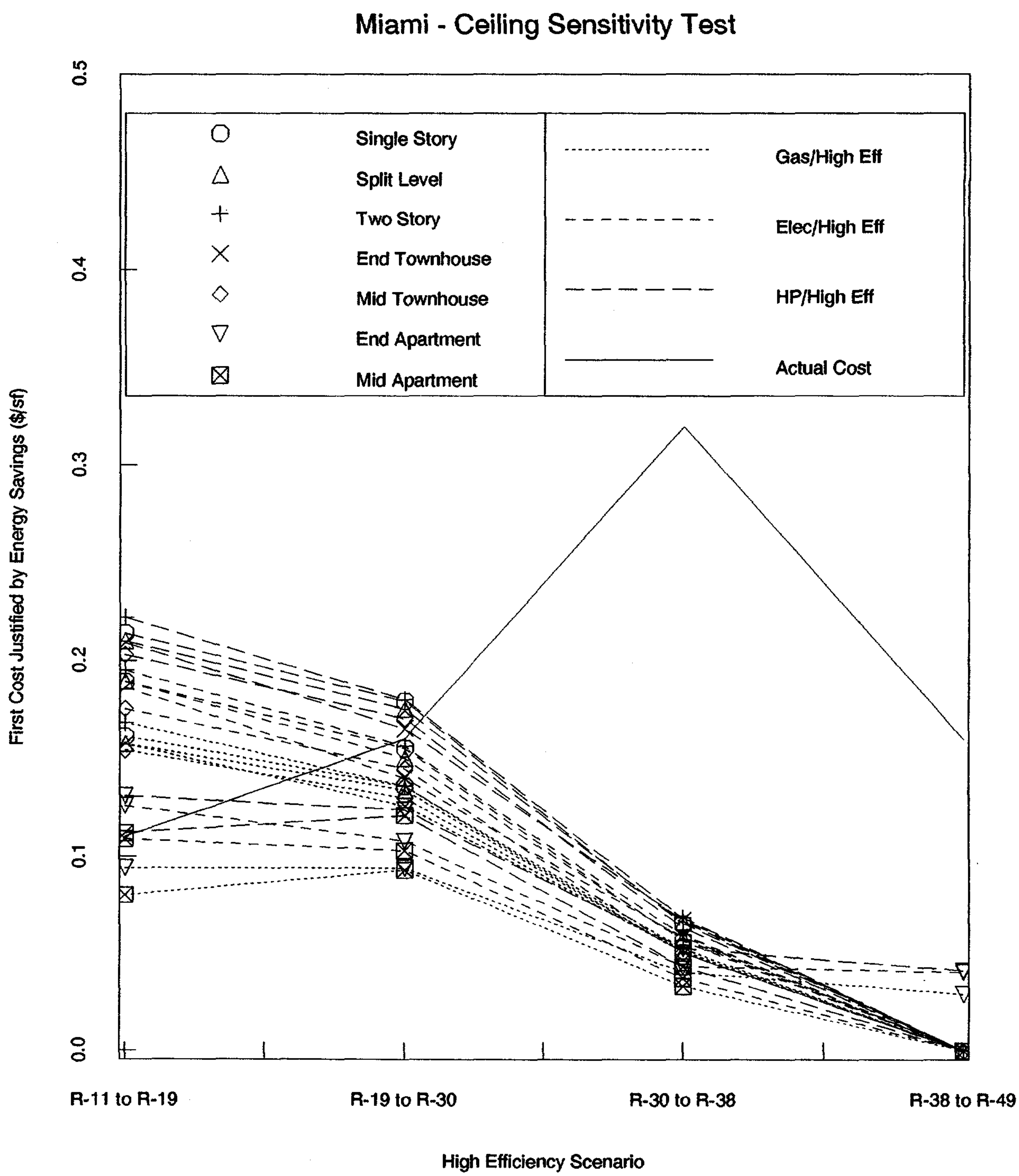
Washington DC - Wall Sensitivity Test
2.5
2.0
1.5
1.0
0.5
0.0
First Cost Justified by Energy Savings ($/sf)
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/High Eff
Elec/High Eff
HP/High Eff
Actual Cost
R-11 to R-19
R-19 to R-30
R-30 to R-38
R-38 to R-49
High Efficiency Scenario


Washington DC - Window Sensitivity Test
First Cost Justified by Energy Savings ($/sf)
0
5
10
15
20
25
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/Low Eff
Elec/Low Eff
HP/Low Eff
Actual Cost
clr-sgl to dbl
clr-dbl to tpl
Low Efficiency Scenario

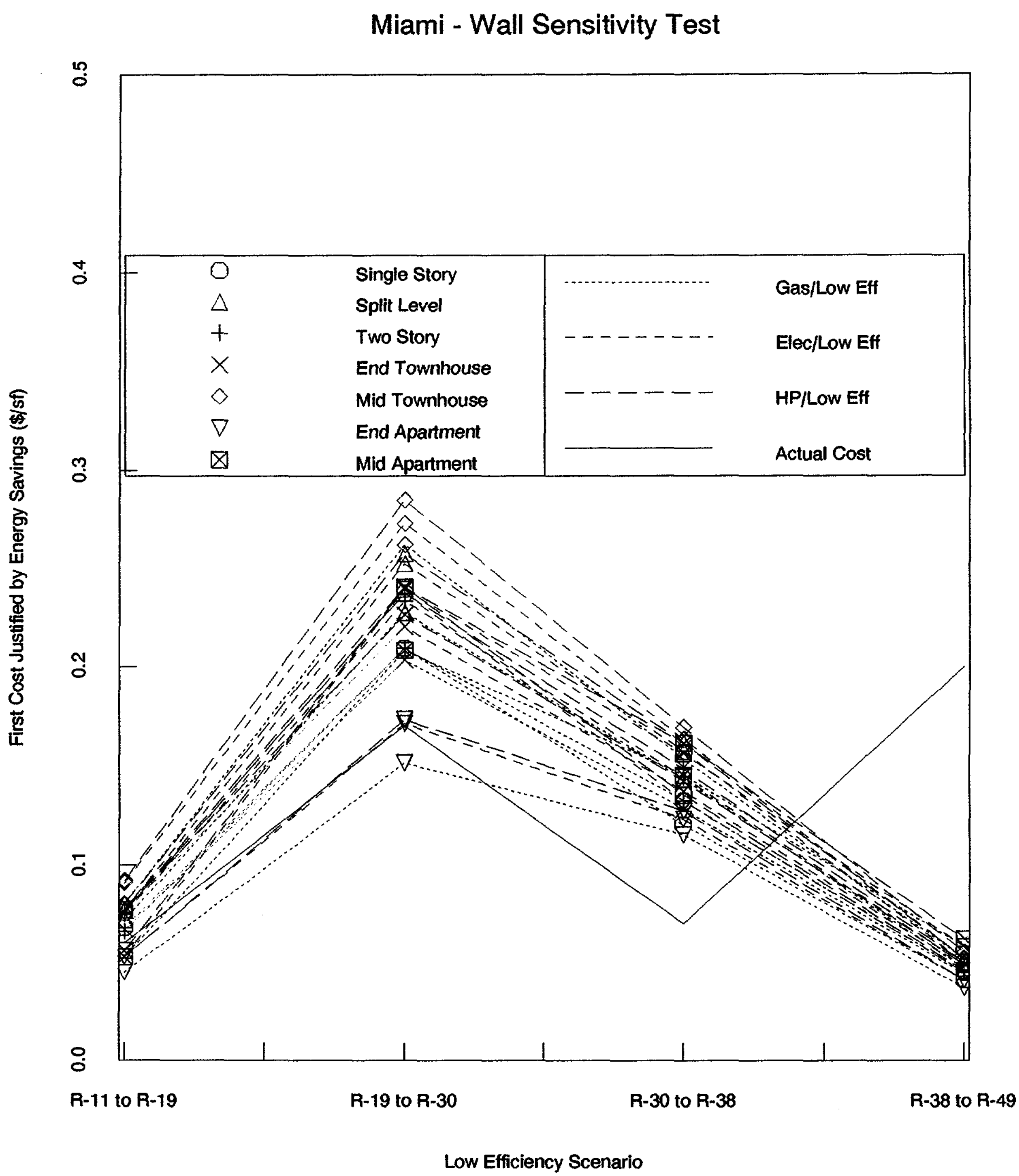

Washington DC - Window Sensitivity Test
First Cost Justified by Energy Savings ($/sf)
25
20
15
10
5
0
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/High Eff
Elec/High Eff
HP/High Eff
Actual Cost
clr-sgl to dbl
clr-dbl to tpl
High Efficiency Scenario



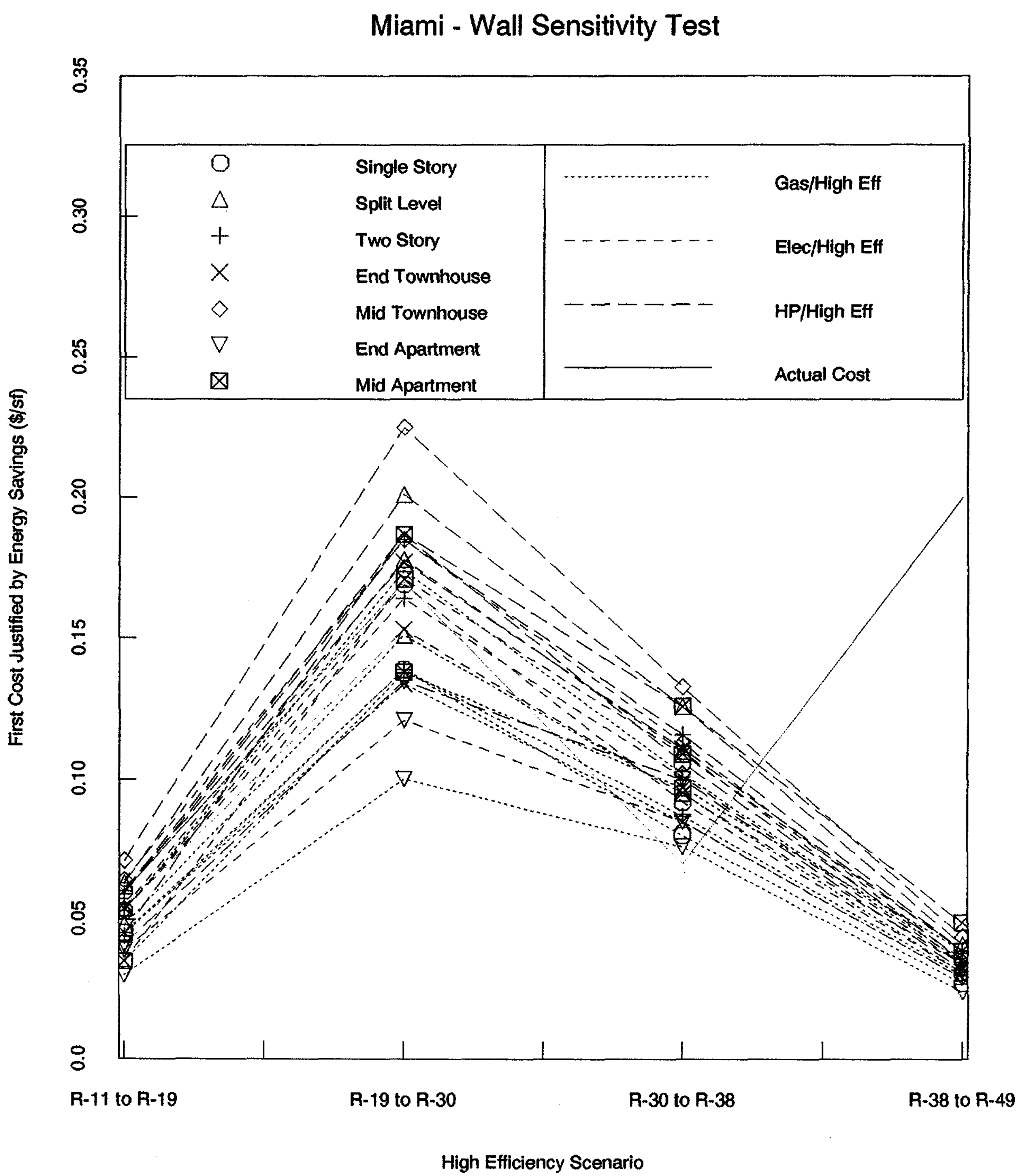
Miami - Ceiling Sensitivity Test
First Cost Justified by Energy Savings ($/sf)
0.0
0.1
0.2
0.3
0.4
0.5
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/Low Eff
Elec/Low Eff
HP/Low Eff
Actual Cost
R-11 to R-19
R-19 to R-30
R-30 to R-38
R-38 to R-49
Low Efficiency Scenario



Miami - Ceiling Sensitivity Test
First Cost Justified by Energy Savings ($/sf)
0.0
0.1
0.2
0.3
0.4
0.5
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/High Eff
Elec/High Eff
HP/High Eff
Actual Cost
R-11 to R-19
R-19 to R-30
R-30 to R-38
R-38 to R-49
High Efficiency Scenario

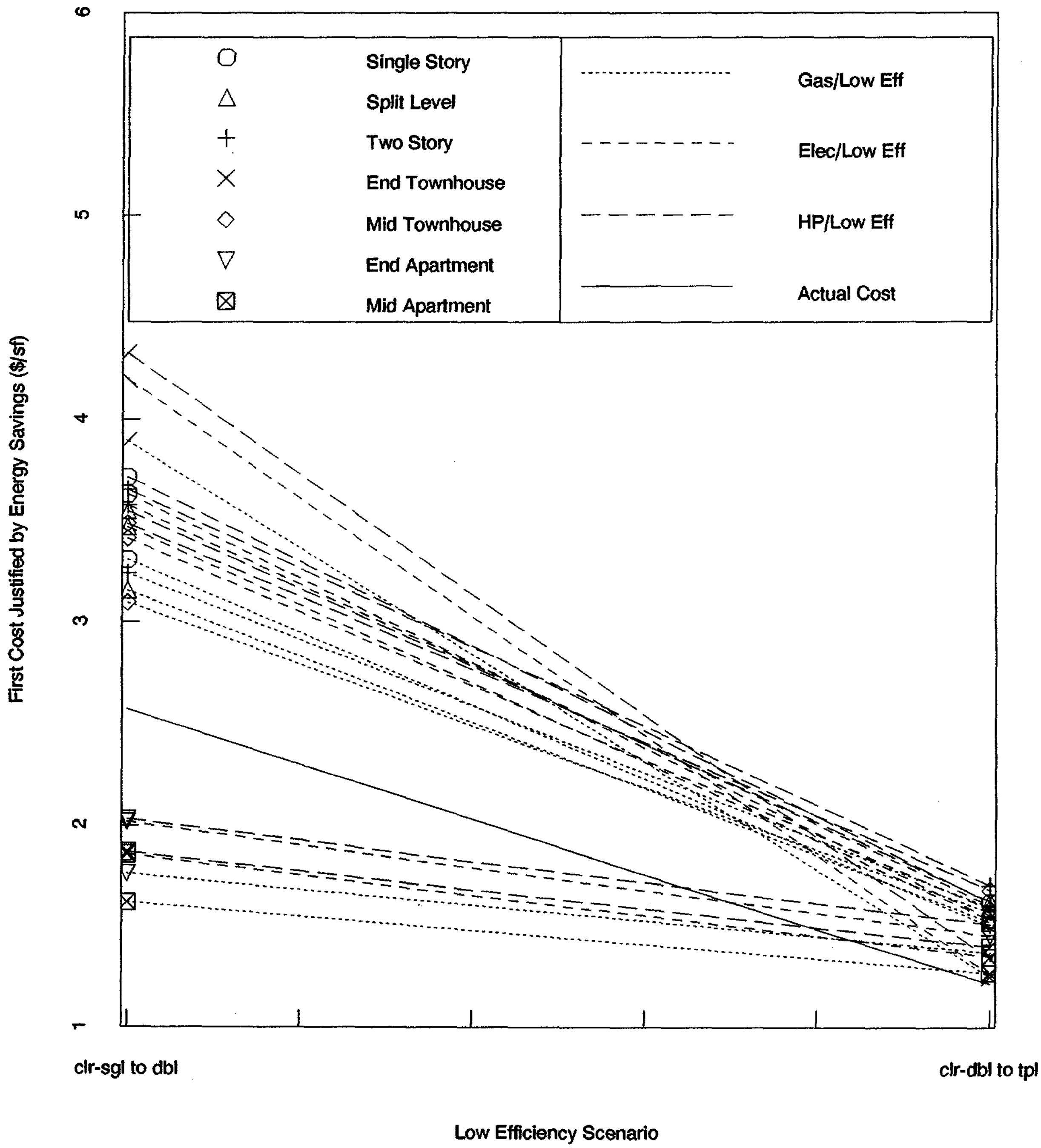


Miami - Wall Sensitivity Test
First Cost Justified by Energy Savings ($/sf)
0.0
0.1
0.2
0.3
0.4
0.5
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/Low Eff
Elec/Low Eff
HP/Low Eff
Actual Cost
R-11 to R-19
R-19 to R-30
R-30 to R-38
R-38 to R-49
Low Efficiency Scenario

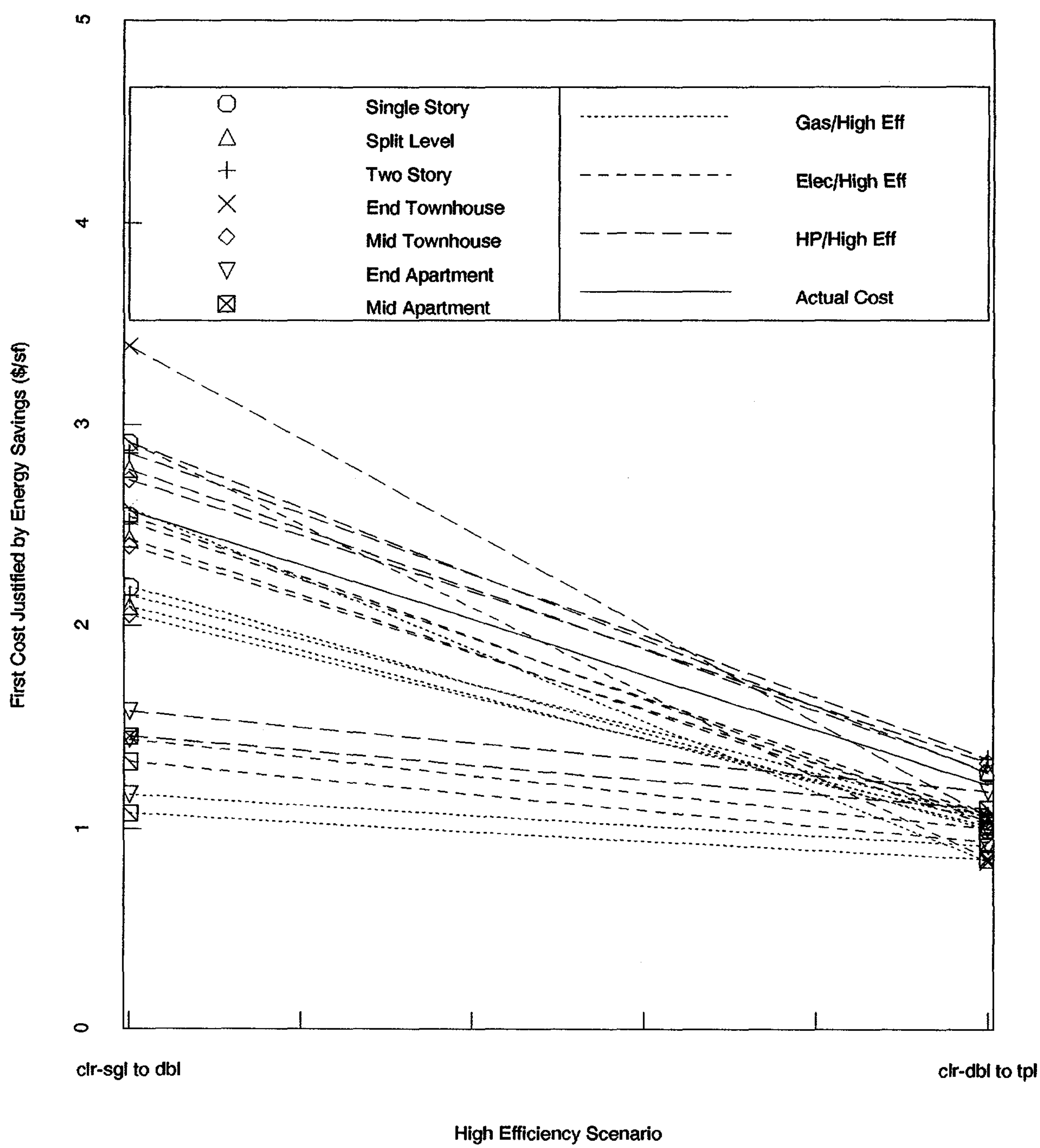


Miami - Wall Sensitivity Test
First Cost Justified by Energy Savings ($/sf)
0.0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/High Eff
Elec/High Eff
HP/High Eff
Actual Cost
R-11 to R-19
R-19 to R-30
R-30 to R-38
R-38 to R-49
High Efficiency Scenario

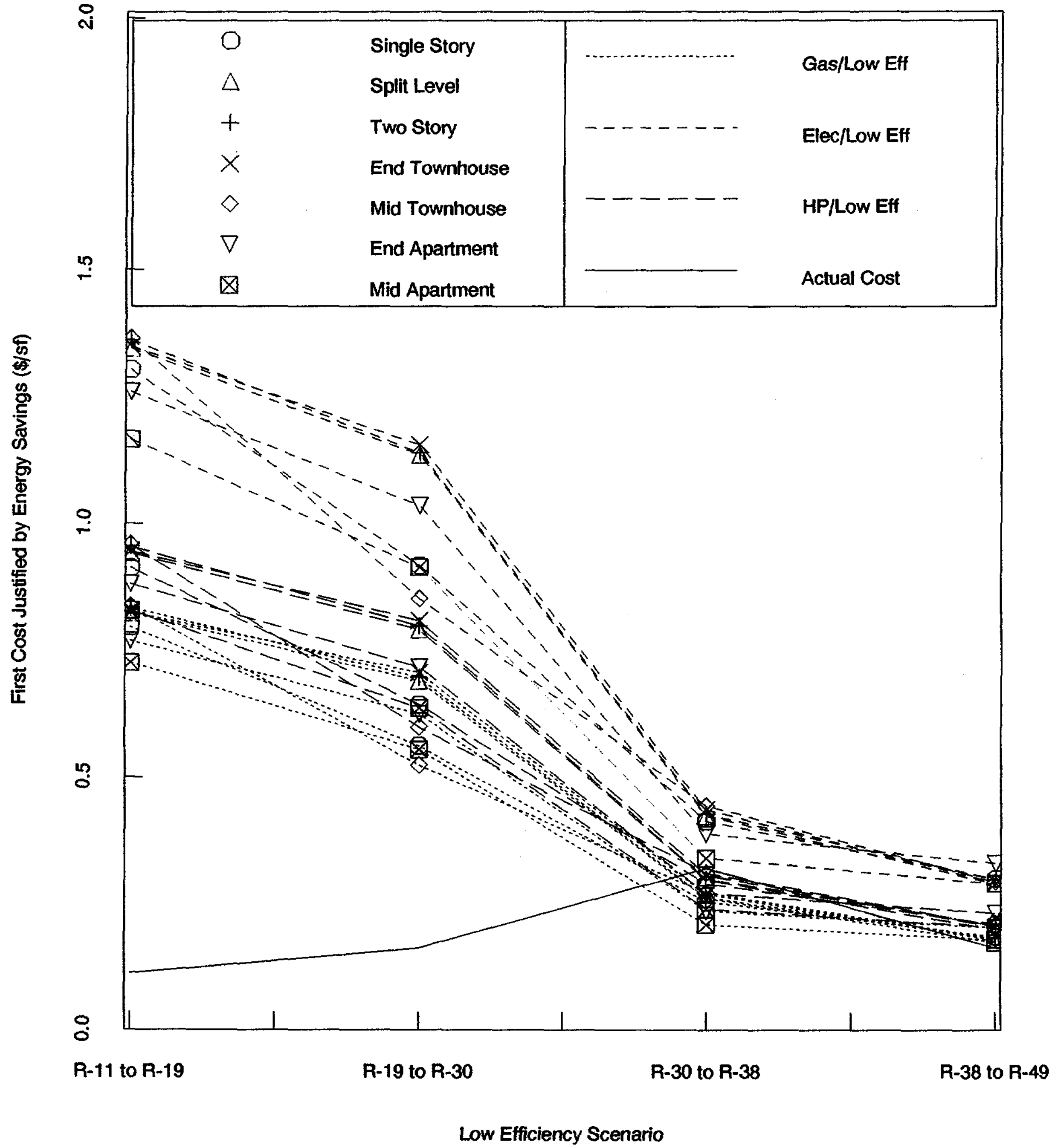
Miami - Window Sensitivity Test



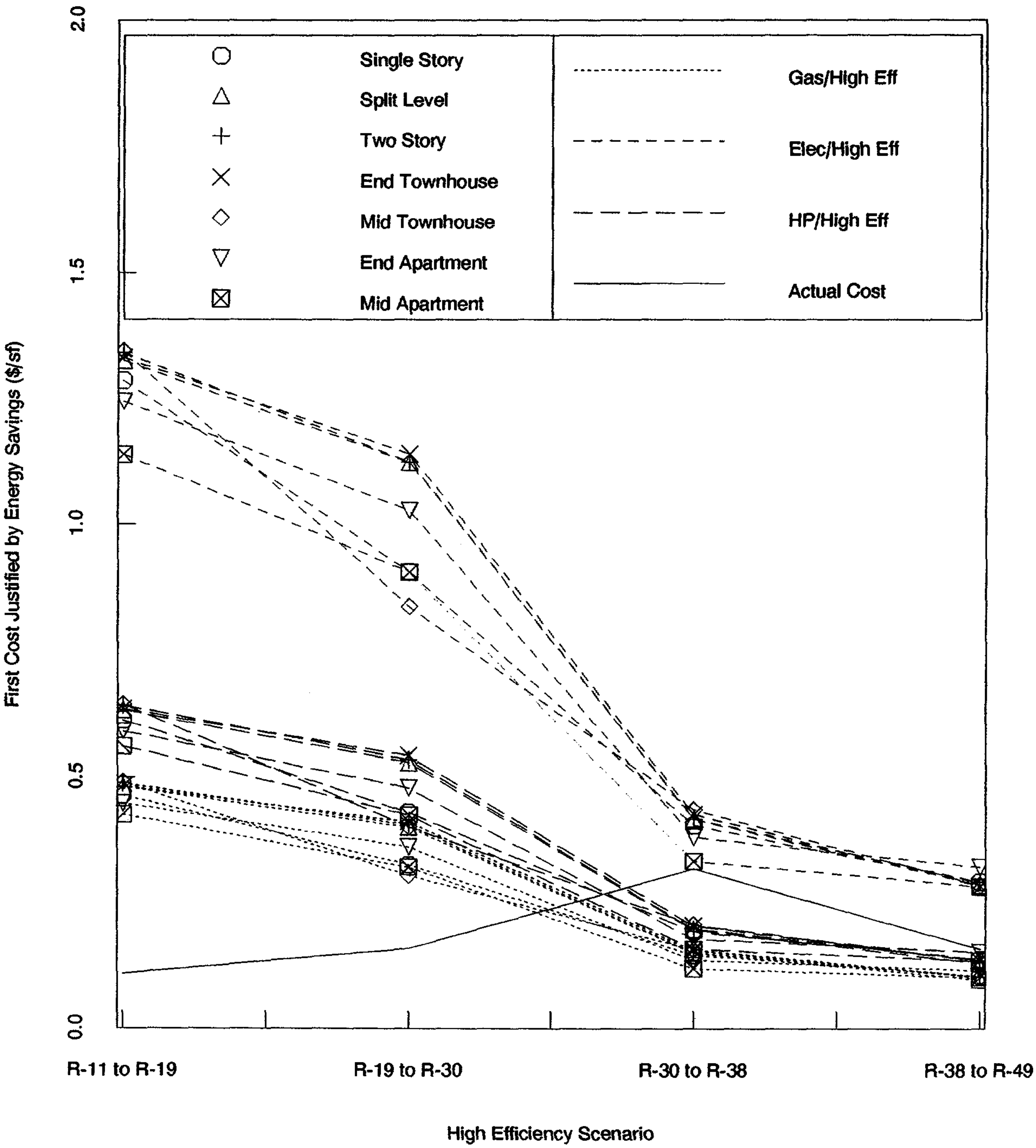
Miami - Window Sensitivity Test

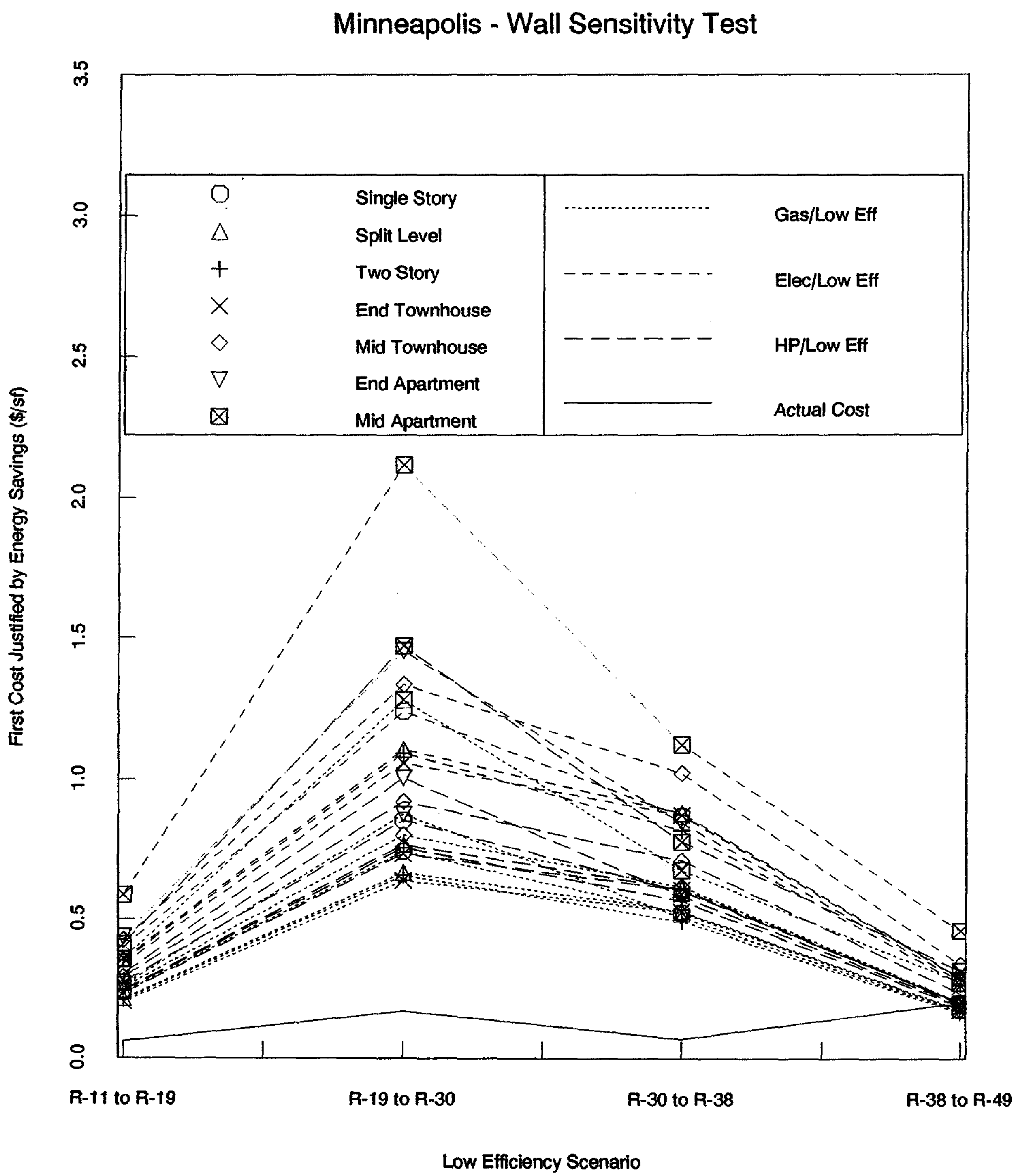


Minneapolis - Ceiling Sensitivity Test

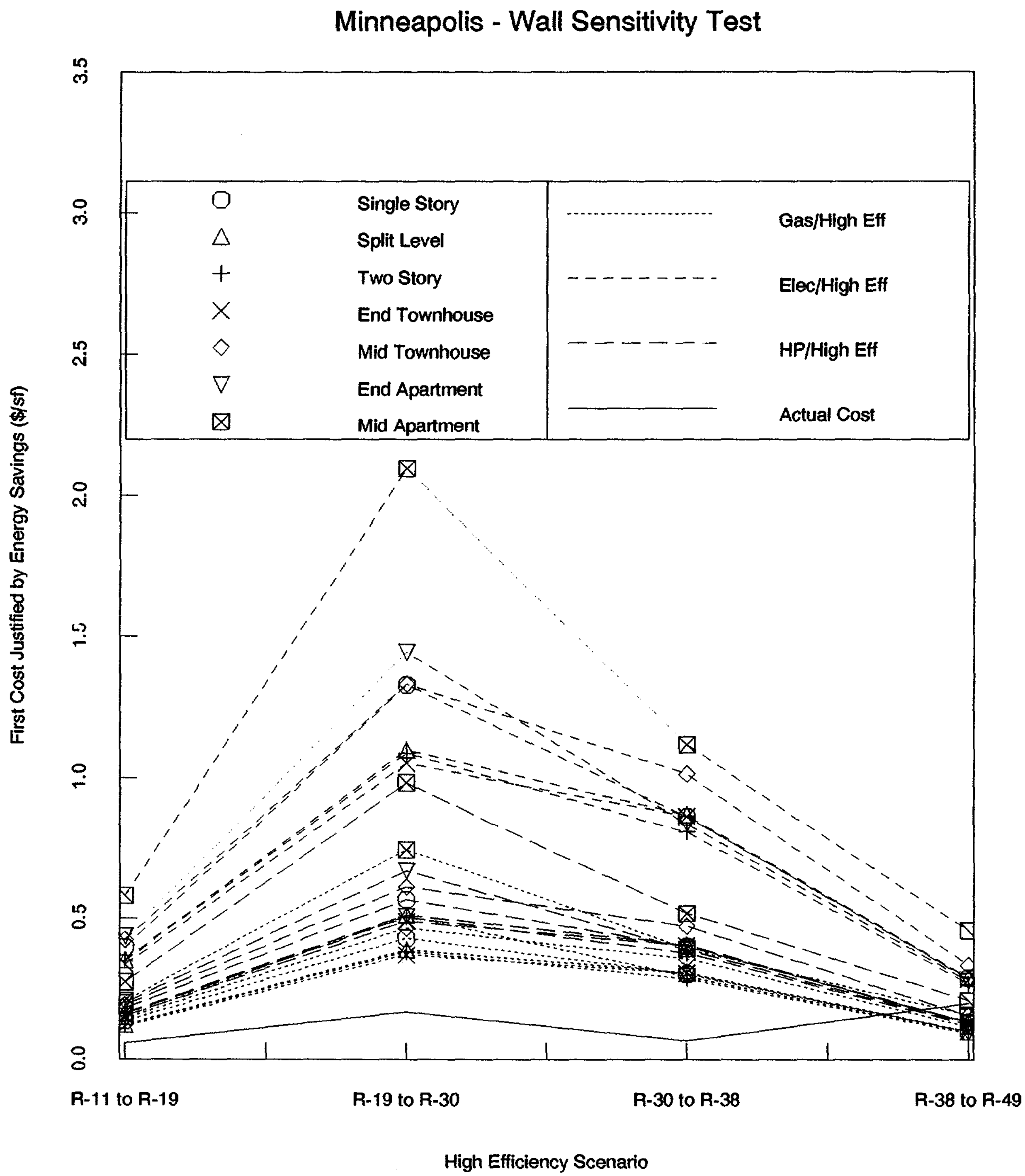


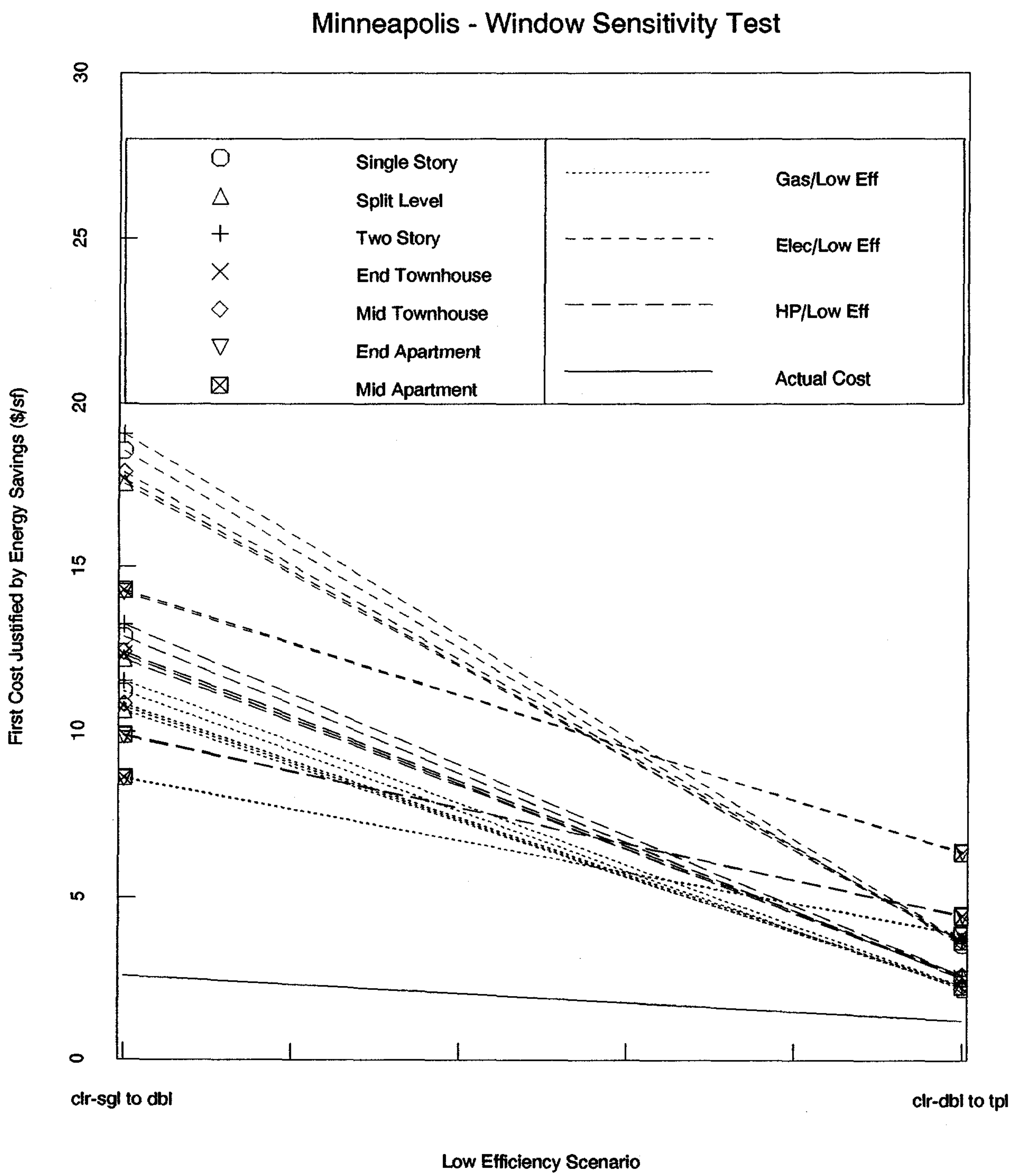
Minneapolis - Ceiling Sensitivity Test



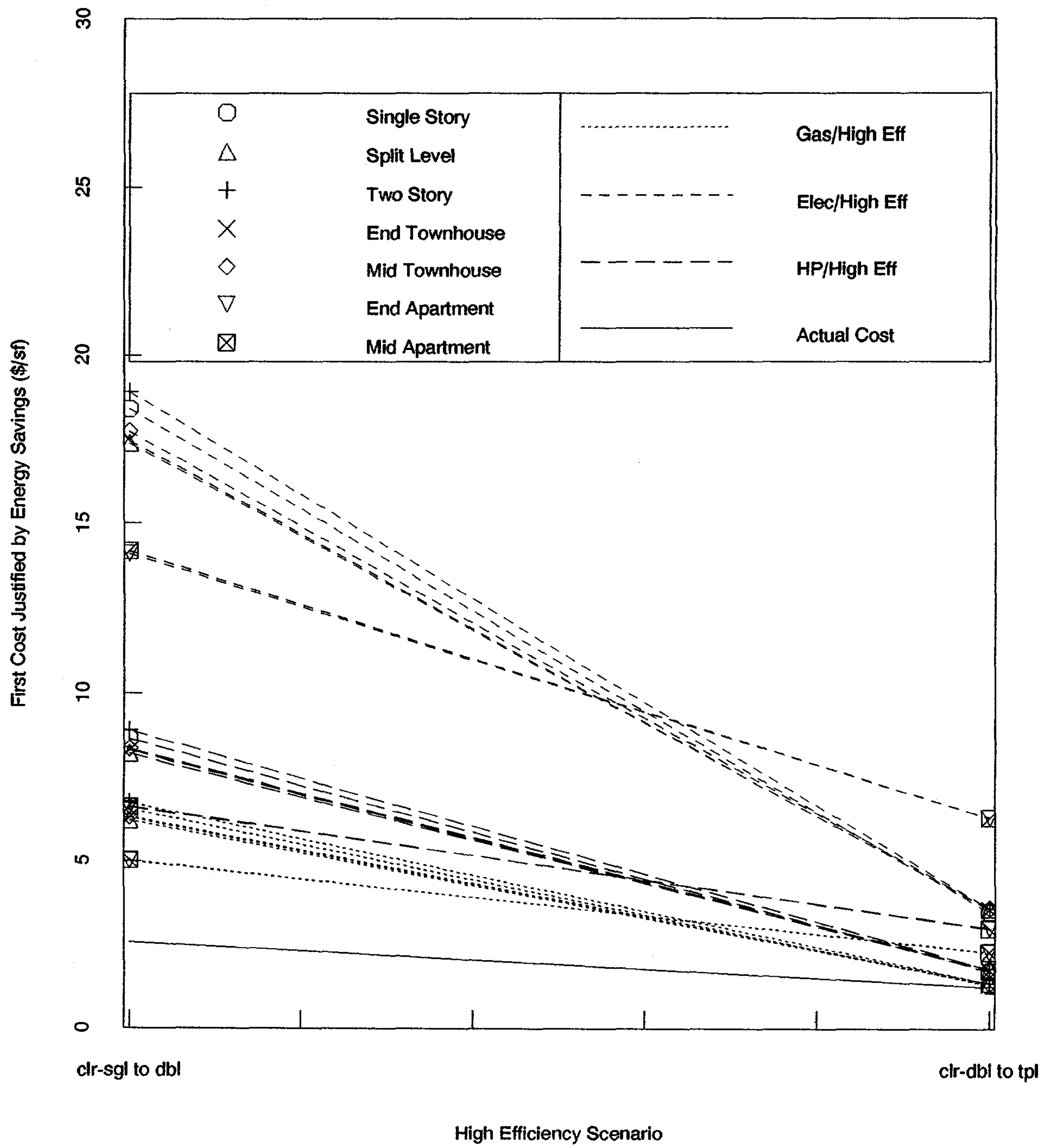


Minneapolis - Wall Sensitivity Test
First Cost Justified by Energy Savings ($/sf)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/Low Eff
Elec/Low Eff
HP/Low Eff
Actual Cost
R-11 to R-19
R-19 to R-30
R-30 to R-38
R-38 to R-49
Low Efficiency Scenario


Minneapolis - Wall Sensitivity Test
First Cost Justified by Energy Savings ($/sf)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/High Eff
Elec/High Eff
HP/High Eff
Actual Cost
R-11 to R-19
R-19 to R-30
R-30 to R-38
R-38 to R-49
High Efficiency Scenario


Minneapolis - Window Sensitivity Test
Single Story
Split Level
Two Story
End Townhouse
Mid Townhouse
End Apartment
Mid Apartment
Gas/Low Eff
Elec/Low Eff
HP/Low Eff
Actual Cost
First Cost Justified by Energy Savings ($/sf)
0
5
10
15
20
25
30
clr-sgl to dbl
clr-dbl to tpl
Low Efficiency Scenario

Minneapolis - Window Sensitivity Test



Title: LOCATION MULTIPLIERS

Statement of Issue: The data base was developed for 45 base cities, but it is intended that the standard apply to all areas of the country. Therefore, a method is required to extend the results of energy use from the base cities to other locations which are deemed similar.

Resolution: A methodology has been developed which accounts for variations in climate between a base city and other towns in its region. The process determines the boundaries of equivalency for the regions around each base city and then provides a means for determining the heating and cooling multipliers for a location within that region.

Discussion:

Energy uses for each ECM in each of 45 base cities are available from the data base. However, it is the intent of this Standard to reflect local conditions, so some technique is required to extend these values to other towns near the base city. It was decided that an interpolation technique using multipliers based on climatic characteristics should be used. Boundaries around each base city are drawn to indicate the region where an interpolation based on climate information may be accurately (within 10%) performed. Previous analyses in the Affordable Housing project (TSD, Nov. 1983), indicated that multipliers based on heating degree days (HDD) at 57 F and cooling degree days (CDD) at 65 F were most representative of local climate effects. Boundaries around the base cities were based on similarities in ratios of HDD at 65F to HDD at 57F between the base cities for the heating boundary and similarities in ratios of cooling enthalpy hours between the base cities for cooling. The resulting boundaries were merged with more weight given to the predominant conditioning requirement in a base city. (i.e. in Miami, cooling predominates so this boundary was given more weight.) If the criterion was not specific enough to identify boundaries, then additional criteria of equal differences in HDD and CDD were used along with dividing the geographical distances between the base cities into equal parts.

Once the boundaries had been drawn, then the multipliers for heating and cooling energy requirements were derived as ratios of the HDD at 57F for the location of interest to HDD at 57F for the base city, and a ratio of the CDD at 65F for the location of interest to CDD at 65F for the base city. These multipliers were then tabulated and entered into the computer program (ARES) which generates the Standard. Each ECM energy use is multiplied by the appropriate multipliers to account for local climate effects. If the user cannot find a location in the ARES program which matches the location of interest, then he/she must choose one which is closest in terms of climate. This process is not automated, and is therefore up to the user. However, there are almost 900 locations available in the ARES program so the problem of identifying similar locations should seldom arise.

Further information on the interpolation methodology and a test of the resulting boundaries can be found in the Technical Support Document for Affordable Housing Through Energy Conservation, USDOE/SF/00098-1.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #2-4

Title: REGIONALIZED EFFICIENCY OF UNITARY AIR CONDITIONING AND HEAT PUMP EQUIPMENT

Statement of Issue: How will the standard adjust certified SEER and HSPF efficiency ratings to various geographical locations within the United States?

Resolution: A bin energy analysis shall be done using ASHRAE WYEC Bin Data, performance data from the Air Conditioning and Refrigeration Institute (ARI) directory, and assumptions listed herein to generate multipliers to be applied to ARI SEER and HSPF ratings to give regional performance data. The multipliers will be generated for the 45 base cities.

Discussion:

The Air Conditioning and Refrigeration Institute (ARI) certification directory is published twice yearly and provides a readily accessible, up-to-date compilation of capacities, efficiencies, and sound levels for over 90 percent of the HVAC equipment sold in the United States.

The published capacities and sound levels compiled in the directory are for a specific set of climatic conditions. Efficiency is rated on a seasonal basis, where cooling efficiency is termed seasonal energy efficiency ratio (SEER) and heating efficiency is termed heating seasonal performance factor (HSPF). In either case, the climate for these ratings is termed Zone IV, which is approximately the climate of St. Louis, MO. When the product is used in a location with climate different from St. Louis, the seasonal efficiency ratings (SEER and HSPF) should be regionally adjusted to accurately reflect the efficiency in that specific climate. The most straightforward way of doing this is to apply a regional multiplier to the ARI certified efficiency rating to determine the SEER or HSPF for the actual area of interest.

A simplified computer program can be written to accomplish this, but some reasonable assumptions must be made. For purposes of determining the regionalized multipliers, it is suggested that the following values and assumptions be used:

1. ASHRAE WYEC Bin data (temperature vs. number of hours) shall be used where available. For those cities without ASHRAE Bin data, use data from Engineering Weather Data

as published by the Department of the Air Force, Army, and Navy -- July 1978 (AFM 88-29).

2. Summer 2½% design dry-bulb and winter 97½% design dry-bulb from the bin data source location.

3. Cooling capacity of the system (only single-speed systems analyzed here) increases 0.67% per degree that the outdoor temperature declines. Power consumption increases 0.95% per degree that the outdoor temperature increases. (This was determined from tests of Carrier and competitive units).

4. SEER = EER @ 82° $(1 - 0.5\ C_D)$, where C_D is the coefficient of degradation. For purposes of this regionalization analysis, C_D was held constant at 0.25 for heating and at 0.15 for cooling. The difference is due to degradation from a full accumulator in the winter.

5. The sizing factor was fixed at 125% of the unit capacity for the load at summer design conditions for the location. This is the maximum allowed under the standard (see position paper on oversizing). In the computations, a unit with 24,000 Btuh ARI rated capacity was used. Thus, if the summer design temperature for the location was 97°F, the unit capacity would be [1- (97-95)x(0.0067)]x24,000 or 23,678 Btuh. Therefore, for 125% sizing, the load would equal that capacity and thus have a cooling UA of 23678x1.25÷(97-65) or 925 Btuh/sfxF. It was assumed that the sensible portion of the UA would be a constant 75% for all locations (which is not technically correct) and thus the heating UA value would be (925) x (.75) or 694 Btu/sfxF as an example. The load changes with location, but the capacity remains constant.

6. The effect of crankcase heat can have a large effect on the "multiplier" but has little effect on the overall annual energy consumption, especially if the electrical disconnect is opened in the winter (for a cooling-only unit) as the majority of instructions will state. The recommendation is thus to disregard crankcase heating effects on the regionalization multipliers. (see Appendix B on crankcase heater).

7. The approximate COP's to attain various levels of ARI HSPF (Zone IV) ratings is as shown on Figure 1. These values were determined by bin analysis for St. Louis (corresponds very closely to Zone IV) using C_D of 0.25.

8. A defrost penalty of reasonable proportion is assumed based on the equation $X_{INT} = 0.95 - 0.00125 (To)$ where X_{INT} is a multiplier to be applied to the instantaneous heating capacity and To is the outside temperature. The equation is only valid for $T_O \leq 40$ °F. This means that X_{INT} is 0.9 at 40 °F, and linearly to 1.0 at -40 °F. For $T_O > 40$ °F, X_{INT} is 1.0.

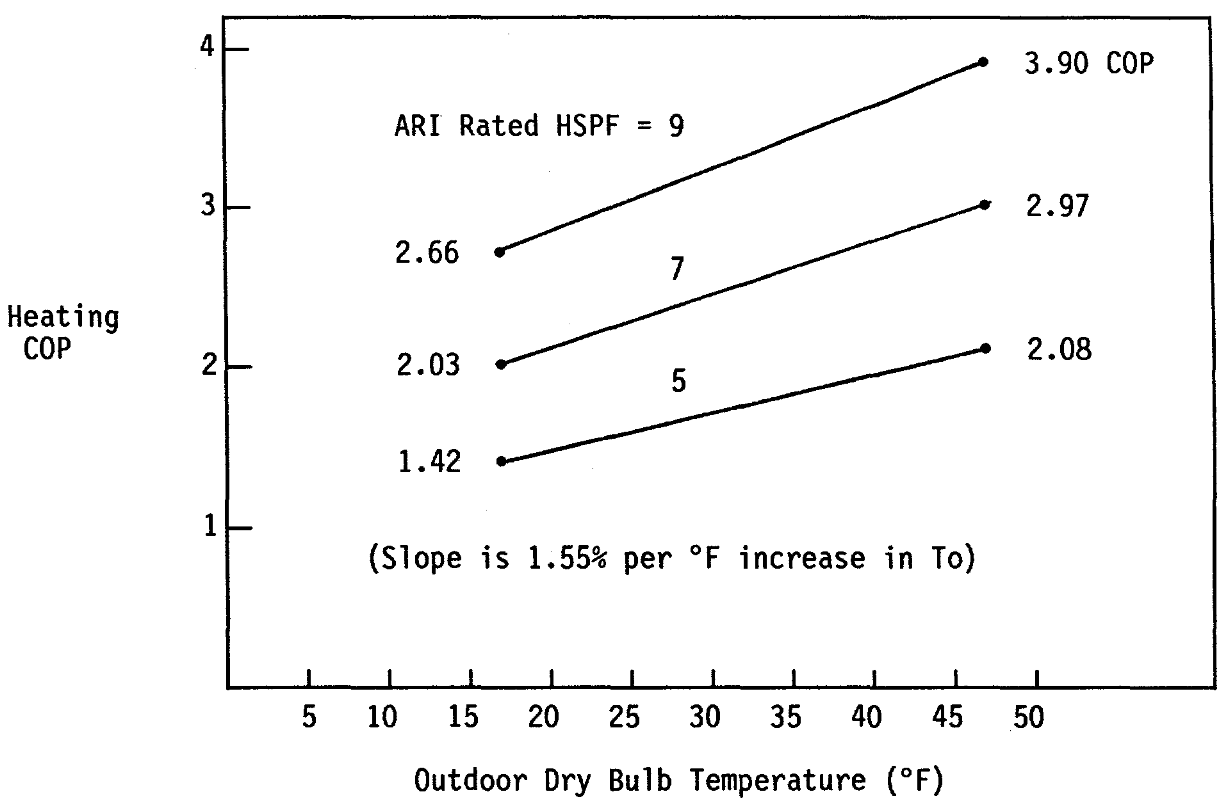


Figure 1 Approximate COPs of a Single-Speed Heat Pump to Attain ARI Rated HSPFs

A Bin Energy analysis using the above assumptions was used to generate multipliers to be applied to the system ARI equipment efficiency ratings to obtain local values of SEER and/or HSPF.

For cooling efficiency (SEER), the multiplier will also be a function of the capacity of the system in relation to the load. That is, the larger the system's capacity is in relation to the load, the lower the multiplier will become. For heating efficiency (HSPF), the multiplier has an added dependency as it varies with the relative level of equipment efficiency. The reason for this is the fact that below the heating balance point the heating "shortfall" must be made up by supplemental resistance heating with a COP of one.

The Tables of multipliers are in Appendix A. A discussion of crankcase heating is given in Appendix B.

Appendix A
Table of HSPF Regional Multipliers

City	Heating Design-F	Cooling Design-F	SEER Ratio	HSPF Ratio
Albuquerque	16	94	0.988	1.030
Atlanta	22	92	1.031	1.047
Birmingham	21	94	1.000	1.088
Bismarck	-19	91	1.013	0.709
Boise	10	94	0.981	0.963
Boston	9	88	1.048	0.948
Brownsville	39	93	0.992	1.170
Buffalo	6	85	1.067	0.834
Burlington, Vt.	-7	85	1.069	0.725
Charleston	28	92	1.020	1.118
Cheyenne	-1	86	1.050	0.827
Chicago	0	91	1.021	0.905
Cincinnati	6	90	1.027	0.932
Denver	1	91	1.007	0.903
El Paso	24	98	0.959	1.084
Fort Worth	22	99	0.954	1.095
Fresno	30	100	0.939	1.114
Great Falls	-15	88	1.043	0.748
Honolulu	63	86	1.062	1.216
Jacksonville	32	94	0.998	1.137
Juneau	1	70	1.235	0.602
Kansas City	6	96	0.982	0.941
L.A. (airport)	43	80	1.127	1.258
L.A. (city)	40	89	1.091	1.207
L.A. (san bern)	33	99	0.938	1.131
Lake Charles	31	93	1.004	1.144
Las Vegas	28	106	0.881	1.073
Medford	23	94	0.980	1.083
Memphis	18	95	0.993	1.038
Miami	47	90	1.023	1.188
Minneapolis	-12	89	1.034	0.748
Nashville	14	94	1.005	1.044
New York City	15	89	1.045	1.007
Oklahoma City	13	97	0.972	1.034
Omaha	-3	91	1.008	0.862
Philadelphia	14	90	1.034	0.986
Phoenix	34	107	0.868	1.116
Pittsburgh	5	86	1.062	0.860
Portland, Me	-1	84	1.080	0.793
Portland, Or	23	86	1.056	1.109
Reno	10	92	0.993	0.958
Salt Lake City	8	95	0.965	1.006
San Antonio	30	97	0.970	1.132
San Diego	44	80	1.137	1.223
San Francisco	38	77	1.143	1.254
S. F. (city)	40	71	1.210	1.068
Seattle	27	82	1.102	1.097

St. Louis	8	94	0.992	0.967
Washington, DC	17	91	1.026	1.048

Appendix B

EFFECT OF CRANKCASE HEAT

Much has been written about the effect of crankcase heaters on SEER, and considerable confusion has resulted. First of all, the purpose of a crankcase heater on the compressor is to keep the refrigerant out of the oil during the time the compressor is deenergized. By so doing, when the compressor starts, after a prolonged off-period, it prevents the oil from being foamed and expelled from the compressor as would occur if the compressor sump contained oil saturated with refrigerant. The standard ARI rating for SEER does not include the effect of crankcase heat except for the time that crankcase heat might be continuously energized as some systems might be controlled. However, even then it would not include the total effect of crankcase heat on an annualized basis.

Most small unitary systems for residential systems will include crankcase heaters if the refrigerant-to-oil ratio exceeds whatever the compressor supplier allows, which is generally in the area of 2½ to 1. That is, if the refrigerant-to-oil quantity exceeds 1½:1, then crankcase heat (or its equivalent) is deemed necessary.

There are several ways of controlling crankcase heaters, and some control methods consume more energy than others. For example, the most usual heater for small residential systems is 40 watts. The control system could vary from allowing it to run continuously (consuming 350 kWh per year), to not being required at all. If the crankcase heater is deenergized in the winter (which is recommended in much of the homeowner literature), then about 60% of the annual usage is eliminated, dropping the usage from 350 kWh to about 140 kWh in St. Louis. In fact, the greater the usage of a unit the more important its efficiency is and the less important crankcase heating becomes.

The best way to illustrate this is to look at a high usage cooling area like San Antonio vs. a low usage cooling area like Loring Air Force Base in Maine. Let's assume the crankcase heater operates for half of the "off" hours during the cooling season and in one case is left energized all year and in the second case is shut off at the disconnect during the winter.

		Loring Air Force Base	San Antonio
A.	Total cooling hours above 65°F	1062	3492
B.	Hours unit runs (100% sizing)	392	1306
C.	Unit "off" hours -- cooling mode	670	2186
D.	Crankcase heater hours of operation in cooling season	335	1093
E.	kWh usage if left energized all year (40 watt heater)	$\frac{(7698 + 335)(40)}{1000}$ =321	$\frac{(5268 + 1093)(40)}{1000}$ =254
F.	Effect on SEER	Drops it from 9.45 to 6.99 or by 26%	Drops it from 8.25 to 7.77 or by 5.8%
G.	kWh usage if left off during winter	13	44
H.	Effect on SEER	Drops it from 9.45 to 9.31 or by 1.5%	Drops it from 8.25 to 8.18 or by 0.8%

The point is if we want to look at the effect a crankcase heater has on seasonal efficiency, it is true that for low usage cooling areas (like Loring Air Force Base) then the SEER can be considerably affected. However, this is a meaningless consideration as can be shown by looking at total annualized kWh usage and operating cost. Operating cost is calculated at $.075/kWh.

Total Annual Usage (100% sizing)		Loring Air Force Base		San Antonio	
		kWh	$	kWh	$
A.	Not considering crankcase heater	913	$68	5448	$409
B.	Crankcase heater energized all year	1234	93	5702	428
C.	Crankcase heater turned off during winter	926	69	5492	412

Therefore, although we can show large effects on the SEER in light usage cooling areas, the effect on the user is negligible especially if the disconnect to the unit is deenergized during winter as most literature will state. But, even if it isn't, the real effect on energy usage and operating costs are very small. Therefore, we should not consider it in our recommendations.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #3-1

Title: ECONOMIC ANALYSIS FOR A RESIDENTIAL ENERGY CONSERVATION STANDARD

Statement of Issue: How should economics be used to support development of the standard so that it will reflect the consumer's economic perspective?

Resolution: The standard's requirements shall be determined by a modified life cycle cost analysis from the homeowner's perspective.

Discussion:

The residential energy conservation standard developed under the technical guidance of ASHRAE's Technical Evaluation Committee for Special Project 53 is based upon a consumer's perspective of the economic performance of residential energy conservation measures. The conservation measures and the levels of implementation for these measures required by the standard are selected on the basis of economic performance. A methodology has been developed to evaluate these measures from a consumer's economic perspective and to select levels of implementation that represent "economic wisdom" for the consumer.

The concept of this methodology is to create a detailed and specific model of consumer investment opportunity and to use the result of that model as a criterion for judging the performance of conservation investments. The model for investment opportunity should be realistic and should use parameters with which consumers are familiar. It should show low sensitivity to parameters that require forecasting.

The model compares the economic performance of a conservation investment with that of an "alternative" investment familiar to consumers. The performance of this alternative investment could then be used to calculate a required first-year energy cost savings for a given nominal first cost for conservation that would provide equivalent investment performance. The ratio between this given nominal cost and the required first-year savings is directly comparable to the "scalar methodology" used to develop ASHRAE Standard 90.2. This required ratio is a function of total fuel costs, equipment life and economic parameters only. For a given set of economic assumptions, a set of ratios for each fuel type and for each equipment type can be calculated.

In calculating energy cost savings, fuel costs are assumed to be those experienced by a typical homeowner. This allows market forces to drive any consumer preferences between fuel sources and avoids the issues of site versus source energy accounting. Furthermore, the economic criteria will be evaluated separately for each fuel type, eliminating any economic comparisons across fuel types. This is important in the framework of a building energy conservation standard to insure that any code referencing the standard demonstrates no fuel preferences. While, in a location, one fuel may indeed be more cost effective than another, factors other than economics often dictate consumer fuel preferences (e.g., local availability, etc.).

This economic methodology closely reflects the economic experience of the consumer from initial purchase through resale. The models of the two investments (conservation and alternative) assume that the consumer does not pay cash but rather makes installment payments on the investment. The methodology sums the total after-tax cash available from the alternative investment for the period of analysis and requires that the conservation investment perform accordingly. It recognizes that the two products of the conservation investment are acquired equity and energy cost savings and that these must equal the after-tax cash available from the alternative investment. The methodology uses current dollars to compare the two investments because the assumptions necessary for a current dollar analysis are more familiar to homeowners.

Because the products of the alternative investment are liquid, the methodology for analyzing the conservation investment must recognize the issue of resale. Other economic analysis methodologies ignore resale, implying that it is an economically neutral event. In other words, by ignoring resale, other methods assume that the resale would accrue sufficient funds (either in constant or current dollars, depending upon the method) to cancel any outstanding liabilities and to make liquid any equity value.

This proposed methodology explicitly assumes that the proceeds of the sale in current dollars exactly equal the nominal cost of the conservation measure plus any cost of the sale. Recently, some treatment of this issue has appeared in the literature. A study in Knoxville, TN statistically determined that consumers would value an annual savings of one dollar on fuel bills at over twenty dollars increase in purchase price.(1) Studies in Columbus, OH and in Minneapolis, MN found the purchase price value of a dollar savings in annual fuel costs at over \$11 and over \$18, respectively.(2,3)

Finally, a recent survey of real estate professionals has determined that 77% of the first cost of minor energy conservation measures can be recaptured on immediate resale.(4) The assumption that resale recaptures nominal first cost plus real estate commission at the end of seven years and that this recovery represents 77% of the current dollar appreciated value of the property upgrade would imply a nominal appreciation rate of 5 percent per year for the property. With current inflation rates of 3 to 5 percent, this result seems conservative.

In this method, after-tax current dollar equivalency is assumed between a conventional interest-bearing investment and a conservation investment with an unknown ratio between nominal first cost and net first-year energy cost savings. The resulting equation is then solved for this ratio.

The calculation process for the analysis method is as follows:

1. Calculate the pre-tax, pre-transaction-cost income necessary to pay the additional down payment required for the purchase of the conservation measure. Include taxed closing costs and non-taxed points.

$$PreTaxDP = U * \left\{ \frac{[R_{dp} + Cc*(1-R_{dp})]}{(1-R_{tax})} + R_{mp}*(1-R_{dp}) \right\}$$

where

where	PreTaxDP	=	pre-tax down payment and costs ($)
	R_{dp}	=	after-tax down payment rate (p.u.)[a]
	R_{tax}	=	income tax rate (p.u.)
	Cc	=	bank closing costs fee rate (p.u.)
	R_{mp}	=	points for mortgage (p.u.)
	U	=	unit first cost of conservation investment ($)

This calculation is necessary because mortgage points are tax sheltered.

(a) Per Unit, or %/100 (e.g., a down payment of 15% is expressed as the decimal value 0.15).

2. Calculate the after-tax down payment into the conservation investment.

$$DP = PreTaxDP * (1-R_{tax})$$

where	DP	=	initial down payment into the conservation investment ($)
	PreTaxDP	=	pre-tax down payment and costs ($)
	R_{tax}	=	income tax rate (p.u.)

An equivalent pre-tax income results in an initial down payment into the alternative investment that differs from the amount of money available for the purchase of a conservation measure.

3. Calculate the annual mortgage payment required for conservation investment.

$$MtgPmt = U * (1-R_{dp}) * \left[\frac{i*(1+i)^T}{(1+i)^T-1}\right]$$

where	MtgPmt	=	annual mortgage payment ($)
	U	=	unit first cost of conservation investment ($)
	i	=	annual mortgage interest rate (p.u.)
	T	=	term of mortgage (years)
	R_{dp}	=	after-tax down payment rate (p.u.)

The standard compound interest formula is used to calculate the payment on the principal of the conservation investment mortgage.

4. Calculate pre-tax annual mortgage payment cost, assuming property taxes and interest are not taxable, but that principal payment is.

$$PreTaxPmt_y = (U^*R_{property}) + MtgInt_y + [\frac{MtgPrn_y}{(1-R_{tax})}]$$

where	$PreTaxPmt_y$	=	pre-tax annual mortgage payment in year y ($)
	$R_{property}$	=	property tax rate (p.u.)
	R_{tax}	=	income tax rate (p.u.)
	$MtgInt_y$	=	interest payment in year y ($)
	$MtgPrn_y$	=	principal payment in year y ($)
	U	=	unit first cost of conservation investment ($)

where the annual principal payment can be found by the following formula:

$$MtgPrn_y = U * (1-R_{dp}) * [\frac{i*(1+i)^{y-1}}{(1+i)^T - 1}]$$

where	$MtgPrn_y$	=	principal payment in year y ($)
	y	=	number of years into study
	R_{dp}	=	after-tax down payment rate (p.u.)
	U	=	unit first cost of conservation investment ($)
	T	=	term of mortgage (years)
	i	=	annual mortgage interest rate (p.u.)

and the interest payment in year y can be found as follows:

$$MtgInt_y = MtgPmt - MtgPrn_y$$

where	$MtgInt_y$	=	interest payment in year y ($)
	MtgPmt	=	annual mortgage payment ($)
	$MtgPrn_y$	=	principal payment in year y ($)

5. The pre-tax installment mortgage cost is also the pre-tax deposit into the alternative investment. This pre-tax equivalence assures that the two investment scenarios are completely equal in the eyes of the consumer.

$$Deposit_y = PreTaxPmt_y * (1-R_{tax})$$

where
$Deposit_y$ = deposit into alternative investment in year y ($)
$PreTaxPmt_y$ = pre-tax annual mortgage payment in year y ($)
R_{tax} = income tax rate (p.u.)

For the alternative investment, the entire deposit is taxable.

6. The alternative investment is assumed to earn interest at a nominal interest rate. However, since taxes must be paid on the interest, the investment actually grows at an after-tax interest rate.

$$R_{eff} = R_{alt} * (1-R_{tax})$$

where
R_{eff} = after-tax interest rate (p.u.)
R_{alt} = nominal interest rate for alternative investment (p.u.)
R_{tax} = income tax rate (p.u.)

7. The total nominal amount available from the alternative investment at the end of the period of study can be calculated as follows (assuming $N \leq T$):

$$VALUE_{alt} = DP * (1+R_{eff})^{N} + sum_{y=1,N} [Deposit_y * (1+R_{eff})^{(N-y+0.5)}]$$

where	$VALUE_{alt}$	=	cash value of alternative investment at year N ($)
	DP	=	initial payment into alternative investment ($)
	$Deposit_y$	=	deposit into alternative investment in year y ($)
	N	=	term of study (years)
	R_{eff}	=	after-tax interest rate (p.u.)
	y	=	number of years into study

The yield of the alternative investment equals the principal plus interest earned over the period of study plus the annual deposits and the interest they earn.

8. The post-sale balance for the conservation investment is calculated according to the procedures noted earlier. The net return from the sale is assumed to exactly equal the nominal first cost of the conservation improvement. That is, the value of the conservation improvement does not keep up with inflation, but rather depreciates in real terms at a rate equal to the inflation rate. After the sale, the net return to the owner thus becomes the down payment plus any part of the principal paid off over the period of study.

For equipment such as a water heater, which has an expected useful life equal to or less than the period of study, there is some probability that replacement will be required during that period. The net return to the owner should reflect the probability of replacement over the period and the current dollar cost of replacement (assumed to be at the end of the study). The owner's equity at the end of the study thus consists of the down payment plus the paid-off loan principal less an allowance for replacement based on probability of failure as shown in the following equation:

$$\text{Equity} = U * R_{dp} \qquad \text{(recovery of down payment)}$$

$$+ U * (1-R_{dp}) * \{1 - [\frac{(1+i)^T - (1+i)^N}{(1+i)^T - 1}]\} \qquad \text{(paid-off portion of loan)}$$

$$- U * F_{rep} * F_{fail} * (1+R_{inf})^N \qquad \text{(allowance for replacement)}$$

where
- Equity = equity value ($)
- R_{dp} = after-tax down payment rate (p.u.)
- T = term of mortgage (years)
- N = term of study (years)
- F_{rep} = replacement cost of equipment (fraction of first cost; actual at end of period of analysis)
- R_{inf} = inflation rate (p.u.)
- F_{fail} = replacement fraction in period of study (p.u.)
- U = unit first cost of conservation investment ($)
- i = annual mortgage interest rate (p.u.)

9. For equivalence to exist between the energy and the alternative investments, the value of the savings accumulating over the term of the study added to the available equity from the conservation measure must be equal to the cash available from the alternative investment at the end of the study. Thus:

$$\text{VALUE}_{energy} + \text{Equity} - \text{VALUE}_{om} = \text{VALUE}_{alt}$$

where
- VALUE_{energy} = value of energy savings at the end of the study ($)
- Equity = equity value ($)
- VALUE_{om} = value of incremental operation and maintenance costs associated with the conservation investment (acts as a deduction to the value of energy saved) ($)

$VALUE_{alt}$	=	cash value of alternative investment at year N ($)

10. The energy savings each year can be considered to be tax-free income that can be deposited into the alternative investment, where the interest earned would be taxable. The nominal dollar value of the energy savings, furthermore, would be considered to escalate with inflation and perhaps beyond. The following equation gives the cash value of the energy savings at the end of the period of analysis:

$$VALUE_{energy} = VO * \{[\frac{(1+R_e)}{(R_{eff}-R_e)}] * [(1+R_{eff})^N - (1+R_e)^N]\}$$

where	$VALUE_{energy}$	=	value of energy savings at the end of the study ($)
	VO	=	energy savings in year 0 (i.e., before any escalation in fuel prices) ($)
	R_e	=	nominal energy escalation rate (p.u.)
	R_{eff}	=	after-tax interest rate (p.u.)
	N	=	term of study (years)

Because most published fuel price escalation rates are expressed in real terms (i.e., relative to the general inflation rate), the value of R_e must usually be calculated as follows:

$$R_e = (1+R_{inf}) * (1+R_{e,real}) - 1$$

where	R_e	=	nominal energy escalation rate (p.u.)
	R_{inf}	=	inflation rate (p.u.)
	$R_{e,real}$	=	real energy price escalation rate (p.u.)

Any increases in operation and maintenance (O&M) costs must be deducted from the annual deposits of energy savings into the alternative investment. The annual O&M costs are assumed to escalate with inflation and perhaps beyond. For mathematical simplicity, these are treated as a separate cash flow stream, the future value of which is deducted as a lump sum at the end of the period of analysis (rather than deducting them from each annual energy savings value). The value of the O&M costs at the end of the study is thus:

$$VALUE_{om} = OMO * \{[\frac{(1+R_m)}{(R_{eff}-R_m)}] * [(1+R_{eff})^N - (1+R_m)^N]\}$$

where OMO = O&M costs in year 0 (i.e., before any escalation in O&M costs) ($)

R_m = nominal O&M cost escalation rate (p.u.)

R_{eff} = post-tax interest rate (p.u.)

N = term of study (years)

If the O&M cost escalation rate is expressed in real terms (i.e., relative to the general inflation rate), the value of R_m must be calculated as follows:

$$R_m = (1+R_{inf}) * (1+R_{m,real}) - 1$$

where R_{inf} = inflation rate (p.u.)

$R_{m,real}$ = real O&M cost escalation rate (p.u.)

11. For equivalency to exist between the alternative investment and the conservation investment, the following must hold:

$$VALUE_{energy} = VALUE_{alt} - Equity + VALUE_{om}$$

where $VALUE_{alt}$ = cash value of alternative investment at year N ($)

Equity = equity value ($)

$VALUE_{om}$ = value of incremental operation and maintenance costs associated with the conservation investment (acts as a deduction to the value of energy saved) ($)

Let M be equal to the expression within the braces {} of the first equation in step 10. That equation can then be abbreviated as $VALUE_{energy} = M * VO$. Substituting this into the equation immediately above gives:

$$VO = \frac{VALUE_{alt} - Equity + VALUE_{om}}{M}$$

Thus VO is the annual energy dollar savings (based on initial fuel prices) necessary for the conservation investment to be equivalent to the alternative investment. The ratio U/VO is the "scalar" used for evaluating conservation measures. Conceptually, the ratio gives the first-cost expenditure justified for each dollar of expected annual energy savings.

If the scalar ratio is combined with the expression for VO above, the following results:

$$scalar = \frac{U * M}{VALUE_{alt} - Equity + VALUE_{om}}$$

Furthermore, if the initial annual O&M costs (OMO) are expressed as a fraction of the first cost of the conservation measure, it is clear that the above equation contains U as a direct multiplier in both the numerator and denominator. Thus the scalar is not a function of U.

References

1. Johnson, R. C. July 1981. Housing Market Capitalization of Energy Savings Durable Good Investments. ORNL/CON-74.
2. Dinan, T. M. 1984. Obtaining the Optimal Fuel Conserving Investment Mix: A Linear Programming-Hedonic Technique Approach. Ph.D. thesis, Iowa State University.
3. Laquatra, J. "Valuation of Household Investment in Energy Efficient Design," ACEEE 1984, p. F-154.
4. (c) New Shelter, p. 47. May/June 1986. Rodale Press.

APPENDIX A
REQUIRED INPUTS FOR ECONOMIC ANALYSIS

	PARAMETER	DEFAULT VALUE	CATEGORY[a]
General			
N	Number of years in study	7	B
R_{tax}	Marginal income tax rate (federal+state)	21%	A
rp	Property tax rate	1%	A
Mortgage			
R_{dp}	After-tax down payment percentage	10%	A
Cc	Closing cost rate	3.3%	A
R_{mp}	Mortgage points	1.5%	A
i	Mortgage interest rate (annual)	9%	A
T	Term of mortgage	30 yrs	A
Alternative Investment			
R_{alt}	Interest rate	5.5%	A
Escalation Rates			
R_{inf}	Inflation rate	4%	A
$R_{e,real}$	Energy cost escalation rate (above inflation)	0%	A
rm	Maintenance cost escalation rate (above inflation)	0%	A

(a) A = Optional input for each computer run
B = Internal parameter not generally available for modification

	PARAMETER		DEFAULT VALUE	CATEGORY
Equipment				
F_{fail}	Fraction of failures during study:			
		HVAC	3%	B
		DHW	10%	B
		Envelope	0%	B
F_{rep}	Replacement cost of equipment (percentage of first cost)			
		HVAC	100%	B
		DHW	100%	B
		Envelope	100%	B
Cm	Differential maintenance cost (above conventional equipment)			
		HVAC	0	B
		DHW	0	B
		Envelope	0	B

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #3-2

Title: ECONOMIC ANALYSIS PROCEDURES IN MICROCOMPUTER PROGRAM

Statement of Issue: How should the economic test (Position Paper #3-1) be implemented in the microcomputer program?

Resolution: A modified Life Cycle Cost function, equivalent to the economic test described in Position Paper #3-1, will be minimized to identify the optimal building configuration. Location of the minimum will be via exhaustive search of all possible combinations of conservation measures.

Discussion:

The economic test of energy conservation measures described in Position Paper #3-1 is intended to minimize energy consumption in a residence with the constraint that energy conservation measures (ECMs) must have economic performance that is at least equivalent to the typical consumer's best alternative investment opportunity. The method basically requires that the sum of energy cost savings and increased home equity of the ECMs be at least equivalent to the earnings possible if the money spent on conservation were instead invested elsewhere, taking account of all relevant tax impacts.

While the economic methodology in Position Paper #3-1 describes the intent of the standard quite well, it has several attributes that make it difficult or impractical to use directly in a computer program:

- The methodology, as written, only accounts for savings from one fuel type. The scalar ratio is a function of a single fuel escalation rate. If dissimilar fuels are used for heating and cooling, a single scalar cannot be defined for the economic test. Instead, two interdependent scalar ratios are obtained (one equation, two unknowns).
- The methodology does not deal with equipment options and envelope options simultaneously. The method assumes a fixed equipment efficiency, then locates the optimal envelope options. Since the Standard will be based on the optimal **combination** of equipment and envelope options, the methodology must accommodate both.
- The methodology assumes that a straightforward ranking of options is possible. That is, it assumes there exists a "smooth" relationship between energy consumption and first cost. Sequentially testing "higher" levels of conservation, the method stops searching when the economic test applied to a marginal upgrade is violated. This marginal analysis

can be a serious problem if the nature of cost-energy relationship is unknown or discontinuous. The simplest example is windows (e.g., Which is more energy efficient: single-pane with thermal break or double-pane without thermal break? Which costs more?). The problem is compounded because users will be allowed to change ECM costs. By setting an unreasonably high cost for a relatively inefficient option (either by accident or otherwise), a user could force the program to always select the lowest efficiency levels.

With these considerations in mind, an economic algorithm with the following features is desired: 1) accommodates dissimilar fuels for heating and cooling, 2) simultaneously optimizes equipment and envelope ECMs, 3) is robust to discontinuities in the cost-energy function, and 4) is mathematically equivalent to the method described in Position Paper #3-1. A life cycle cost (LCC) analysis has the desired features. This paper describes an LCC analysis that results in optimal building configurations identical to those obtained by the simpler method of Position Paper #3-1.

Actually, the methodology described in Position Paper #3-1 is a life cycle analysis reduced to a simple, dimensionless parameter. It compares the value of energy savings and home equity with the value of an alternative investment at the end of the period of analysis. By using a discount rate equal to the after-tax rate of return on the alternative investment, LCC concepts can be used to obtain a parameter with dimensions of dollars (i.e., the life cycle cost.) The LCC function, because it has scale, can be used directly as the objective function in an optimization procedure, whereas the dimensionless parameter can only be used as a constraint in optimizing the energy consumption function. The advantage of this seemingly insignificant difference is that ECMs need not be examined in any particular order, thus satisfying requirement 3 above.

The LCC function, because it includes all significant cash flows in proper proportions, accurately accounts for trade-offs between envelope and equipment options. There is also no requirement that annual operation and maintenance costs be expressed as a fraction of first cost (this is necessary in the scalar ratio method to prevent the ratio from being a function of first cost.)

Finally, the LCC accounts for an arbitrary number of fuels and escalation rates without changing the form of the result.

The scalar ratio test makes a comparison between conservation and alternative investments at the end of the analysis period. For convenience, the LCC function will be based at the beginning of the analysis period (year 0). This allows the use of common financial functions giving present values of various types of cash flows, simplifying the coding of the LCC function. The only substantive difference between the LCC function and the scalar ratio function is the assumption of when foregone conservation expenditures are "deposited" in the alternative investment. The scalar method described in Position Paper #3-1 assumes that all annual expenses (e.g., mortgage payment) are deposited in the alternative investment at mid-year (i.e., interest is earned for one-half of the year in which savings are realized.) The LCC function, because it uses standard financial functions, assumes all cash flows occur at the end of the year in which they are realized. This simplifies the mathematics, and is consistent with the treatment of all other cash flows (e.g., the scalar method assumes inflation compounds at year-end.) This difference tends to make the LCC function select slightly higher conservation levels than would the scalar test because foregone conservation expenditures "earn interest" for less time in the alternative investment. However, the magnitude of the difference is quite small,[a] and is negligible in light of the advantages of simpler math and consistent cash flow assumptions.

Using the new economic formulation, the microcomputer must find the combination of ECMs that results in the minimum life cycle cost. This can be accomplished in several ways. A number of "smart" search algorithms have been developed for finding the minimum of a multidimensional function such as the LCC function to be minimized by the ARES computer program. These algorithms are vital when the functions contain cross terms which cause the search space to grow exponentially with each added dimension. The benefit of these algorithms is that they restrict the number of points which must be searched. The disadvantage is that they are highly dependent upon the characteristics of the search space and are vulnerable to being fooled by a

(a) See Appendix A for comparisons of scalar ratios calculated with the two methods.

local minimum. The ARES computer program will be especially vulnerable to permutations in its function since users will be allowed to change the data for ECM levels and costs.

Exhaustive search avoids the problems of the more sophisticated algorithms, but it is only feasible if the characteristics of the function allow a method of limiting the size of the search space. An analysis of the function to be optimized by the ARES computer program reveals a way to limit the search space enough that the execution time of an exhaustive search will be comparable to one of the more complicated algorithms.

The only cross-term interactions are between the envelope ECMs and the space conditioning efficiencies. The optimizer will eliminate this path of interactions by explicitly looping over a set of heating and cooling efficiencies for the equipment type being optimized. Since the equipment efficiencies will be held constant, the ECMs will become completely independent of each other, and the search space becomes only the sum of the number of levels of the different envelope ECMs instead of their product. This represents a reduction in the search space by a factor of between 500 and 1000, depending on how many levels are actually defined in the ARES cost database.

The program will make some simplifying assumptions concerning equipment sizes and efficiency levels. A continuous range of equipment capacity will be assumed so that the load ratio (ratio of equipment capacity to design load) for equipment of a given nominal efficiency can be held constant as ECM choices change the design load of the building. It is important to hold the load ratio constant, so the real efficiency of the equipment remains constant regardless of which ECM levels are chosen. The program will loop over a range of commonly available nominal efficiencies for the equipment, and the corresponding real efficiencies used in the optimization will be determined by a function of the nominal efficiencies and the assumed load ratio.

At each pair of equipment efficiency levels (heating and cooling), the program will calculate the life cycle cost of the individual levels of each envelope ECM and will choose the best level for that ECM. The computer program will select the optimum package for a given combination of equipment in a given prototype by choosing the combination of optimized envelope and equipment efficiency which results in the lowest overall life cycle cost to the consumer.

The huge reduction in the search space achieved through eliminating interactions between ECMs will enable the computer to completely ignore local minima in the function and always find the global minimum through exhaustive search. As a result, the computer program will be much more resistant to inconsistencies introduced by users who change the cost data or create their own ECM levels. Furthermore, the simplicity of the algorithm will make it very easy to implement and debug.

APPENDIX A

COMPARISONS OF SCALAR RATIO AND LCC METHODS

This appendix contains the results of tests to demonstrate the equivalence of the LCC function used in the microprogram and the scalar ratio method of Position Paper #3-1. By computing a scalar ratio for a marginal LCC based on a single fuel, the two methods can be directly compared over a range of inputs. Figures A.1 through A.7 on the following pages contain some intermediate results and the final scalar ratios computed by both methods for 7 different input scenarios. The first scenario (Case 1) is based on the default economic parameters specified in Position Paper #3-1, Appendix A. Cases 2 through 7 involve various deviations from the first case.

Note that the only mathematical difference between the two methods is the assumption of when cash flows for a particular year occur. The LCC assumes all cash flows occur at the end of the period in which they are realized. The scalar ratio method assumes all cash flows occur at the end of the period except for "deposits" of foregone conservation expenditures into the alternative investment, which occur at mid-year.

Figures A.8 through A.14 contain the same seven comparisons of the two methods with the scalar ratio method modified to account for all cash flows at the end of the period. Clearly, the two methods are identical when this adjustment is made. Even without the adjustment, the differences in scalar ratios due to methodology are much smaller than the those due to varying the input parameters. As expected, the largest methodology-attributable differences in scalar ratios occur when the alternative investment rate is high relative to the inflation rate (see, for example, Case 3.)

Figure A.1. Scalar Ratio/LCC Comparison - Case 1

```
Enter Down Payment Rate            ==>  0.100000
Enter Income Tax Rate              ==>  0.210000
Enter Closing Cost Rate            ==>  0.033000
Enter Mortgage Points              ==>  0.015000
Enter Mortgage Interest Rate       ==>  0.090000
Enter Property Tax Rate            ==>  0.010000
Enter Alternative Investment Rate  ==>  0.055000
Enter Replacement Cost Fraction    ==>  1.000000
Enter Fraction of Failures         ==>  0.000000
Enter Inflation Rate               ==>  0.040000
Enter Energy Escalation Rate       ==>  0.040000
Enter Annual O&M Costs (year 0)    ==>  0.000000
Enter O&M Cost Escalation Rate     ==>  0.040000

Step 1.............
I1 =     0.177677
Step 2.............
D1 =     0.140365
Step 3.............
Pa =     0.087603
Steps 4, 5, 6, 7...
reff =     0.043450
S =     0.832334
Step 8...............
E =     0.160748
Steps 9, 10..........
MM =     9.303703
OM =     0.000000
Step 11................
VO            =     0.072185
Scalar Ratio =    13.853325

LCC Method.......................
HeatEscMult =   6.908032
DownPayment =   0.100000
LoanFee =   0.029700
PvMtg =   0.519158
PvPoints =   0.013500
PvPointsTax =   0.002835
PvLoanBal =   0.623148
PRE-PvTax =   5.347711
PvTax =       0.098380
PvOM =   0.000000
PvResale =   0.742503
PvPropertyTax =   0.046818
AllTheRest =   0.488605

LCC Scalar =  14.138285
```

Figure A.2. Scalar Ratio/LCC Comparison - Case 2

```
Enter Down Payment Rate              ==>   0.100000
Enter Income Tax Rate                ==>   0.210000
Enter Closing Cost Rate              ==>   0.033000
Enter Mortgage Points                ==>   0.015000
Enter Mortgage Interest Rate         ==>   0.150000
Enter Property Tax Rate              ==>   0.010000
Enter Alternative Investment Rate    ==>   0.055000
Enter Replacement Cost Fraction      ==>   1.000000
Enter Fraction of Failures           ==>   0.000000
Enter Inflation Rate                 ==>   0.040000
Enter Energy Escalation Rate         ==>   0.040000
Enter Annual O&M Costs (year 0)      ==>   0.000000
Enter O&M Cost Escalation Rate       ==>   0.040000

Step 1.............
I1 =     0.177677
Step 2.............
D1 =     0.140365
Step 3.............
Pa =     0.137070
Steps 4, 5, 6, 7...
reff =     0.043450
S =     1.141779
Step 8...............
E =     0.122910
Steps 9, 10..........
MM =     9.303703
OM =     0.000000
Step 11...............
VO             =     0.109512
Scalar Ratio =     9.131403

LCC Method.......................
HeatEscMult =   6.908032
DownPayment =   0.100000
LoanFee =   0.029700
PvMtg =   0.812315
PvPoints =   0.013500
PvPointsTax =   0.002835
PvLoanBal =   0.651242
PRE-PvTax =   5.788059
PvTax =       0.166608
PvOM =   0.000000
PvResale =   0.742503
PvPropertyTax =   0.046818
AllTheRest =   0.741629

LCC Scalar =   9.314678
```

Figure A.3. Scalar Ratio/LCC Comparison - Case 3

Enter Down Payment Rate	==>	0.100000
Enter Income Tax Rate	==>	0.210000
Enter Closing Cost Rate	==>	0.033000
Enter Mortgage Points	==>	0.015000
Enter Mortgage Interest Rate	==>	0.090000
Enter Property Tax Rate	==>	0.010000
Enter Alternative Investment Rate	==>	0.100000
Enter Replacement Cost Fraction	==>	1.000000
Enter Fraction of Failures	==>	0.000000
Enter Inflation Rate	==>	0.040000
Enter Energy Escalation Rate	==>	0.040000
Enter Annual O&M Costs (year 0)	==>	0.000000
Enter O&M Cost Escalation Rate	==>	0.040000

```
Step 1.............
I1 =     0.177677
Step 2.............
D1 =     0.140365
Step 3.............
Pa =     0.087603
Steps 4, 5, 6, 7...
reff =     0.079000
S =     0.967890
Step 8...............
E =     0.160748
Steps 9, 10...........
MM =    10.315071
OM =     0.000000
Step 11................
V0            =     0.078249
Scalar Ratio =    12.779752

LCC Method.......................
HeatEscMult =   6.057900
DownPayment =   0.100000
LoanFee =   0.029700
PvMtg =   0.457656
PvPoints =   0.013500
PvPointsTax =   0.002835
PvLoanBal =   0.492881
PRE-PvTax =   4.720043
PvTax =         0.086833
PvOM =   0.000000
PvResale =   0.587286
PvPropertyTax =   0.041271
AllTheRest =   0.458055

LCC Scalar =  13.225270
```

Figure A.4. Scalar Ratio/LCC Comparison - Case 4

```
Enter Down Payment Rate              ==>  0.100000
Enter Income Tax Rate                ==>  0.210000
Enter Closing Cost Rate              ==>  0.033000
Enter Mortgage Points                ==>  0.015000
Enter Mortgage Interest Rate         ==>  0.090000
Enter Property Tax Rate              ==>  0.030000
Enter Alternative Investment Rate    ==>  0.055000
Enter Replacement Cost Fraction      ==>  1.000000
Enter Fraction of Failures           ==>  0.000000
Enter Inflation Rate                 ==>  0.040000
Enter Energy Escalation Rate         ==>  0.040000
Enter Annual O&M Costs (year 0)      ==>  0.000000
Enter O&M Cost Escalation Rate       ==>  0.040000

Step 1.............
I1 =     0.177677
Step 2.............
D1 =     0.140365
Step 3.............
Pa =     0.087603
Steps 4, 5, 6, 7...
reff =     0.043450
S =     0.961152
Step 8...............
E =     0.160748
Steps 9, 10..........
MM =     9.303703
OM =     0.000000
Step 11................
VO              =     0.086031
Scalar Ratio =    11.623757

LCC Method.......................
HeatEscMult =   6.908032
DownPayment =   0.100000
LoanFee =   0.029700
PvMtg =   0.519158
PvPoints =   0.013500
PvPointsTax =   0.002835
PvLoanBal =   0.623148
PRE-PvTax =   5.347711
PvTax =       0.098380
PvOM =   0.000000
PvResale =   0.742503
PvPropertyTax =   0.140453
AllTheRest =   0.582240

LCC Scalar =  11.864583
```

Figure A.5. Scalar Ratio/LCC Comparison - Case 5

```
Enter Down Payment Rate             ==>   0.100000
Enter Income Tax Rate               ==>   0.210000
Enter Closing Cost Rate             ==>   0.033000
Enter Mortgage Points               ==>   0.015000
Enter Mortgage Interest Rate        ==>   0.070000
Enter Property Tax Rate             ==>   0.010000
Enter Alternative Investment Rate   ==>   0.055000
Enter Replacement Cost Fraction     ==>   1.000000
Enter Fraction of Failures          ==>   0.000000
Enter Inflation Rate                ==>   0.040000
Enter Energy Escalation Rate        ==>   0.040000
Enter Annual O&M Costs (year 0)     ==>   0.000000
Enter O&M Cost Escalation Rate      ==>   0.040000

Step 1.............
I1 =     0.177677
Step 2.............
D1 =     0.140365
Step 3.............
Pa =     0.072528
Steps 4, 5, 6, 7...
reff =     0.043450
S =     0.740532
Step 8...............
E =     0.182453
Steps 9, 10...........
MM =     9.303703
OM =     0.000000
Step 11................
V0           =     0.059985
Scalar Ratio =    16.670951

LCC Method.......................
HeatEscMult =   6.908032
DownPayment =   0.100000
LoanFee =   0.029700
PvMtg =   0.429819
PvPoints =   0.013500
PvPointsTax =   0.002835
PvLoanBal =   0.607031
PRE-PvTax =   4.974796
PvTax =       0.075770
PvOM =   0.000000
PvResale =   0.742503
PvPropertyTax =   0.046818
AllTheRest =   0.405759

LCC Scalar =  17.024956
```

Figure A.6. Scalar Ratio/LCC Comparison - Case 6

```
Enter Down Payment Rate             ==>   0.100000
Enter Income Tax Rate               ==>   0.210000
Enter Closing Cost Rate             ==>   0.033000
Enter Mortgage Points               ==>   0.015000
Enter Mortgage Interest Rate        ==>   0.060000
Enter Property Tax Rate             ==>   0.010000
Enter Alternative Investment Rate   ==>   0.055000
Enter Replacement Cost Fraction     ==>   1.000000
Enter Fraction of Failures          ==>   0.000000
Enter Inflation Rate                ==>   0.040000
Enter Energy Escalation Rate        ==>   0.040000
Enter Annual O&M Costs (year 0)     ==>   0.000000
Enter O&M Cost Escalation Rate      ==>   0.040000

Step 1.............
I1 =     0.177677
Step 2.............
D1 =     0.140365
Step 3.............
Pa =     0.065384
Steps 4, 5, 6, 7...
reff =     0.043450
S =     0.697725
Step 8..............
E =     0.195556
Steps 9, 10..........
MM =     9.303703
OM =     0.000000
Step 11...............
VO             =     0.053975
Scalar Ratio =    18.527024

LCC Method.......................
HeatEscMult =   6.908032
DownPayment =   0.100000
LoanFee =   0.029700
PvMtg =   0.387483
PvPoints =   0.013500
PvPointsTax =   0.002835
PvLoanBal =   0.597303
PRE-PvTax =   4.701181
PvTax =       0.064550
PvOM =   0.000000
PvResale =   0.742503
PvPropertyTax =   0.046818
AllTheRest =   0.364915

LCC Scalar =  18.930521
```

Figure A.7. Scalar Ratio/LCC Comparison - Case 7

```
Enter Down Payment Rate             ==>  0.100000
Enter Income Tax Rate               ==>  0.500000
Enter Closing Cost Rate             ==>  0.020000
Enter Mortgage Points               ==>  0.015000
Enter Mortgage Interest Rate        ==>  0.020000
Enter Property Tax Rate             ==>  0.000000
Enter Alternative Investment Rate   ==>  0.020000
Enter Replacement Cost Fraction     ==>  1.000000
Enter Fraction of Failures          ==>  0.000000
Enter Inflation Rate                ==>  0.040000
Enter Energy Escalation Rate        ==>  0.040000
Enter Annual O&M Costs (year 0)     ==>  0.000000
Enter O&M Cost Escalation Rate      ==>  0.040000

Step 1.............
I1 =     0.249500
Step 2.............
D1 =     0.124750
Step 3.............
Pa =     0.040185
Steps 4, 5, 6, 7...
reff =     0.010000
S =     0.364746
Step 8...............
E =     0.264929
Steps 9, 10...........
MM =     8.451609
OM =     0.000000
Step 11................
VO            =     0.011810
Scalar Ratio =    84.670960

LCC Method.......................
HeatEscMult =    7.882969
DownPayment =    0.100000
LoanFee =   0.018000
PvMtg =   0.270372
PvPoints =   0.013500
PvPointsTax =   0.006750
PvLoanBal =   0.685614
PRE-PvTax =   2.786416
PvTax =       0.055986
PvOM =   0.000000
PvResale =   0.932718
PvPropertyTax =   0.000000
AllTheRest =   0.092032

LCC Scalar =  85.654701
```

Figure A.8. Comparison of Modified Scalar Ratio with LCC - Case 1

```
Enter Down Payment Rate              ==>   0.100000
Enter Income Tax Rate                ==>   0.210000
Enter Closing Cost Rate              ==>   0.033000
Enter Mortgage Points                ==>   0.015000
Enter Mortgage Interest Rate         ==>   0.090000
Enter Property Tax Rate              ==>   0.010000
Enter Alternative Investment Rate    ==>   0.055000
Enter Replacement Cost Fraction      ==>   1.000000
Enter Fraction of Failures           ==>   0.000000
Enter Inflation Rate                 ==>   0.040000
Enter Energy Escalation Rate         ==>   0.040000
Enter Annual O&M Costs (year 0)      ==>   0.000000
Enter O&M Cost Escalation Rate       ==>   0.040000

Step 1.............
I1 =      0.177677
Step 2.............
D1 =      0.140365
Step 3.............
Pa =      0.087603
Steps 4, 5, 6, 7...
reff =      0.043450
S =      0.818798
Step 8...............
E =      0.160748
Steps 9, 10..........
MM =      9.303703
OM =      0.000000
Step 11...............
VO             =      0.070730
Scalar Ratio =    14.138285

LCC Method.......................
HeatEscMult =   6.908032
DownPayment =   0.100000
LoanFee =   0.029700
PvMtg =   0.519158
PvPoints =   0.013500
PvPointsTax =   0.002835
PvLoanBal =   0.623148
PRE-PvTax =   5.347711
PvTax =        0.098380
PvOM =   0.000000
PvResale =   0.742503
PvPropertyTax =   0.046818
AllTheRest =   0.488605

LCC Scalar =  14.138285
```

Figure A.9. Comparison of Modified Scalar Ratio with LCC - Case 2

```
Enter Down Payment Rate            ==>   0.100000
Enter Income Tax Rate              ==>   0.210000
Enter Closing Cost Rate            ==>   0.033000
Enter Mortgage Points              ==>   0.015000
Enter Mortgage Interest Rate       ==>   0.150000
Enter Property Tax Rate            ==>   0.010000
Enter Alternative Investment Rate  ==>   0.055000
Enter Replacement Cost Fraction    ==>   1.000000
Enter Fraction of Failures         ==>   0.000000
Enter Inflation Rate               ==>   0.040000
Enter Energy Escalation Rate       ==>   0.040000
Enter Annual O&M Costs (year 0)    ==>   0.000000
Enter O&M Cost Escalation Rate     ==>   0.040000

Step 1.............
I1 =     0.177677
Step 2.............
D1 =     0.140365
Step 3.............
Pa =     0.137070
Steps 4, 5, 6, 7...
reff =     0.043450
S =     1.121732
Step 8...............
E =     0.122910
Steps 9, 10..........
MM =     9.303703
OM =     0.000000
Step 11................
V0             =     0.107357
Scalar Ratio =     9.314678

LCC Method........................
HeatEscMult =   6.908032
DownPayment =   0.100000
LoanFee =   0.029700
PvMtg =   0.812315
PvPoints =   0.013500
PvPointsTax =   0.002835
PvLoanBal =   0.651242
PRE-PvTax =   5.788059
PvTax =       0.166608
PvOM =   0.000000
PvResale =   0.742503
PvPropertyTax =   0.046818
AllTheRest =   0.741629

LCC Scalar =   9.314678
```

Figure A.10. Comparison of Modified Scalar Ratio with LCC - Case 3

```
Enter Down Payment Rate              ==>  0.100000
Enter Income Tax Rate                ==>  0.210000
Enter Closing Cost Rate              ==>  0.033000
Enter Mortgage Points                ==>  0.015000
Enter Mortgage Interest Rate         ==>  0.090000
Enter Property Tax Rate              ==>  0.010000
Enter Alternative Investment Rate    ==>  0.100000
Enter Replacement Cost Fraction      ==>  1.000000
Enter Fraction of Failures           ==>  0.000000
Enter Inflation Rate                 ==>  0.040000
Enter Energy Escalation Rate         ==>  0.040000
Enter Annual O&M Costs (year 0)      ==>  0.000000
Enter O&M Cost Escalation Rate       ==>  0.040000

Step 1.............
I1 =     0.177677
Step 2.............
D1 =     0.140365
Step 3.............
Pa =     0.087603
Steps 4, 5, 6, 7...
reff =     0.079000
S =     0.940700
Step 8..............
E =     0.160748
Steps 9, 10..........
MM =     10.315071
OM =     0.000000
Step 11...............
VO             =     0.075613
Scalar Ratio =     13.225270

LCC Method......................
HeatEscMult =   6.057900
DownPayment =   0.100000
LoanFee =   0.029700
PvMtg =   0.457656
PvPoints =   0.013500
PvPointsTax =   0.002835
PvLoanBal =   0.492881
PRE-PvTax =   4.720043
PvTax =         0.086833
PvOM =   0.000000
PvResale =   0.587286
PvPropertyTax =   0.041271
AllTheRest =   0.458055

LCC Scalar =  13.225270
```

Figure A.11. Comparison of Modified Scalar Ratio with LCC - Case 4

```
Enter Down Payment Rate             ==>  0.100000
Enter Income Tax Rate               ==>  0.210000
Enter Closing Cost Rate             ==>  0.033000
Enter Mortgage Points               ==>  0.015000
Enter Mortgage Interest Rate        ==>  0.090000
Enter Property Tax Rate             ==>  0.030000
Enter Alternative Investment Rate   ==>  0.055000
Enter Replacement Cost Fraction     ==>  1.000000
Enter Fraction of Failures          ==>  0.000000
Enter Inflation Rate                ==>  0.040000
Enter Energy Escalation Rate        ==>  0.040000
Enter Annual O&M Costs (year 0)     ==>  0.000000
Enter O&M Cost Escalation Rate      ==>  0.040000

Step 1.............
I1 =     0.177677
Step 2.............
D1 =     0.140365
Step 3.............
Pa =     0.087603
Steps 4, 5, 6, 7...
reff =     0.043450
S =     0.944905
Step 8...............
E =     0.160748
Steps 9, 10..........
MM =     9.303703
OM =     0.000000
Step 11...............
VO           =     0.084284
Scalar Ratio =    11.864583

LCC Method.......................
HeatEscMult =   6.908032
DownPayment =   0.100000
LoanFee =   0.029700
PvMtg =   0.519158
PvPoints =   0.013500
PvPointsTax =   0.002835
PvLoanBal =   0.623148
PRE-PvTax =   5.347711
PvTax =       0.098380
PvOM =   0.000000
PvResale =   0.742503
PvPropertyTax =   0.140453
AllTheRest =   0.582240

LCC Scalar =  11.864583
```

Figure A.12. Comparison of Modified Scalar Ratio with LCC - Case 5

```
Enter Down Payment Rate             ==>   0.100000
Enter Income Tax Rate               ==>   0.210000
Enter Closing Cost Rate             ==>   0.033000
Enter Mortgage Points               ==>   0.015000
Enter Mortgage Interest Rate        ==>   0.070000
Enter Property Tax Rate             ==>   0.010000
Enter Alternative Investment Rate   ==>   0.055000
Enter Replacement Cost Fraction     ==>   1.000000
Enter Fraction of Failures          ==>   0.000000
Enter Inflation Rate                ==>   0.040000
Enter Energy Escalation Rate        ==>   0.040000
Enter Annual O&M Costs (year 0)     ==>   0.000000
Enter O&M Cost Escalation Rate      ==>   0.040000

Step 1.............
I1 =     0.177677
Step 2.............
D1 =     0.140365
Step 3.............
Pa =     0.072528
Steps 4, 5, 6, 7...
reff =     0.043450
S =     0.728928
Step 8...............
E =     0.182453
Steps 9, 10..........
MM =     9.303703
OM =     0.000000
Step 11................
VO            =     0.058737
Scalar Ratio =    17.024956

LCC Method.......................
HeatEscMult =   6.908032
DownPayment =   0.100000
LoanFee =   0.029700
PvMtg =   0.429819
PvPoints =   0.013500
PvPointsTax =   0.002835
PvLoanBal =   0.607031
PRE-PvTax =   4.974796
PvTax =       0.075770
PvOM =   0.000000
PvResale =   0.742503
PvPropertyTax =   0.046818
AllTheRest =   0.405759

LCC Scalar =  17.024956
```

Figure A.13. Comparison of Modified Scalar Ratio with LCC - Case 6

```
Enter Down Payment Rate             ==>   0.100000
Enter Income Tax Rate               ==>   0.210000
Enter Closing Cost Rate             ==>   0.033000
Enter Mortgage Points               ==>   0.015000
Enter Mortgage Interest Rate        ==>   0.060000
Enter Property Tax Rate             ==>   0.010000
Enter Alternative Investment Rate   ==>   0.055000
Enter Replacement Cost Fraction     ==>   1.000000
Enter Fraction of Failures          ==>   0.000000
Enter Inflation Rate                ==>   0.040000
Enter Energy Escalation Rate        ==>   0.040000
Enter Annual O&M Costs (year 0)     ==>   0.000000
Enter O&M Cost Escalation Rate      ==>   0.040000

Step 1.............
I1 =     0.177677
Step 2.............
D1 =     0.140365
Step 3.............
Pa =     0.065384
Steps 4, 5, 6, 7...
reff =     0.043450
S =     0.687021
Step 8...............
E =     0.195556
Steps 9, 10..........
MM =     9.303703
OM =     0.000000
Step 11................
V0           =     0.052825
Scalar Ratio =    18.930521

LCC Method.......................
HeatEscMult =   6.908032
DownPayment =   0.100000
LoanFee =   0.029700
PvMtg =   0.387483
PvPoints =   0.013500
PvPointsTax =   0.002835
PvLoanBal =   0.597303
PRE-PvTax =   4.701181
PvTax =       0.064550
PvOM =   0.000000
PvResale =   0.742503
PvPropertyTax =   0.046818
AllTheRest =   0.364915

LCC Scalar =  18.930521
```

Figure A.14. Comparison of Modified Scalar Ratio with LCC - Case 7

```
Enter Down Payment Rate              ==>   0.100000
Enter Income Tax Rate                ==>   0.500000
Enter Closing Cost Rate              ==>   0.020000
Enter Mortgage Points                ==>   0.015000
Enter Mortgage Interest Rate         ==>   0.020000
Enter Property Tax Rate              ==>   0.000000
Enter Alternative Investment Rate    ==>   0.020000
Enter Replacement Cost Fraction      ==>   1.000000
Enter Fraction of Failures           ==>   0.000000
Enter Inflation Rate                 ==>   0.040000
Enter Energy Escalation Rate         ==>   0.040000
Enter Annual O&M Costs (year 0)      ==>   0.000000
Enter O&M Cost Escalation Rate       ==>   0.040000

Step 1.............
I1 =     0.249500
Step 2.............
D1 =     0.124750
Step 3.............
Pa =     0.040185
Steps 4, 5, 6, 7...
reff =     0.010000
S =     0.363600
Step 8...............
E =     0.264929
Steps 9, 10...........
MM =     8.451609
OM =     0.000000
Step 11................
VO             =     0.011675
Scalar Ratio =    85.654701

LCC Method.......................
HeatEscMult =   7.882969
DownPayment =   0.100000
LoanFee =   0.018000
PvMtg =   0.270372
PvPoints =   0.013500
PvPointsTax =   0.006750
PvLoanBal =   0.685614
PRE-PvTax =   2.786416
PvTax =       0.055986
PvOM =   0.000000
PvResale =   0.932718
PvPropertyTax =   0.000000
AllTheRest =   0.092032

LCC Scalar =  85.654701
```

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #3-3

Title: CREATION OF COST DATABASE

Statement of Issue: To determine the cost effectiveness of the energy conservation measures (ECMs), cost data for various levels of each ECM are required. The user can enter cost data for any or all of the ECMs and associated levels. However, a set of default data needs to be provided which is representative of national costs. This allows the user to create a Standard based on cost effectiveness without having to enter costs that may be hard to obtain in a given area. These data should be consistent representing the cost to the consumer of each ECM.

Resolution: ASHRAE supported a research project by the National Association of Home Builders to acquire the necessary cost data for construction components. This was supplemented by a study of HVAC and DHW equipment costs from ADM.

Discussion:

The NAHB final report, An Economic Data Base in Support of SPC 90.2, dated December 1, 1986 was used to provide the cost data for entry into the ARES computer program. This was supplemented with cost data from an unpublished study produced by ADM, Associates which dealt with costs for furnaces, heat pumps, DX air conditioners, and hot water heaters. These costs are provided as defaults in the ARES program to be used if local costs are not available. Testing of the Standard indicated some areas of concern with respect to costs for windows, heat pumps, and furnaces. Surveys were performed by members of SP-53 to obtain additional data in these areas with the intent of verifying the NAHB and ADM data. These surveys indicated that the costs for these ECMs varied widely with quality of the units.

Additional equipment data costs were acquired from conversations with local suppliers for items of similar quality and capacity. These were combined to reflect the cost on a capacity and efficiency basis for an average quality unit. This analysis verified the ADM relationship among capacities and indicated a sharper rise in cost for higher efficiency units. As the ADM data did not have indications of unit quality, it was difficult to reduce the cost information to be indicative of an average quality unit. With this in mind, the ADM data was used to provide the correlation between capacity and cost while the SP-53 survey data provided the correlation between efficiency and cost.

In a similar manner, surveys of window distributors were performed by SP-53 to obtain data on costs with quality and technical specifications. This information was used to create costs for window systems whose technical specifications matched those in the data base. The data indicated a consistency in percentage changes among the different levels and types of glazings. These percentage changes were then applied to the NAHB data base numbers for clear, single pane glazing to calculate costs for other levels in all regions of the country. This approach was used to maintain the consistency of the data and retain the relative relationship between window costs and other envelope ECM costs as acquired by NAHB.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #4-1

Title: CEILING INSULATION

Statement of Issue: How should ceiling insulation be handled in the standard?

Resolution: Ceiling insulation should be included as a basic option in all paths and used in the determination of the energy target in the standard development process.

Discussion:

As the roof/ceiling assembly covers a major portion of the envelope, it can be a major source of heat loss/gain. Insulation in this area has been proven to be effective in reducing energy use. The products are readily available, acceptable in the market place, and easily checked for compliance by code officials. In most cases, there is no conflict between the use of this ECM and typical health and safety codes. (Note the last paragraph.) For recessed light fixtures, safety problems are reduced by using only those fixtures listed for zero clearance by Underwriters Laboratories. Energy savings from the implementation of ceiling insulation are easily calculated and are accepted as accurate. In addition, a substantial amount of data for this ECM currently exists in the DOE-2 data base.

Levels of conservation for ceiling insulation are generally expressed in the R-value of the insulating material. A more applicable description would be the overall R-value (or equivalent U-value) of the ceiling/roof assembly with a minimum R-value required for the insulation. Values in the current data base range from R-7 to R-38 with some values of R-49 and R-60 for higher heating degree day locations. These ECM data are useful for the package approach and for creating points for additional insulation levels. Any level of insulation can be handled by most models used in the performance path. However, these models must be capable of using the R-value of the overall ceiling assembly with insulation R-values as derived from independent testing.

The R-value of the overall ceiling/roof assembly will vary between flat roof and pitched roof structures. But as insulation is evaluated in increments, the variations of overall R-value by roof type will have little impact on economic optima. The economic optimum will vary by house type and location, however, so these must be explicitly analyzed.

Various types of ceiling insulation materials, such as those with radon content or with urethane, may pose health problems. These should be considered as part of the standard and restricted as required through provision of a list of certified insulation materials.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #4-2

Title: WALL INSULATION

Statement of Issue: How should wall insulation be dealt with in the standard?

Resolution: Wall insulation should be included as a basic option in all paths and used in the determination of the energy target in the standard development process.

Discussion:

One of the largest heat loss/gain areas in the envelope is the wall assembly. Insulation in this area has been proven to be effective in reducing energy use. The products are readily available, acceptable in the market place, and easily checked for compliance by code officials. There is no conflict between the use of this ECM and typical health and safety codes. (Note the last paragraph.) Energy savings from the implementation of wall insulation are easily calculated and are accepted as accurate. In addition, a substantial amount of data for this ECM currently exists in the DOE-2 data base.

Levels of conservation for wall insulation are generally expressed in the R-value of the insulating material. A more applicable description would be the overall R-value (or equivalent U-value) of the wall assembly with a minimum R-value required for the insulation. Values in the current data base range from R-7 to R-27. Values for R-34 have been added for all locations. These ECM data are useful for the package approach and for creating points for additional insulation levels. Any level of insulation can be handled by most models used in the performance path. However, these models must be capable of handling the R-value of the overall wall assembly utilizing insulation R-values as derived from independent testing.

Since walls can be divided into category by the mass of the assembly, there needs to be some differentiation between insulation requirements for mass walls and those for frame walls. A mass wall will be defined as one for which the entire wall assembly exceeds 40 pounds per square foot. The insulation on the mass walls also has a different effect depending on location, so three configurations are under study by LBL for inclusion in the data base: interior insulation, exterior insulation, and integral insulation. As the effect of interior insulation is to mask the mass effects, mass walls with interior insulation should be required to meet the frame wall insulation requirements. To be considered under the mass wall category, the insulation must be integral with or installed on the outside of the exterior mass. The inside surface of the thermal mass, including plaster or gypsum board, in direct contact with the mass wall shall be exposed to room air.

The R-value of the overall wall assembly will vary between Heavy Mass and Light Mass wall types. The standard should deal separately with each of these wall types and provide minimum insulation values for each which allows them to meet the same effective overall R-value. The economic optimum will vary by wall type, house type, and location, so these must be explicitly analyzed. However, as the frame walls are most prevalent, these will be used in the optimization. Mass walls are covered through the points and performance paths (see position paper #4-5 on Mass Walls).

Various types of wall insulation materials, such as those with radon content or with urethane, may pose health problems. These should be considered as part of the standard and restricted as required through provision of a list of certified insulation materials.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #4-3

Title: FLOOR/FOUNDATION INSULATION

Statement of Issue: How should floor/foundation insulation be treated in the standard, particularly with respect to the various types of floors/foundations typically found in residences?

Resolution: Floor/foundation insulation should be included as a basic option in all paths and used in the determination of the energy target in the standard development process.

Discussion:

As part of the building envelope, the floor/foundation has a significant impact on energy use if it is not insulated to the same relative level as the rest of the envelope. Insulation in this area has been proven to be effective in reducing energy use. The products are readily available, acceptable in the market place, and easily checked for compliance by code officials. There is no conflict between the use of this ECM and typical health and safety codes. (Note the last paragraph.) Energy savings from the implementation of floor and foundation insulation can only be calculated accurately with some finite difference or finite element codes. Because the data base primarily used DOE-2.1A for its calculations, a redo of the delta loads for both floor and foundation insulation is required and will be done so that these values can be formatted for use with DOE-2.1 analyses.

Levels of conservation for floor insulation are generally expressed in the R-value of the insulating material. Raised floor insulation may be omitted only if the foundation walls are insulated to meet the insulation levels required, a vapor barrier is placed over the entire floor of the crawl space, and the vents in the crawl space are fitted with operable louvers. Values for floor insulation need to range from R-11 to R-49 for crawl spaces and R-11 to R-30 for unheated basements. Since basements are not ventilated like crawl spaces, the insulation level may be reduced. Levels of conservation for foundation perimeters and heated basements are generally expressed in the R-value of the insulating material and the depth of the insulation from floor/ground level (as defined by the bottom of the wall insulation).

Values for perimeter insulation are required for R-5 and R-10 with depths of 2 and 4 feet. All depths are measured from grade to bottom of insulation.

Values for basement insulation are required for R-5 at 4 and 8 feet, and R-10 at 4 and 8 feet. These ECM data will be useful for the package approach and for creating points for these insulation levels. Since most models used in the performance path cannot handle the mass and ground contact heat transfer effects accurately, it is suggested that trade-offs in foundation insulation levels not be allowed in the performance path. For heated slabs, the perimeter insulation shall have an additional R-1.5 above that required for unheated slabs. This will keep the requirements in line with those existing in the Model Energy Code.

The R-value of floor/foundation insulation will vary according to foundation type. The standard should deal separately with each of the four major types and provide minimum insulation values for each based on economic criteria. The economic optimum will vary by floor/foundation type, house type, and location so these must be explicitly analyzed.

Various types of floor insulation materials, such as those with radon content or with urethane, may pose health problems. These should be considered as part of the standard and restricted as required through provision of a list of certified insulation materials. Basement and perimeter insulation materials should have low water absorption qualities like that of smooth-skin extruded polystyrene (i.e., rate no greater than 0.3% when tested in accordance with ASTM-C-272-33 and a water vapor transmission rate no greater than 2.0 perm per inch when tested in accordance with ASTM-C-355-64) and should be protected from physical damage and ultraviolet light deterioration by backfill or other appropriate techniques. If termite protection is not provided (i.e., a termite shield), soil treatment should be strongly recommended.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #4-4

Title: DOOR INSULATION

Statement of Issue: How should door insulation be treated in the standard?

Resolution: In the case of door insulation, the standard should include solid core wood or insulated metal as mandatory in all paths. If significant U-value improvement is available with other materials and designs, then provide for this ECM in the performance path.

Discussion:

Although opaque doors represent a relatively small part of the envelope, they can represent a significant loss/gain in efficient envelopes if they are not insulated to the same relative level as the rest of the envelope. For this reason, it is suggested that either solid core wood or insulated metal doors be mandatory for all compliance paths. The California code[a] lists the U-value for either of these components as 0.39, so trade-offs between them have no effect on energy. The addition of a storm door or the replacement with a lower U-value component should save energy and thus be allowed under the performance path. To reduce complexity and the number of calculations, it is suggested that doors not be explicitly considered in the points path. The acceptable level would be that of any component or assembly which would reduce the U-value below 0.39.

The basic approach outlined above can be the same for all housing types and locations although the magnitude will vary by type and location.

(a)California Energy Commission, Energy Conservation Manual for New Residential Buildings, Item Code P400-84-016, Fall 1984.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #4-5

Title: THERMAL MASS

Statement of Issue: How should envelope thermal mass be handled in the standard?

Resolution: External thermal mass should be included as a basic option in all compliance paths, but this ECM should not be utilized in the process of setting standard levels of energy performance. Internal thermal mass should not be an ECM under consideration in the standard.

Discussion:

The performance of thermal mass is directly related to the amount and orientation of glazing and to the HVAC control strategies. There are two approaches to using thermal mass for residential energy conservation. The first is using the mass as external mass which delays the cyclic climatic variations and reduces their effects on the interior environment. This is the energy conservation measure (ECM) applied in mass construction such as adobe, brick, or CMU houses. The impact of this ECM on energy use is dependent on the thermostat deadband and settings. Energy savings from this ECM are easily calculated once the thermostat strategy is defined, the materials are readily available and acceptable in the market place (some regional variations of indigenous materials occur), and this option does not conflict with health and safety codes. For these reasons, the "External" Thermal Mass ECM should be included as an equivalent package, be accepted as a trade-off in the points path, and be available as an ECM in the performance approach.

The second technique for utilizing thermal mass is as internal mass which stores and releases heat usually obtained from internal sources or solar gains to the building interior. This may be thought of as the Passive Solar ECM when the mass is used to justify glazing or store solar gains. Although internal mass can be effective with internal loads, the gains in a residence are small enough that this approach is not useful. For this reason, "Internal" Thermal Mass should not be included as an ECM separate from any Passive Solar ECMs which may utilize this concept.

For the package approach, the wall assemblies should be divided into two categories: "Mass" and "Frame Wall". Most of the packages will use the Frame Wall category and associated R-values. For the Mass package(s), entire wall assemblies exceeding 40 pounds per square foot must meet a minimum R-value. This R-value is for the entire wall and is deemed equivalent with the Frame Wall cases through computer simulation. Insulating material that is used to meet the minimum R-value must be integral with or on the outside of the exterior mass so the wall can effectively store and release energy to the interior. The exterior wall used to meet the wall assembly R-value cannot also be used to meet any interior thermal mass requirements.

The question of how to handle thermal mass in the three different compliance approaches and in the standard in general was discussed at length by the committee. The consensus was to accept mass as a wall construction type. The form of mass would not matter nearly as much as the heat capacity and the location of the insulation. There are three basic insulation locations: external insulation with mass on the inside, internal insulation with mass on the outside, and insulation integral with the mass (this is typical of log structures). However, internal insulation masks the effects of mass so is not acceptable for the thermal mass ECM.

Package Approach

A mass package could be defined as an alternative in each location on the basis of energy equivalency with the cost effective frame (typical) construction prototype. If there is a significant difference in energy characteristics based on insulation location, then multiple packages could be created. In essence, this equivalency means that for a given amount of mass, a specified R-value of insulation would have to be added in the appropriate location to create a structure which uses the same amount of total energy as the energy target.

Points Approach

For the points compliance, points for mass and various insulation levels and locations would be based on the deltas calculated from the mass base case. Mass walls will be separated into two categores: 1) those up to 110 pounds per square foot, and 2) those greater than 110 pounds per square foot. Insulation levels are provided for R-5, R-10, R-15, and R-30 added either exterior to the mass, or integral with it.

Performance Approach

In the performance approach, any type of mass structure can be simulated, as long as the simulation program is capable of accurately modeling the mass storage and time delay effects on an hourly basis. Compliance will be based on a lower energy use for the mass structure than for the appropriate prototype.

Exterior Thermal Mass is probably not valid for manufactured housing since the mass makes the transportation costs unacceptable in the market place. For other housing types, Exterior Thermal Mass is a valid ECM and is very common in multistory, multifamily dwellings. The major regional variation will be in the type of construction used to provide the mass: adobe in the southwest, brick in the southeast, and brick or CMU in the northeast. Energy savings can be calculated for all of these based on an in-place density.

Mass has some structural and safety requirements which must be met, particularly in multistory structures. However, these do not change when the mass is used as an ECM so there would be no additional requirements in this area imposed by the creation of an energy standard which utilizes this ECM.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #4-6

Title: ATTIC RADIANT BARRIER SYSTEMS

Statement of Issue: How should radiant barrier systems be treated in the Standard?

Resolution: Radiant Barrier Systems shall not be an option at this time.

Discussion:

Attic radiant barrier systems have variations but they generally entail a reflective surface such as aluminum foil installed either on the attic floor (over the insulation) or beneath the roof rafters with an airspace between the foil and the roof. It can be shown that the radiant barrier reduces heat transmission to the surface of the insulation on the attic floor (especially in the summer months) because the majority of the heat transfer is by radiation from the roof[4]. The overall effectiveness of the radiant barrier is quite dependent on the level of insulation on the attic floor, because this insulation represents a significant thermal resistance over an area of substantial heat loss/gain in a residence.

Considerable experimentation on radiant barrier systems has occurred during the past several years. The work at the Florida Solar Energy Center and Oak Ridge National Laboratory[1,2,3] is probably the most notable. Experimenters at the laboratories have reaffirmed the theory.

In spite of all the work done, many questions remain. Presumably one could reduce the regular insulation on the attic floor when a radiant barrier is used. Therefore, there must be an optimal insulation level in combination with the radiant barrier system. It is not simple to arrive at this optimum because of the time dependent and nonlinear nature of the system. At this time, no systematic experiments have been performed to evaluate this effect. The economic trade-off is a very questionable quantity in the absence of more experience in designing, installing and maintaining these systems. Regular insulation is low in cost and inexpensive to install. With the present state of the art of radiant barrier systems, it would be foolish to reduce the basic insulation level. Therefore, the cost effectiveness of adding the radiant barrier must be computed on the basis of paying for itself with whatever energy it alone saves.

The effectiveness of the system will also be regionally specific due to climate considerations. There are apparently computer simulation programs in place or under development, but no literature giving results of simulations or design data is presently available.

Questions persist relative to the degradation of the radiant barrier due to dust and condensation. Long term tests are required to evaluate this.

Installing the radiant barrier over the attic insulation seems to be most effective[1,2], but this could cause problems in blocking the transfer of moisture from the insulation in wet climates.

Field installation practice significantly affects the performance of radiant barriers which is a problem for code enforcement.

The radiant barrier system must be considered a developing technology from the standpoint of standards development. There are still too many questions to be answered to include the concept in an economics based standard at this time.

It does appear that the radiant barrier system has application in at least some regions where cooling of a structure is a burden, but the benefit over the life of the analysis cannot be adequately determined at this time. We should encourage experimentation, development of design methods and reporting of findings in the open literature. However, it is recommended that the radiant barrier system not be an option in the standard until some of the above questions can be answered.

References:

1. Levins, W.P. and M.A. Karnitz, "Heating Energy Measurements of Unoccupied Single-Family Houses with Attics Containing Radiant Barriers", ORNC/CON-213, January 87.

2. Levins, W.P. and M.A. Karnitz, "Cooling Energy Measurements of Unoccupied Single-Family Houses with Attics Containing Radiant Barriers", ORNL/CON-200, July 86.

3. Fairey, Philip, "The Measured, Side-by Side Performance of Attic Radiant Barrier Systems in Hot-Humid Climates", Florida Energy Center, 300 State Road 401, Cape Canaveral, FL, 1986.

4. McQuiston, F.C., "Thermal Simulation of Attic and Ceiling Spaces," ASHRAE Transactions, Vol. 90, Part 1, 1984.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #4-7

Title: ROOF ABSORPTIVITY

Statement of Issue: How should roof absorptivity be treated in the standard?

Resolution: Roof absorptivity should not be included as an option in the standard.

Discussion:

Some energy savings can be attributed to the color or absorptivity of the roof. However, most of its effects are evident in the outer layers of the roof system and these effects are greatly reduced by insulation and other materials that normally are installed within a roof assembly. The effects of roof absorptivity on interior comfort are more evident in uninsulated or very lightly insulated buildings. Since the standard will not allow uninsulated or under insulated buildings, we feel that the effects of roof absorptivity on the total annual energy consumption of the home would become a relatively minor load and should not be treated in the standard.

There is a general lack of documentation of roof color energy savings and an unreliability in the longevity of the color without substantial maintenance because of the deterioration of color over time, due to weather, industrialization and airborne industrial wastes.

Roof absorptivity has no conflict with safety or health issues. However, the attributes of roof absorptivity which afford its effects on energy consumption may be better and more effectively achieved using other means.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #4-8

Title: GLAZING AND SASH MATERIAL

Statement of Issue: How should glazing area, layers, shading coefficients, and orientation be dealt with in the standard.

Resolution: Maximum area and minimum layers of glazing will be established in the standard. Variations in area, layers, shading coefficients and orientation will be available in all paths, as alternatives to meeting an energy target.

Discussion:

Reduced glazing area can cause the greatest reduction in both heating and cooling energy of all structural ECMs after "state-of-the-art" insulation levels have been incorporated (and average infiltration values have been obtained). Given a simplified formula, code officials can easily identify compliance with either a percentage of wall or percentage of floor space given as a limit for compliance. Credits for reduced glazing areas can be maximized by performance paths and at least a fair credit can be established in prescriptive or point system methods.

The glazing area decision should not be a function of house type, but rather a function of wall area or floor area. It should be tied in part to standards, either existing or revised, for proper light and ventilation. A standard should attempt to allow equal areas of glazing in all regions by improving the performance of the glazing, either by additional layers or improved types. The use of microclimate variations should not be necessary.

Multiple glazing levels can significantly reduce energy consumption. In addition, multiple glazing is one of the most significant ECMs with respect to increasing occupant comfort while conserving energy. Dual glazing is readily available in most areas of the country with increasing availability occurring in the southern climates. Triple and quad glazing are common in the northern tier of the country. Standards are in place for users to evaluate the performance of multiple glazing levels.

Levels of conservation can also be directly related to the number of glazing levels provided. However, compliance paths of a standard must allow the user to increase the performance of glazing in exchange for the ability to use greater glass areas to satisfy the aesthetic and lifestyle desires of the public.

Glazing materials such as low emissivity glass, reflective glazing, and heat absorbing glazing should be included in all compliance paths as options.

ASHRAE recognizes the performance of Low-E glass and provides values which can be used for performance based simulations to establish compliance with a standard. Prescriptive paths or point systems could be developed on an "equal to" basis that relates to glazing levels. The value of reflective and heat absorbing glazings as they pertain to cooling energy reductions is more difficult to quantify, but the methodology does exist and a standard should include the appropriate credits for the use of these products.

A standard could allow credit for certified improved sash performance, but it is extremely difficult to make a judgment regarding the performance of sash as a function of its material or construction. While ASHRAE assigns values for wood, metal, and "thermally improved" metal frame, factors such as the ratio of frame to glass and the integrity of the "thermal improvement" can cause significant variations in the actual thermal performance of windows. Manufacturers can and do use the ASHRAE values to calculate the thermal performance of windows. In some cases this results in certification data that does not accurately depict the actual performance of the unit. Any credit given for improved sash should therefore be based on actual thermal testing.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #4-9

Title: MOVABLE INSULATION

Statement of Issue: How should movable insulation for fenestration be handled in the standard?

Resolution: Movable insulation should be included for trade-off in the performance path with appropriate modeling requirements provided. Do not include in the packages, the point system, or in development of the standard.

Discussion:

The use of movable insulation to periodically increase the R-value of exterior glazing is well understood and materials are readily available. Projections of energy savings are highly dependent on use profiles. If automatic operation is available to ensure proper use, then the energy savings projections can be made with more confidence. Without automatic controls, then the energy savings must be based on a probability of proper operation. For this reason, it is suggested that movable insulation not be one of the ECMs included in the standard. However, since it is a viable measure whose existence can be verified in the field, it could be included under the performance path. Effectiveness of the measure in these cases should be based on a combination of energy savings and probability of use. There does not seem to be a conflict between the use of movable insulation and health and safety codes as long as the materials used are in compliance with fire safety requirements and egress requirements from bedrooms are not compromised. (Note the final paragraph.) Finally, the technique is acceptable in the marketplace and energy savings data exists in the DOE-2 data base.

For the performance path, computer analyses can be performed for movable insulation of any R-value. Energy savings can be determined for any product which has an R-value from independent laboratory tests. To account for uncertain occupant behavior, operable systems without automatic controls shall be assumed to achieve only 50% of their rated performance in the modeling approach.

The approach outlined above is valid for all housing types and climate regions although the energy savings will vary by type and location. The validity of movable insulation as a cooling energy savings measure is questionable due to material degradation in sunlight, problems with acceptance in the marketplace, and uncertainty of the effects of the trapping of heat between insulation and glazing on energy use. At this time, it is suggested that movable insulation be handled as a heating-only ECM.

To be an effective insulating device, the movable insulation must be fitted to limit infiltration and convective air flow around the device. In this context, however, it must be noted that the installation of the device should in no way inhibit the use of the glazing as a fire exit or interfere with other safety considerations.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #4-10

Title: AIR INFILTRATION

Statement of Issue: How should air infiltration reduction techniques be handled in the standard?

Resolution: Air infiltration reduction techniques should be included as a basic option in all compliance paths. However, air infiltration is not a part of the economic optimization process used to create the basic packages.

Discussion:

Techniques to reduce the rate of air infiltration into homes can be significant energy savers, are readily available, are for the most part understood by builders, can be checked and validated in the field, and are acceptable in the market place. In general, their use does not conflict with health and safety codes, other than situations where the availability of combustion air and outside ventilation air must be closely checked. Finally, using existing data from the DOE-2.1 data base and material contained in Chapter 22 of ASHRAE Fundamentals (1985), a defensible technique can be developed for estimating the energy savings associated with air infiltration reduction strategies.

The levels of conservation can be expressed in two ways. First, levels of air infiltration can be developed (e.g. Standard, Tight, Very Tight) that are tied to combinations of infiltration reduction techniques. Handling the range of infiltration levels as discrete units is appropriate for the package compliance approach.

Second, the points and performance approaches allow conservation levels to be expressed in smaller gradations. A system can be created whereby individual air infiltration reduction measures are assigned values that can be directly equated to units or points of energy saving value. However, since the reduction in infiltration levels are often difficult to quantify, it is suggested that the levels used in the package approach also be used in the points and performance approaches.

The basic approach outlined above should be the same for all housing types although the magnitude of energy savings for a particular air infiltration reduction technique will vary by type. Depending upon the severity of climate, it may not be necessary to include both heating and cooling energy savings in all locations.

The issue of how the level of air infiltration influences air quality needs to be clarified as a basis for potentially restricting the extent of infiltration rate reduction. Further, if devices such as air-to-air heat exchangers are to be required, the level of infiltration at which they would be required needs to be determined.

In terms of implementation of air infiltration as an ECM under this standard, it is recommended that the following be adopted:

Mandatory Requirements:

- All doors and windows used in a residential structure shall be certified as to air leakage. Rates of air leakage shall be determined in accordance with ANSI/ASTM E 283-84 "Standard Method of Test for Rate of Air Leakage through Exterior Windows, Curtain Walls and Doors." The testing shall be done at a pressure differential of 1.57 lb/ft^2 (75 Pa), which is equivalent to a 25 mph (11.1 m/sec) wind speed. All air leakage requirements identified in this standard are based upon tests at the above condition.
- Foundation walls and below grade walls enclosing conditioned space shall be treated, caulked, and sealed in thorough manner to avoid entry of unwanted moisture, chemicals, or radon gas.
- All exterior joints (such as soleplate, wall frame corners, wall and ceiling joints, window and door frames) shall be properly sealed with durable caulking material. Joints between dissimilar materials (wood & masonry or concrete & metal) shall allow for differential expansion and contraction of such materials so as to provide a permanent seal.
- All outside penetrations in the envelope between conditioned and unconditioned spaces must be sealed with caulking or other suitable materials. Such penetrations include those for faucets, electrical outlets and wiring, flues and vents, and all penetrations through the top plate of exterior walls.

- All moveable joints between doors and door frames and windows and window frames shall be weather-stripped or gasketed with appropriate materials.
- All interior joints between walls and interior ceilings shall be taped to reduce infiltration.
- Exhaust air from bathrooms, kitchens, and utility areas shall be provided as required by other health and safety standards to assure acceptable indoor air quality. Such exhaust systems shall be filled with approved back draft dampers to prevent air leakage into the conditioned space while fans are not operating.
- Fireplaces shall be enclosed with reasonably air-tight door assemblies fitted across the openings of their combustion chambers. The perimeters of such assemblies shall be fitted with materials to make as leak proof a seal to the fireplace as possible. Makeup combustion air shall be provided from the outside air with an operable damper to avoid excessive losses of warm interior air during winter use. The fireplace flue shall be provided with all building code required dampers and components, and the dampers shall be fitted with readily accessible controls.

Minimum Requirements:

- The minimum infiltration package shall contain all of the mandatory requirements as specified above.
- All windows shall be designed to limit air leakage such that infiltration rates shall not exceed 0.37 ft^3/min ($5.72x10^{-4}$ m^3/sec) per ft (m) of crack. These rates shall be determined according to the standard method specified in mandatory requirements.
- Under average conditions, this package of infiltration measures should result in an air change rate of 0.42 per hour without occupant effects.

Tight Package:

- The tight infiltration package shall contain all of the mandatory requirements as specified above.

- All windows shall be designed to limit air leakage such that infiltration rates shall not exceed 0.28 ft^3/min (4.33×10^{-4} m^3/sec) per ft (m) of crack. These rates shall be determined according to the standard method specified in mandatory requirements.
- All access areas to attics from conditioned spaces shall be weather-stripped or gasketed to seal the conditioned spaces from outside air leakage.
- All electrical outlets, receptacles, or switches on interior and exterior walls shall have gaskets installed over these pieces of equipment and under the cover plates.
- Air infiltration barriers shall be provided on walls and ceilings continuous to the exterior surface of the structure. All barrier materials shall have a perm rating greater than or equal to 4, and not less than that of any other continuous membrane in the building section. All joints and penetrations of the air barrier shall be sealed against air leakage.
- Under average conditions, this package of infiltration measures should result in an air change rate of 0.27 per hour without occupant effects and 0.37 per hour based on an additional 0.1 ACH for occupants.

The following table indicates features of both packages and associated air change rates for different locations.

Location	dT htg	Wind htg	ACH/ sq.in.	ACH good	ACH best	dACH	
Bismarck	44	11.4	0.0067	0.52	0.34	0.19	
New York	27	11.3	0.0062	0.48	0.31	0.17	
Seattle	23	10.1	0.0056	0.43	0.28	0.16	
Charleston	12	8.8	0.0046	0.36	0.23	0.13	* <0.35 w/0.1 occupant
Ft. Worth	15	11.8	0.0060	0.47	0.30	0.17	
Albuquerque	30	7.1	0.0047	0.37	0.24	0.13	* <0.35 w/0.1 occupant
Denver	36	9.0	0.0056	0.44	0.28	0.16	
Miami	0	9.5	0.0044	0.35	0.22	0.12	* <0.35 w/0.1 occupant
Minneapolis	50	10.3	0.0065	0.50	0.32	0.18	
Phoenix	15	6.0	0.0037	0.29	0.18	0.10	* <0.35 w/0.1 occupant
Washington D.C.	30	10.0	0.0057	0.45	0.29	0.16	
Average cond.	26.6	9.6	0.0054	0.42	0.27	0.15	
Leakage area in square inches				78.10	50.13		
Infilt ratio (ELA, sf/Floor Area, sf)1540				0.00035	0.00023		

Component	Option A Area or Quantity	Option B Minimum Package Condition	Factor	Leakage	Best Package Condition	Factor	Leakage	
Soleplate	157	caulked	0.04	6.28	caulked	0.04	6.28	
Wall-ceiling	157	taped	0.00	0.00	taped	0.00	0.00	
Windows	194	sgl, 0.37	0.051	9.84	sgl, 0.28	0.038	7.37	
Framing	194	caulked	0.004	0.78	caulked	0.004	0.78	
Doors	20	sgl, ws	0.114	2.28	sgl, ws	0.114	2.28	
Framing	20	caulked	0.004	0.08	caulked	0.004	0.08	
Attic Access	1	no wthrstr	4.6	4.60	w/s	2.8	2.80	
Elec. Outlets	20	no gasket	0.076	1.52	gasket	0	0.00	
Duct Penetrat.	2	sealed	0.25	0.50	sealed	0.25	0.50	
Fireplace	1	w/o insert	10.7	10.70	w/o insert	10.7	10.70	
Fans, Kitchen	1	closed	0.775	0.78	closed	0.775	0.78	
Fans, Bathroom	2	closed	1.7	3.40	closed	1.7	3.40	
Dryer Vent	1	closed	0.47	0.47	closed	0.47	0.47	
Ducts	1	taped	11	11.00	taped	11	11.00	
Air Conditioner	1	1 penetr.	3.7	3.70	1 penetr	3.7	3.70	
Infilt. Barrier	2796 sf	No AIB	0.004	11.18	Full AIB	0.000	0.00	
	157 lf		0.07	10.99		0.000	0.00	
TOTAL (sq.in.)				78.10			50.13	
					1289.38			957.76

Pressure (Pa)	75		
Wind speed (mph)	24.5		
cfm/sq.in.	2.35	cfm/sq.in.	2.35
cfm/ft @ 75Pa	0.37	sq.in./sf	0.026
Total crack ft	125	Total sf	194
Total cfm	23.125	Total cfm	11.851
Equiv. sq.in./sf	0.051		

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #4-11

Title: PIPING INSULATION

Statement of Issue: How should the thermal insulation needs for piping be dealt with in the standard?

Resolution: Insulation shall be mandatory on all piping located outside conditioned spaces, with the specific level determined by the type of piping and its contents.

Discussion:

Hydronic heating pipes located within the conditioned space should not be insulated. Hydronic heating pipes located outside the conditioned space shall be insulated with R4 pipe covering.

DHW piping for once through systems that are located above ground shall be insulated with R2 pipe covering (it may be omitted on small diameter piping when less than 15 feet is involved between DHW heater and service point).

DHW piping carrying continuously circulating hot water shall be insulated with R4 pipe covering.

HVAC chilled water piping, regardless of location shall be insulated with R4 material having a permeance of one (1) grain/h•ft^2•in•Hg or less. Material not meeting this permeance shall be protected with a vapor retarding covering having a permeance of one-tenth (0.1) grain/h•ft^2•in•Hg or less.

Piping Layout:

In areas of the country where freezing conditions may exist for a duration of several days it is important to avoid locating any water lines in exterior walls.

Locating all piping in service tunnels and stacks is recommended. These tunnels and stacks should be located away from freezing conditions and should be sealed to avoid undesirable air movement.

The piping DHW heater and service areas should be laid out to minimize piping length.

Domestic Water Supply:

The piping carrying the potable service water into and through a dwelling does not require a covering of thermal insulation if its temperature is above the dwelling's design dew point temperature. If the source temperature is lower than the dwelling design dew point temperature, action must be taken to raise the water temperature or to accommodate and/or control condensation.

When the service water temperature is lower than the design dew point temperature, a tempering tank or coil should be considered to raise the temperature to or above the dew point temperature before distributing the water throughout the dwelling. The area under the tempering device must be protected by a sink or drain basin.

If the builder chooses to distribute the low temperature water then all lines, valves, fittings, and devices such as toilet tanks must be insulated. A minimum of R2 insulation is usually required.

Domestic Hot Water System:

The equipment and piping layout (location) of the DHW systems is as important as the use of thermal insulation.

The DHW heater should be located as close to the point of use of the hot water as is practical.

The piping on a once-through DHW system does not require thermal insulation if the lines are 15 feet in length or less. For longer runs, a thermal insulation with an equivalent thickness thermal resistance of R2 should be used.

Large DHW systems using pumped circulation to deliver hot water on demand should be insulated with at least R2 thermal insulation (R4 on the piping of very large systems).

Point-of-use DHW Heaters:

In some areas of the country, "point-of-use" water heaters are finding an expanding market. They have many advantages: there is little energy wasted; only the cold water needs to be piped to each service point; each service point can be supplied with the most desirable temperature; there is seldom a need for using mixing valves; in some larger dwellings a spare unit is justified; and most are easily serviced to remove scale deposits.

For these systems, the manufacturer's instructions should be closely followed and care should be exercised when planning the locations of each unit to allow easy service of the equipment.

Hydronic Heating Systems:

The piping for hydronic heating systems should be carefully located away from freezing conditions and preferably in areas which allow all heat losses to contribute to the dwelling comfort. Heating system piping that is located such that the heat losses aid in maintaining comfort should be not insulated.

If the piping is located so that heat losses from it flow outside the comfort envelope, then R4 thermal insulation is required.

Equivalent Thickness:

When dealing with pipe insulation, it is necessary to consider the relationship between actual thickness and equivalent thickness. The smaller the pipe radius the more effective a given thickness of insulation will be. Equivalent thickness is defined as that which equals the thermal performance of the same material installed on a flat surface when both pipe and flat surface temperatures are equal and located in the same ambient condition.

If one is to consider a unit area of a pipe surface, the equivalent thickness will be equal to:

$$r_1 \ln (r_2/r_1)$$

r_1 = pipe radius

r_2 = outside radius of the insulation

ln - natural or Napierian logarithm

If one is to consider a unit area of the insulation surface, the equivalent thickness will be equal to:

$$r_2 \ln (r_2/r_1)$$

General Consideration:

The stated needs and levels of thermal resistance to be applied to various piping have been determined by considering average conditions, compromise based on desired performance and common practice. Small variations in these levels will have little impact on the total energy needs of a dwelling.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #4-12

Title: INSULATION AND SEALING OF AIR DISTRIBUTION DUCTS IN HVAC SYSTEMS

Statement of Issue: Should a minimum level of duct insulation be required and should credit be given for levels greater than the minimum? How should duct leakage be controlled?

Resolution: A minimum insulation level of R-6 shall be installed on all HVAC ducts located outside the conditioned space when heated or refrigerated air is used. This is exclusive of the inside and outside air film resistances. No credit shall be given for insulation levels greater than R-6. A plastic or aluminum foil vapor retardant must be present on the outside of the insulation. All joints in both the ducts and the insulation system shall be sealed with foil backed, acrylic tape.

Discussion:

There are basically three ways of constructing and insulating ducts in residential buildings. These are: metal ducts sealed and wrapped with batt insulation; fibrous glass duct board of round or rectangular cross section where the duct and insulation are integral; and flexible ducts which are essentially batt insulation installed between two thin plastic tubes. Air leakage and heat transfer to or from the duct system are detrimental to efficient system operation. Installation, sealing and insulation of the ducts are generally performed by the same contractor and are all part of the same system. Therefore, these items have been combined in this paper.

The duct system has a relatively long useful life and all components of the system should have about the same life. It is well known that the common gray duct tape cannot withstand the environment found in attics, crawl spaces, etc more than a few years. On the other hand, high quality materials such as pressure sensitive, foil backed, acrylic duct tape have a useful life about equal to metal ducts. The Sheet Metal Air Conditioning Contractors of America (SMACNA) recommends, as a minimum, that the metal foil tape be used[1,2,3]. Careful installation of this product renders a duct system essentially leak free[4]. It is recommended foil backed acrylic tape be the minimum acceptable sealant for all ducts. Further, this same sealant should be used to seal all joints in the insulation/vapor retardant system.

To evaluate the requirement for the thermal resistance of the duct insulation, an analysis was made of a single family residence located in three different climates: Minneapolis, MN, Stillwater, OK and Austin, TX. These locations were judged to represent a range of conditions from where heating is dominant to where cooling is dominant. A range of duct systems, including all exposed to unconditioned space, partially exposed, and none exposed were examined. These results are shown in Figures 1,2, and 3. The results are shown separately for heating and cooling and for return and supply ducts to evaluate the particular duct system in use. For example, in Austin, TX the typical system will have all ducts overhead in an attic. In Oklahoma, the return system may be in the attic, while the supply ducts may be beneath a floor slab. In Minnesota all ducts may be within the conditioned space or a minimal amount exposed in the attic. The results show that regardless of how much duct is exposed, insulation is definitely required. The National Association of Home Builders (NAHB), in their survey of cost data performed to support the ASHRAE Standard 90.2 effort[5], reports the costs to install various levels of duct insulation as follows:

R Value	Cost/Sqft duct
4	$0.45
6	0.55
12	0.85

It is assumed that these costs represent the insulation in all systems. Using payback periods, the economic effectiveness of the various levels can be evaluated. Assume that at least R-4 can be justified as a starting point and consider each location with a typical duct system:

Location	Type System	R-Value hr-ft2-F/Btu	Operation Cost $/sqft	Installation Cost $/sqft	Instl$/Oper$
Austin, TX	All Exp.	4	1.34	0.45	
					0.34
		6	1.05	0.55	
					0.86
		12	0.70	0.85	
Minn., MN	Rtn. Exp.	4	0.30	0.45	
					1.0
		6	0.20	0.55	
					6.0
		12	0.15	0.85	
Stillwater, OK	Rtn. Exp.	4	0.37	0.45	
					1.11
		6	0.28	0.55	
					3.0
		12	0.18	0.85	
Stillwater, OK	All Exp.	4	1.44	0.45	
					0.34
		6	1.15	0.55	
					1.00
		12	0.85	0.85	

Noting that the payback periods are mostly very short, almost any level of duct insulation can be justified economically. However, there are practical considerations. For example, it is very difficult to effectively insulate small ducts with more than about 2 inches of batt insulation. Duct board is readily available up to 1 1//2 inch thickness. Flexible duct is not available in thicknesses greater than 1 1/2 inches. Batt insulation is readily available up to 2 inches thicknesses but generally not available in greater thicknesses for use on ducts. Considering the very favorable payback on duct insulation, manufacturers should move to supply insulation products with greater R factors. However, optimization with respect to insulation level is not recommended.

A survey of four major insulation manufacturers revealed that an R-value of R-6 can be readily achieved in at least three different type duct insulation systems. These are 2 inch fibrous glass duct wrap, 1 1/2 inch duct board (round or rectangular), and 1 1/2 inch flexible duct. It is therefore recommended that a minimum insulation level of R-6 be established whenever refrigerated or heated air is used. Higher levels should be encouraged whenever possible (large ducts and plenums), but no trade offs with other ECM's should be allowed.

One final point must be considered. An effective vapor retardant must be provided on the outside of the duct insulation. This is an integral part of duct board and flexible ducts and is available on all batt insulation. Aluminum foil is considered to be of superior quality. It is recommended that as a minimum, the plastic type retardant may be used but the use of aluminum foil be encouraged. Both systems must be sealed with foil backed acrylic duct tape.

References:

1. Sheet Metal and Air Conditioning Contractors National Association (SMACNA) Heating and Air Conditioning Systems Installation Standards.

2. SMACNA Fibrous Glass duct Construction Standards, 5th Edition, 1979.

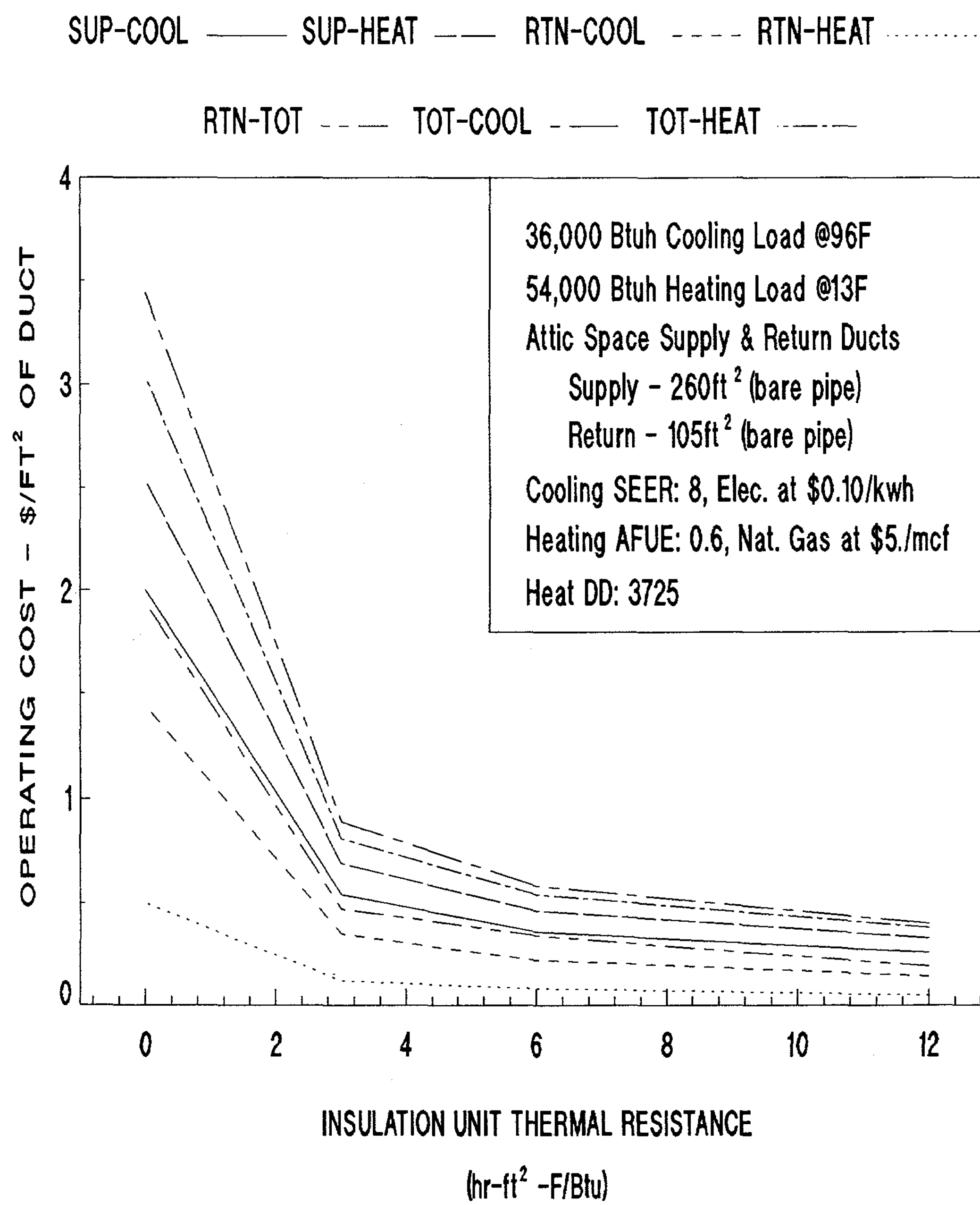
3. SMACNA/TIMA/ADC Standard on Flexible Duct, 1980.

4. SMACNA HVAC Duct Leakage Test Manual, 1985.

5. NAHB Cost Survey for ASHRAE.

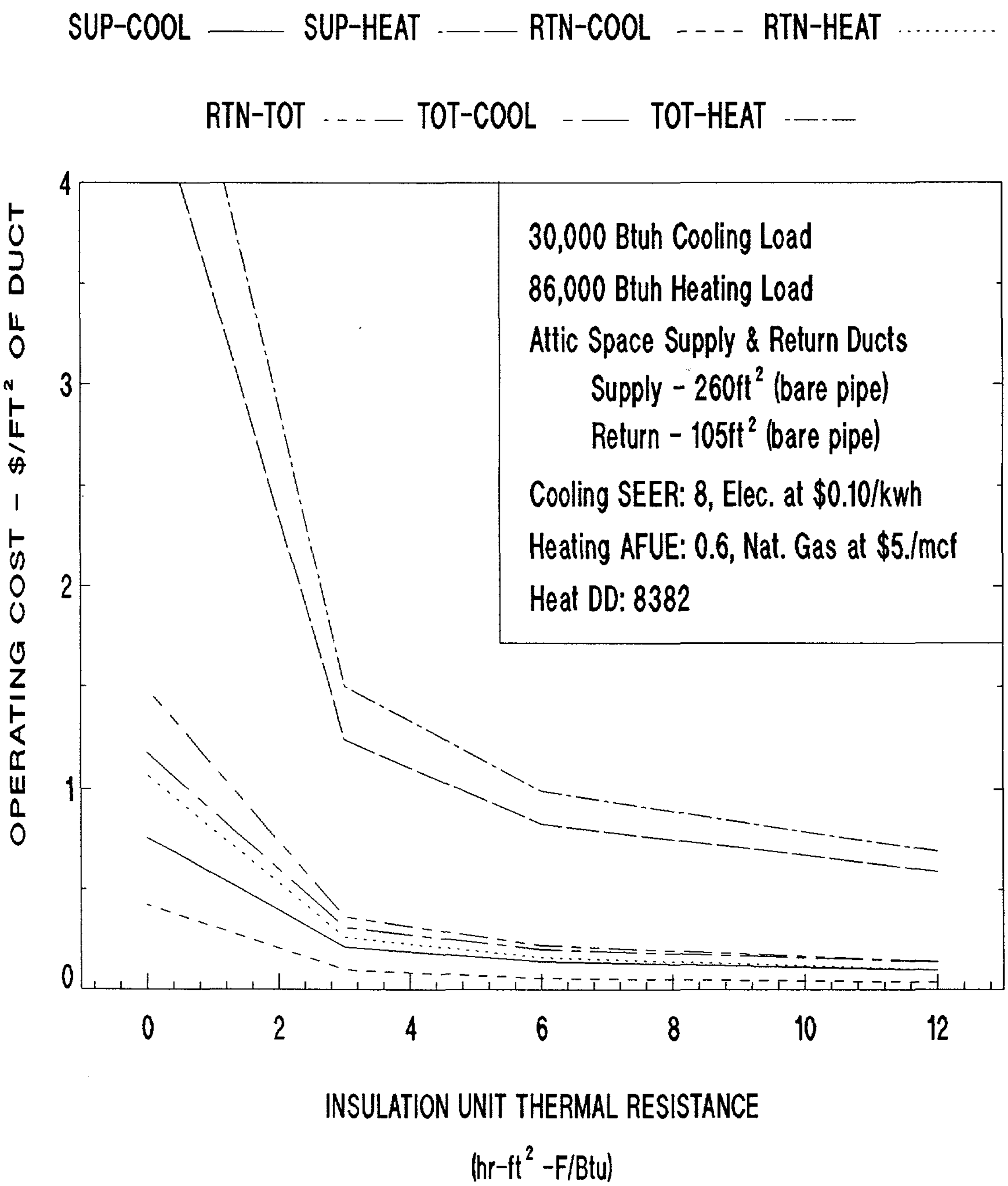
DUCT LOSS ANALYSIS

Single Family Detached - 2000 ft² Stillwater, OK



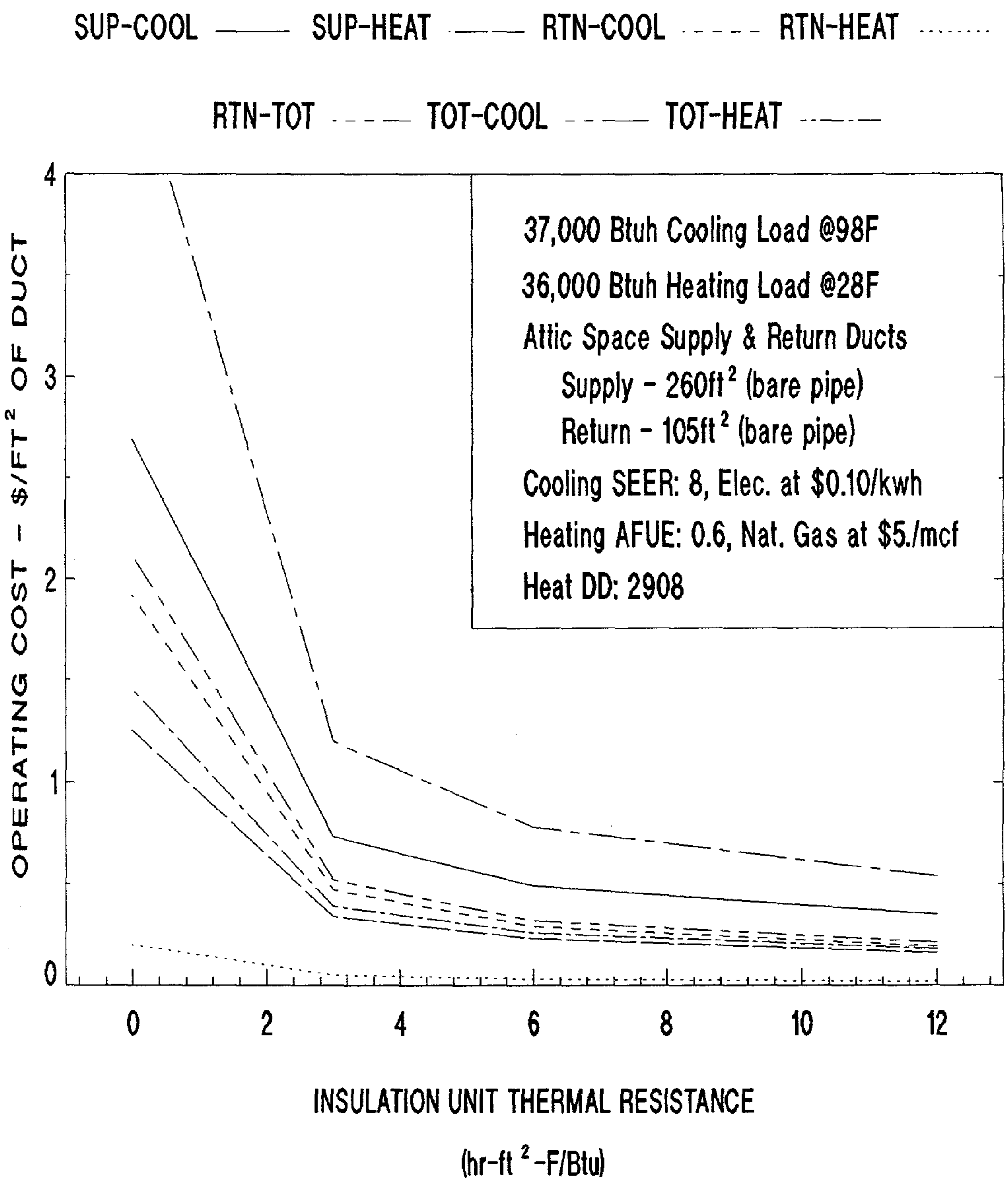
DUCT LOSS ANALYSIS

Single Family Detached - 2000 ft^2 Minneapolis, MN



DUCT LOSS ANALYSIS

Single Family Detached - 2000 ft² Austin, TX



ASHRAE SPECIAL PROJECT 53 POSITION PAPER #5-1

Title: SOLAR SPACE CONDITIONING

Statement of Issue: How should solar space conditioning options be handled in the standard?

Resolution: Weighted glass allowances by orientation will allow most sun tempering options to be built without restriction. However, credit for system operation of both passive and active systems can only be obtained through the performance path.

Discussion:

Solar loads on a house can be one of the most significant loads, especially in cooling climates. Improperly placed glass can cause mechanical equipment to be oversized and cause comfort problems within the house. It can cause daily swings in comfort areas within the structure. Most sun tempering options respond well to selected orientation of glazing. For these strategies, glass on the south is preferred.

Because of the rotation of the earth about its axis and the axis tilt in relationship to the sun, the glass on the south side of the building receives the most insolation during the winter months and very little insolation during the summer months. In most climates, unshaded glass on the east and west produces heating during at least part of the year when it can be detrimental to human comfort within the structure. Glass on the north side, in some very cold climates, can be detrimental and should be minimized. However, in milder climates, north glass can be used with very few comfort and mechanical problems within the structure. DOE 2.1 is adept at modeling building orientation and percentage of glass on a given orientation. The program will be used in allocating points for glass by climate and orientation. The climate responses will cause the points given for various percentages of the glass (based on floor area) to be adjusted for the climate in which the houses are to be built.

Glass also responds to a shading sensitivity - especially at times when the sun is not needed on the glass, if the glass can be shaded, the detrimental effects of direct gain on that glass can be greatly minimized. This discussion is more extensive in another position paper, No. 5-3, on external shading devices.

Prescriptive Path

The energy target is set based on glass used in average orientation allowing no special treatment of glass for any particular orientation. The basic prescriptive package is derived assuming the worst-case placement of glass, assumed to be equally divided between the east and west faces of the house. The computer program will allow the generation of packages using different glass types and orientations. Further discussion is included in position paper No. 9-1 on packages.

Points Path

The DOE 2.1 runs will be used to weight the glass orientation and percentage of glass based on floor area by orientation. Eight orientations, both the 4 cardinal points and the midpoint between those cardinal points, will be used. Points will be adjusted when the percentage of glass is configured in such a way that a change in energy consumed by the building occurs. Careful weighting for the orientation of glass with the point system should allow any sun tempered or passive solar building to be built without restrictions.

Performance Path

Due to the variation of insolation on glazing during the seasons and its interrelationship with other loads in the house, the only approach that can give credit to solar space conditioning involving increased thermal mass or active systems will be the performance path. In the performance path, the proper winter and summer modeling is performed in a relationship with one another to quantify on an annual basis the amount of energy that may be saved by orientation of the glazing and its relationship to the spaces within the house for passive systems. It will also quantify the savings for the orientation of the collectors and the operation of its collectors and storage system on active systems.

There is no conflict with safety and health issues with properly designed and installed active or passive solar space conditioning.

The standard should be developed in such a way that on the simpler path there is no restriction or hindrance in any way to the proper orientation of glazing, thereby allowing houses to be built which respond to the path of the sun and its relationship to interior space without restriction. It is further the intent that by using more comprehensive paths, systems can be documented to show the reduction of energy consumption, and that credit should be given to these systems. It will usually be necessary for that documentation to be verified in the performance path.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #5-2

Title: INTERNAL SHADING DEVICES

Statement of Issue: Should inside shading devices be treated in the standard?

Resolution: Manually operated internal shading devices should not be included as an option in the standard. It is the policy of this committee to avoid giving credit for user dependent ECMs. Automatic internal shading devices can be used in the performance path based on a combination of shading coefficients and probability of use.

Discussion:

The use of internal shading devices can reduce the energy consumption of a residence when they are properly installed and maintained. The primary summer savings are from a reduction in heat gain during the day. Internal shading devices can also be used to allow heat gain on clear winter days and reduce heat loss on cloudy winter days and winter nights. The amount of savings is dependent to a great extent on user acceptance and operation. Therefore, the magnitude of the savings can be difficult to quantify. In the opinion of the committee, there is insufficient documentation of the magnitude of those savings. One of the largest potential savings is from proper operation of drapes, blinds, or insulated shutters. The possibility of this measure being improperly operated by the homeowner is higher than most ECMs, especially since most will be used by individuals to provide privacy. Most homeowners will not install internal shading devices for energy conservation. It is the policy of this committee to avoid giving credit for user dependent ECMs in this standard.

Effectiveness of automatic internal shading devices can be used when their operation is modeled in the performance path and is based on a combination of shading coefficient and probability of use.

There does not seem to be a conflict between the use of properly designed and installed internal shading devices and health and safety codes. Savings are available, however, they are difficult to document due to the reliability of this strategy for proper use by the homeowner unless automatic controls are used.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #5-3

Title: EXTERNAL SHADING DEVICES

Statement of Issue: Should outside shading devices be treated in the standard?

Resolution: External shading devices are a permanent part of the house and usually have a substantial effect on total energy consumption, especially in cooling climates and climates where heating loads are coincidental with clear skies. These effects are orientation dependent and do not fit into the format required for the packages except when used in a sun tempering package. They should be included as a basic option in the points and performance path.

Discussion:

A major source of heat gain through glass in houses is due to solar load on the glass. One of the most effective and widely used methods of controlling that gain is with external shading devices. Energy savings due to external shading devices are dependent on the glass orientation and a ratio of overhang width to glass height. Simulations will be run to generate the effect of shading devices and included in the data base.

The shading provided by an external shading device on a window is generally expanded as a ratio of the length of overhang over the height of the window (A 2/1 ratio would have an overhang twice the height of the window). The illustration in Figure 1 shows H = height of window and L = length of the overhang.

The solar load can be expressed graphically using the % solar load reduction being the "x" axis and the overhang/window ratio being the "y" axis. The data assumes that the overhang has an infinite width. Curves can be plotted for winter and summer using DOE-2 values for each of the eight orientations. The plots should be extended until the line begins to flatten out (See Figure 2). The % solar load reduction for a given overhang ratio can be read from the chart. That value can be used as coefficient to modify the solar load through the glass. The summer values can be used for the cooling conditions and the winter values can be used for the heating conditions.

This is no conflict of external shading devices with health or safety issues.

External shading devices can make a significant reduction in annual load in some climates and should be included in the standard. Since the sensitivity is climate based, they can best be included in the points and performance paths.

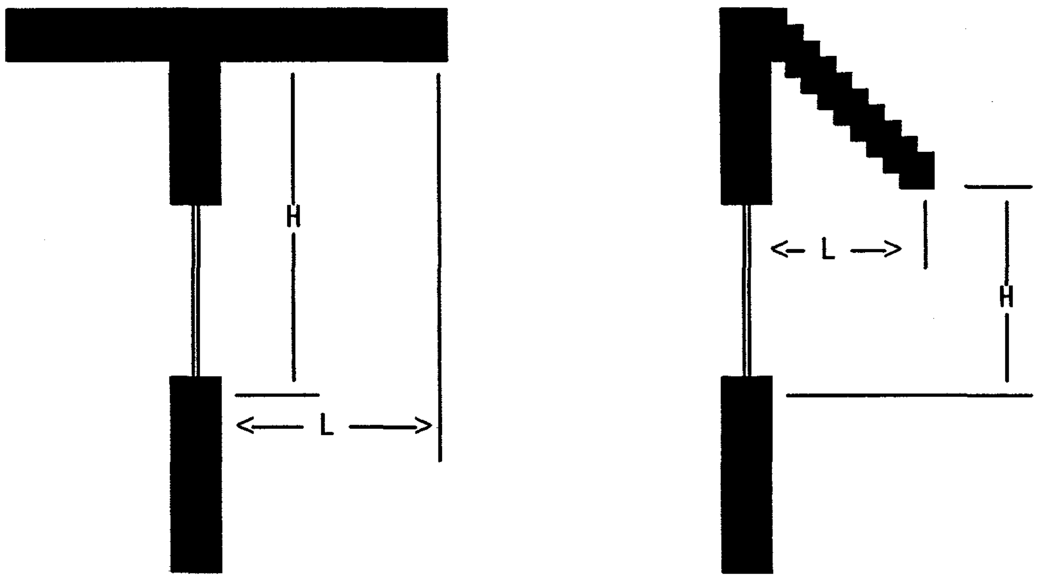


Figure 1. Overhang Length and Window Height (L & H)

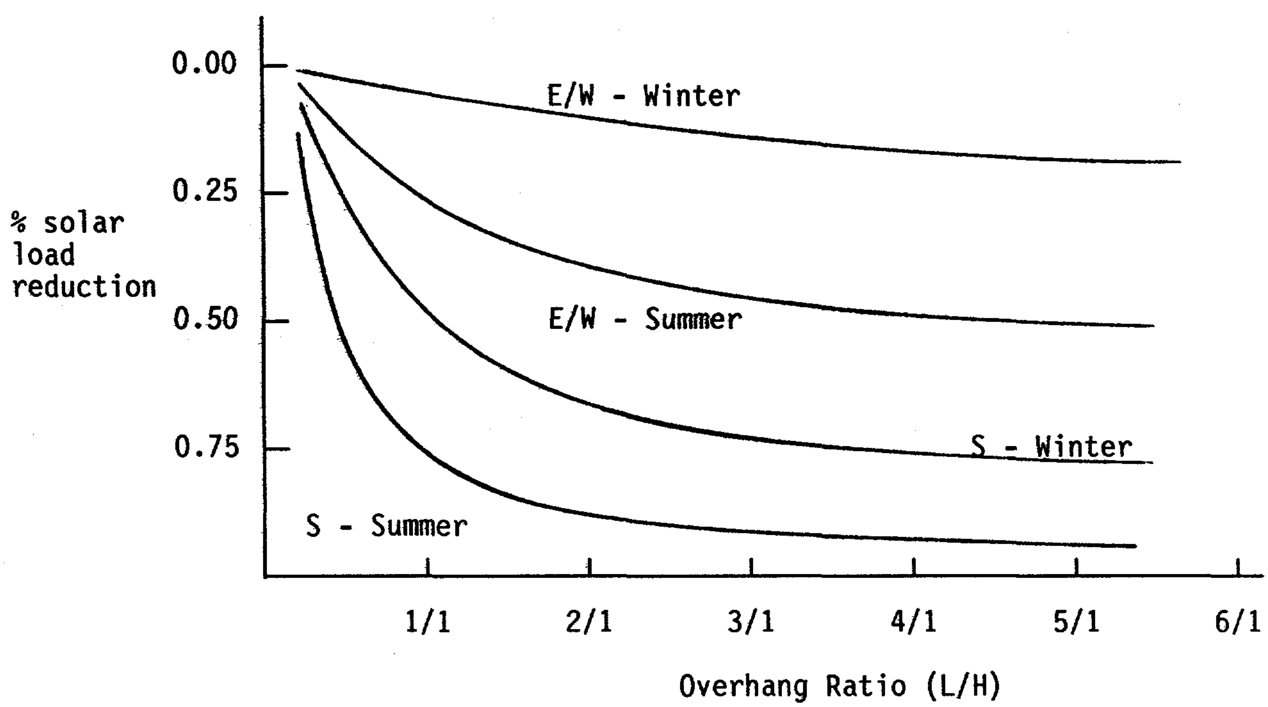


Figure 2. Example Overhang Plot

Development of Overhang Multipliers

The purpose of an overhang is to shade all or part of a window from direct solar gain at some time during the year. With the relationship between solar angles and seasons, overhangs are an effective device for reducing solar gains through windows during the summer while having minimal effect in the winter. Thus, they become an effective energy conservation measure (ECM) for the reduction in cooling energy without having an adverse effect on heating energy. However, since overhangs are a part of the aesthetics of the design, they can not be made mandatory. A base overhang was assumed on all four orientations in creating the database energy estimates, but as the costs vary with the building design, they could not be included as an option in the optimization process or in alternate packages. As overhangs are effective ECMs, some provision must be made to include them in the points and performance approaches.

Consideration under the performance approach requires only that a computer model be used which handles the effects of external shading on windows. In this way, under the performance approach, overhangs can get credit for energy savings. However, it is cumbersome and discriminatory to require that compliance for overhangs be done only with the performance approach. Thus, a procedure was developed to allow credit for overhangs with the points approach. Since the effectiveness of an overhang depends on its orientation and the ratio of its length to the height of the window, overhangs were characterized by orientation and ratio of length to height. Calculations were done for the eight cardinal and mid-cardinal orientations with four categories of length to depth ratio. These compared the solar gain through a 1/8 inch clear glass window without overhang to the solar gain through the same window with the overhang. In this manner, a set of shading coefficient multipliers were created for the eight orientations in the 45 base locations. These are included in the data base to be used as multipliers in the heating and cooling point calculations for fenestration.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #6-1

Title: DESIGN LOAD CALCULATIONS

Statement of Issue: What procedures are required to compute design heating and cooling loads to identify equipment sizes required in compliance paths?

Resolution: For single family residential structures with one central unit use ASHRAE GRP 158 (residential)(3) as updated(4), ACCA Manual J, or other documented method based on ASHRAE algorithms to compute room and block loads. For multifamily structures as described below or zoned single family houses, use ASHRAE GRP 158 (hour-by-hour)(2), the updated multifamily procedure of reference 4, or other hour by hour procedure based on ASHRAE algorithms(1) to compute room and block loads.

Discussion:

The complete design of a building heating and cooling system involves several steps, each important to the satisfactory performance of the system. However, the cooling and heating load estimates are the most crucial because all other system design parameters depend on them. Design loads are used to size and select the equipment for a system and to design the distribution system (air diffusers, grilles, ducts, pipes and radiators). Design loads are based on standard or accepted conditions (a design day) for a given locality.

The basic calculations from which cooling load estimates are derived are the same for all types of buildings. However, the final load estimate is very dependent on how the basic results are handled for different building types. Heating load procedures (winter) are the same for all types of buildings because only the building envelope is considered under night time conditions.

The general building types are:

1. Commercial
2. Single family detached
3. Multifamily (Apartments, Duplexes, Town Houses with common walls)

The reason different building types require different methods for load estimation is related to the heating and cooling systems generally used in each type, the geometrical features of each and the occupancy and internal loads. The nature or definition of each building type is as follows:

1. Commercial Buildings are outside the scope of this standard and will be omitted from further discussion.

2. A single family detached residence will have walls facing in at least four directions with a roof and possibly a floor over ambient or unconditioned space. It may have more than one story. The heating and cooling system will be a single zone type with a constant amount of air distributed to each room and a single thermostat for temperature control. The rooms are reasonably open to each other with a central air return. Each floor may have a separate system. This configuration results in mixing of the air from all rooms with a load leveling effect which requires a different distribution of air to each room than other building types. Since the amount of air supplied to each room is based on the load for that room, the proper calculation procedure must be used to achieve good results.

3. A multifamily residential building is made up of many living units which have most of the same features as a single family detached house except each unit will have only one, two or three exposed walls and may have a roof. In the case of two or three walls, they will be at right angles to each other and <u>both</u> East and West walls <u>do not exist</u>. Each living unit has a heating/cooling unit with central air distribution, rooms open to each other, and one thermostat. This configuration does not have the load leveling effect of the single family detached house, but it is not a pure commercial type where each room may have individual temperature control. Therefore, a procedure which gives loads somewhere between the single family detached and the pure commercial is required.

There are residential buildings that do not fall into one of the above categories exactly. Critical to the designation of single family detached is the presence of both east and west walls. Therefore, some multifamily type structures should be treated as single family detached when the exposed surfaces are oriented in certain ways. For example, a duplex or apartment with exposed east, west and south or east, west and north walls with or without roof should be treated as single family detached. Another example would be an apartment, town house or condominium with only east and west or north and south exposed walls. Any residential structure that does not have both east and west exposed surfaces should be treated as a multifamily structure. Examples are: duplexes, apartments, and town houses with north, south and east or north, south and west walls; and single family detached houses zoned so that east and west exposures are not in the same zone. Single family houses using electric or hydronic baseboard systems with zone control are in this category.

Regardless of the building type, the design load must be done on a room by room basis so that the proper amount of air for each room can be determined for design of the air distribution system. However, for the standard, only the block load is required for compliance. To select a properly sized heating/cooling unit, the peak (maximum) load (block load) for each zone must be computed. This procedure may vary considerably for different types of buildings.

The block load for a single family detached house with one central system is simply the sum of all the room loads. If the house is zoned with a completely separate system for each zone, calculation of each zone block load is required, which is the sum of the loads for all rooms in each zone. If the house is zoned with one central heating/cooling system, the block load must be computed for the complete house as if it has one zone.

In the case of multifamily structures, each living unit has a zone load equal to the sum of the room loads. For apartments with their own separate systems, the block load for each unit establishes the system size. Apartment buildings with a central heating/cooling system for the whole building such as a hydronic system with fan coils in each apartment require a block load calculation for the complete structure to size the central system while each unit load establishes the size of the fan coil and distribution system for each apartment.

There are many acceptable calculation procedures for <u>single family</u> detached residences. ACCA Manual J[1] and ASHRAE[2,3,4] are examples. Many manufacturers publish acceptable methodologies, which are usually based on ASHRAE methods. A special publication entitled "Cooling and Heating Load

Calculation Manual, GRP 158[3] contains hand calculation methods for both commercial and residential buildings. ASHRAE recently published updated methodologies for both single family and multifamily residential structures[4]. The GRP 158 residential section should be updated with this new data. Reference 4 is the only known procedure specifically developed for multifamily residential structures.

Excellent microcomputer software is available to carry out all types of design load calculations. However, one must be careful that a given piece of software is not based on obsolete procedures or limited in scope.

For compliance with the standard, the block load calculations are of fundamental importance because of equipment sizing requirements. The position paper on equipment sizing (#6-2) allows 25 percent oversizing of the equipment output relative to the design load. Therefore, it is essential that load calculation procedures do not produce exaggerated results or contain safety factors. The most common fault is to select improper design conditions. ASHRAE[2] procedures are recommended as follows:

Summer,	Outdoor:	2½% dry bulb and mean coincident wet bulb temperatures
	Indoor:	78F dry bulb temperature and 50% R.H.
Winter,	Outdoor:	97½% dry bulb temperature
	Indoor:	70F dry bulb temperature and 30% R.H. (Max)

These values are known to give reasonable results for design loads even though the system may be operated at slightly different conditions.

Any documented load calculation procedure based on ASHRAE[2,3,4] methodology may be used to carry out load calculations to obtain the <u>block load</u> on which a single system design is based, but care must be taken. If a sophisticated hour-by-hour procedure[2,3] is used, the peak load must be selected from the hourly block load output. When a simplified procedure[1,3,4] is used for a single family detached residential house, only the peak block load is produced.

Load calculations for multifamily units as described above should only be performed using hour-by-hour methods[2,3] or the procedure of reference 4. Experience has shown that single family detached residential procedures[1,3] may produce loads for some multifamily units that are 100 percent low.

In summary: For single family residential structures with one central unit use, ASHRAE GRP 158 (residential)[3] as updated[4], ACCA Manual J, or other documented method based on ASHRAE algorithms to compute block loads.

For multifamily structures as described above or zoned single family houses as described above, use ASHRAE GRP 158 (hour-by-hour)[2], the updated multifamily procedure of reference 4, or other hour-by-hour procedure based on ASHRAE algorithms[1] to compute block loads.

Computer methods are strongly recommended because the results are generally easier to obtain, and are more reliable and consistent from one job to another. However, care must be taken to ensure that the software is not obsolete and is appropriate for the job.

It is the responsibility of the builder or HVAC subcontractor to perform the load calculations discussed above. It generally will not be possible for the code enforcement official to check and validate the load calculations. Therefore, the contractor should certify the design loads and furnish data such as a calculation sheet or computer output giving input and output data as evidence that the loads were actually computed. In questionable cases the data might be verified.

References

1. ACCA Manual J

2. ASHRAE Handbook of Fundamentals - 1985

3. ASHRAE GRP 158

4. McQuiston, F.C., "A Study and Review of Existing Data to Develop a Standard Methodology for Residential Heating and Cooling Load Calculations", ASHRAE Trans., Vol. 90, Part 2, 1984.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #6-2

Title: SIZING OF SPACE HEATING AND COOLING EQUIPMENT

Statement of Issue: What sizing constraints should be imposed for residential HVAC equipment?

Resolution: Neither heating nor cooling equipment shall be oversized more than 25 percent of the design load, except where the next available size exceeds the 25 percent limitation, or where the cooling load requirement dictates an air quantity which forces the heating unit to a larger size. Heat pumps shall be sized to the cooling load. The ASHRAE Handbook of Fundamentals is the recommended source of design conditions and procedures for determining the structure heating and cooling loads.

Discussion:

Although HVAC equipment must be sized large enough to provide the required capacity, oversizing leads to a higher first cost, decreased annual operating efficiency, and poor control of space conditions, especially during the milder seasons. The optimal selection is one that provides the best comfort with the least life cycle cost, recognizing that some amount of compromise may be necessary since the system must be considered in its entirety (airflow, cooling needs, heating needs, moisture control, etc., and equipment size availability.) Ideally, a fossil fuel-fired furnace should be sized to just meet the design heating load calculated using nationally recognized design conditions and procedures. The ASHRAE Handbook of Fundamentals is the recommended source of such information.[a] It is recommended that fossil-fueled furnaces not be undersized and that they not be oversized more than 25 percent of the design heating load, except when the next available size is more than 25 percent greater than the heating load or a larger size is necessary to handle the cooling air quantity.

Where electric resistance heating is used, it should be sized to handle the design load with minimal reserve (again below 25 percent) to prevent thermostat overshoot and high kW demands.

Heat pumps should be sized on the basis of the cooling load. In most cases, electric resistance heating will be required as a supplement at low outdoor temperatures. The amount of electric resistance supplemental heating must meet the supplemental needs for tempering air in defrost, meeting

(a)See Position Paper #6-1

supplemental heat needs at low outdoor temperatures, and meeting emergency needs during times when the refrigeration portion of the HP is inoperative, such as during maintenance periods. A way of handling this is to allow only a portion of the resistance heating to be used during defrost, use outdoor thermostats to allow increased supplemental heating as outdoor temperature declines, and use a shunt to allow full resistance heat capability at times when the refrigeration circuit is inoperative and emergency usage of resistance heating is needed.

The cooling capacity of air conditioners or heat pumps should be as close to the design load as availability of desired models permits and should not be more than 25 percent greater than the design cooling load for the structure, except where the next available unit exceeds the 25 percent limitation.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #6-3

Title: CONTROL AND ZONING OF HVAC SYSTEMS

Statement of Issue: To what extent should HVAC systems be controlled and zoned. What credit, if any, should be given for zoned systems?

Resolution: A space thermostat capable of adjustment between 50 and 90 degrees F is required for all HVAC systems. The space thermostat may be conventional or time/temperature programmable. Credit should be given for zoned HVAC systems, except zoned electric baseboard systems, when each zone is thermostatically controlled and does not exceed 75 percent of the total floor area. This includes central hydronic and air systems and houses zoned by use of separate units in each zone provided the units are sized in accordance with position paper #6-2, and the total capacity of all zones does not exceed 125 percent of the total house block load. Credit for these zoned systems should be in the form of a 5 percent adjustment of the required SEER and AFUE. It is mandatory that electric baseboard heating systems be zoned.

Discussion:

It is fundamental that a space cooling and heating system must be controlled to maintain a uniform, comfortable temperature. To save energy, the control (thermostat) may be capable of automatic setback or setup of the set point or it may be manually reset by the user. The temperature range of the thermostat should be such that at least 20 degree F setback and at least 10 degree F setup can be accomplished (50-90 F range). In either case the thermostat is under control of the user, and one cannot be assured that setup or setback will be used.

Zoning is defined here as providing for separate control of the space temperature in two or more parts of a residential unit. Zoning is encouraged in all larger homes and particularly those with more than one story and/or with separated areas or wings that do not have good thermal communication. Zoning may be done in a number of different ways, such as separate heating or cooling units for each zone (i.e. electric baseboard heaters), or individual zone control of a heating or cooling medium from a central source (i.e. hot water from a boiler with zone thermostats, warm or cool air from a central unit with zone thermostats or a direct expansion AC or HP with fan coils and thermostats in each zone).

Zoning is an effective way to provide desired comfort and, at the same time, conserve on energy usage through providing heating or cooling at levels in accordance with the needs of the user. Quantifying the actual benefit can only be accomplished through detailed simulation of the structure and the specific system. Considerable analysis has been done relating to load calculations, zoning, and energy use of residential buildings[1,2]. The following observations come from that work. Zoned systems using one central unit are the most effective because they require less installed capacity than unzoned systems, which leads to improved operating efficiency. It is assumed that the zones are reasonably balanced in load and a zone should not exceed 75 percent of the total floor area of the house. Houses zoned using individual units in each zone can be effective provided the equipment can be properly sized for each zone and the total capacity does not exceed the total house block load by more than 125 percent. Separate units for each zone have the disadvantages of high installed capacity, total capacity not available to each zone, and generally lower operating efficiency than systems zoned from a central unit. Electric baseboard heating systems are easily controlled in each room (zone). Therefore, in view of the generally high cost of electricity, it is suggested that zoning be mandatory for these systems. It is further highly recommended that central electric heating systems also be zoned.

The only way of quantifying the benefit of zoned systems is through a performance path. However, giving credit using the points and packages approach is not as straightforward. It is suggested that some credit be given for a zoned system with thermostats in each zone by permitting a lower SEER and AFUE for the cooling/heating equipment or by giving credit for a higher SEER and AFUE. The result of effective zoning is to reduce the annualized load of the structure. How much it is reduced depends on several factors, such as area ratio of the zones, temperature and timing of the zones, orientation, thermal communication between zones, etc. It is recommended that a credit be given for zoning a residence as long as a single zone does not exceed 75 percent of the total floor area. When this condition is met, the recommendation is that the annualized load be adjusted downward, which, for simplification of usage, would be equal in the points or package approach to an improvement in system efficiency; i.e., SEER, HSPF, AFUE, etc. Based on experience[2], the recommended credit is 5 percent. In the case of electric heating, the baseboard system will probably save as much as 10 percent relative to a central electric system. No special credit is recommended in this case.

References

1. McQuiston, F.C., "A Study and Review of Existing Data to Develop a Standard Methodology for Residential Heating and Cooling Load Calculations," ASHRAE Transactions, Vol. 90, Part 2, 1984.

2. McQuiston, F.C., "A Practical Zone Temperature Control System for Larger Residential and Light Commercial Application," Proceedings of the Air Movement and Distribution Conference, Purdue University, 1976.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #7-1

Title: MECHANICAL VENTILATION FOR COMFORT

Statement of Issue: How should mechanical ventilation options, including Whole House Fans (WHFs) and Ceiling Fans (CFs), be dealt with in the standard?

Resolution: While mechanical ventilation options such as whole house fans and ceiling fans are effective in reducing the cooling energy requirement, they will not be included as a measure in the standard, nor as a mandatory requirement.

Discussion:

Mechanical ventilation devices can reduce cooling energy use by maintaining comfort conditions at a higher cooling equipment set point temperature. There are two factors associated with the exclusion of mechanical ventilation from the standard.

The first deals with the projection of energy savings. In reviewing the literature (see References 1 and 2), it appears that the existing data and analytical procedures for calculating projected energy savings are either not adequately tested and documented or are technically suspect. Second, the effectiveness of such devices appears to be tied to a range of design conditions that are not well understood (e.g. interior air movement). Their effectiveness also depends upon user operation.

Mechanical ventilation options save energy by creating air movement that allows the occupant to feel comfortable under conditions that normally would require the operation of the cooling equipment. A WHF operates by pulling in air from open windows and exhausting it into the attic space or directly out of the home through ducts. A WHF usually is centrally located in a home. It should also be mentioned that WHFs draw a fair amount of electricity, between 300 and 500 watts, depending on size.[1]

Another slightly less effective, although more popular, method for moving internal air is the ceiling fan. Ceiling fans simply move air without directly exhausting it and have the advantage of being aesthetically pleasing, easy to install and less expensive to operate than Whole House Fans. However, little data exist about their performance, and unlike WHFs, their effectiveness depends upon room geometry and height.

In discussing this issue, only the energy related concerns are addressed. Ventilation devices may be required to satisfy health and safety requirements, aspects not addressed by this standard.

References

1. Chandra, S., et. al., A Handbook for Designing Ventilated Buildings, Final Report, U. S. Department of Energy, San Francisco Operations Office, September, 1983.

2. Spain, S., Energy Savings in Buildings Using Air Movement and Allowing Floating Temperatures in Rooms, CRS Sirrine, Inc., Houston, Texas, 1985.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #8-1

Title: DOMESTIC HOT WATER EFFICIENCY REQUIREMENTS

Statement of Issue: How should DHW storage type heating equipment be treated in the standard?

Resolution: Set a minimum level of efficiency as suggested below. Give credit packages, points, and performance paths for using the recommended level or higher (see Table 1). Allow the use of any efficiency level greater than the minimum in the performance path when properly modeled.

Discussion:

Heating of domestic hot water represents a significant part of the utility cost for a home. As all other ECMs for a home are optimized, the cost of water heating becomes even more important. Therefore, it seems quite reasonable to use DHW heating equipment that is as efficient as economically justified.

Considerable cost data was obtained in one investigation as a function of heater efficiency and size; however, the data were incomplete because quality type features such as the warranty period were not noted. This caused so much scatter in the data that the true relation between cost, size and efficiency could not be determined.

Another independent investigation of one major manufacturer of DHW storage type heaters revealed that the manufacturers do not generally suggest list prices, and there are basically three levels of overall efficiency (energy factor, or EF). The two lower levels fall with the typical 5 year warranted tank and the third (higher level) is a 10 year warranted tank. Based on the dealer costs, it appears that the differential first cost is about equal from one level to the next and the differential operating cost is about equal from one level to the next. Therefore, it appears that the highest quality and efficiency are economically justified.

It does not seem reasonable to make the most efficient tank mandatory but at the same time allowing the least efficient tank isn't rational either.

It is suggested that a minimum EF level be adopted for each type of DHW tank as shown below in Table 1. Further, a credit (to be determined) should be given for a tank of higher efficiency (EF) as indicated in the recommended column of Table 1.

Table 1. DHW Efficiency Requirements

TYPE	Performance Criteria (EF) Minimum	Recommended
Gas	0.62-0.00175V	0.66-0.0016V*
LPG	0.63-0.00175V	0.67-0.0016V
Oil	0.61-0.00175V	0.66-0.0016V
Electric	0.94-0.001V	0.96-0.0008V

*V = Volume of the tank

The minimum level shown above is somewhat higher than that being proposed for ASHRAE Std. 90.2 for 1986 and is one step higher than those tanks used as a general practice now.

It is further recommended that any tank with efficiency (EF) greater than the minimum could be used for the performance path, assuming it is modeled properly.

Performance Path will handle DHW in the same way as it is handled in points. That is, with a selected fuel and tank size, the energy factor will be used to calculate the energy use. This DHW energy use is translated to an energy cost and combined with the space conditioning dollars. For the prototype, the DHW energy use is calculated using the minimum EF for the design size (volume) and selected fuel type. Anything above the minimum levels can receive additional credit in all compliance paths.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #8-2

Title: FLOW REDUCERS ON DHW

Statement of Issue: How should flow reducers be treated in the standard?

Resolution: Flow reducers should not be included as an option in the standard. It is the policy of this committee to avoid giving credit to user dependent ECMs.

Discussion:

The use of flow reducers can reduce the energy consumption of domestic water heaters when they are properly installed and maintained. The primary savings are from a reduction in the amount of water used to perform a certain task (such as showering, washing dishes, washing hands). The amount of savings is dependent to a great extent on user acceptance and, therefore, the magnitude of the savings can be difficult to quantify. In the opinion of the committee, there is insufficient documentation of the magnitude of those savings. One of the largest potential savings is from low flow shower heads which can be easily replaced and, thereby, eliminate much of the advantage of this strategy. The possibility of this measure being removed or replaced by the homeowner is higher than most ECMs, especially since most will be used by individuals who did not elect to install flow reducers. It is the policy of this committee to avoid giving credit for user dependent ECMs in this standard.

There does not seem to be a conflict between the use of properly designed and installed flow reducers and health and safety codes. Though savings are available, they are difficult to document and there is uncertainty for the continued use of this strategy by the homeowner.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #8-3

Title: THERMOSIPHON HEAT LOSSES IN DOMESTIC HOT WATER SYSTEMS

Statement of Issue: How should thermal traps on domestic hot water systems be dealt with in the standards?

Resolution: Thermal traps for the prevention of thermosiphon heat losses in conventional gas or electric domestic hot water systems will not be included as an energy conservation measure in the standard, nor will they be a mandatory requirement.

Discussion:

Thermal traps are devices installed on the inlets and/or outlets of domestic hot water tanks to prevent heat losses due to thermosiphoning. Most thermal traps fall into one of two categories: 1) devices that prevent water circulation by means of a check valve, and 2) devices that prevent water circulation by means of careful piping configurations (the most common being a 270 or 360° loop in the pipe).

Five technical reports dealing with the effectiveness of thermal traps were reviewed. Unfortunately, three of the five were (co-)authored by the same researcher, and appear to contain redundant reports of the same tests.(1,2,3) One of the five dealt specifically with thermal traps used to prevent nighttime back-siphoning in solar domestic hot water systems.(4) Finally, one paper was a report dealing with test procedures for thermal traps.(5) Both electric and gas water heaters are represented.

The basic conclusions gleaned from these reports are as follows:

- The effectiveness of thermal traps is more dependent on the temperature difference (ΔT) between the hot water and ambient air than is the effectiveness of pipe insulation.(1) Indeed, below a ΔT of 65 °F, thermal traps were shown to result in <u>no</u> energy savings.(3) For temperature differences greater than 65 °F, the savings of check-valve type thermal traps on <u>electric</u> water heaters is approximated by the following:(3)

  $$savings\ (Watts) = 0.824 * (\Delta T - 53.6)$$

- Thermal traps save more energy on an otherwise energy efficient water heater than on a 'standard' water heater.(1)

- Thermal traps can reduce piping losses in electric water heaters by ~40%(2)

- Piping losses in electric water heaters comprise ~12% of the stand-by losses of a standard tank, or ~22% of the stand-by losses of an energy efficient (well-insulated) tank.[2]
- There is little or no difference in thermal trap savings between overhead and low-level piping.[2]
- One thermal trap on the discharge pipe is ~64% as effective as traps on both the inlet and outlet. A 360° loop in the pipe is ~35% as effective as a check valve.[3]
- Conclusions differ regarding the relative effectiveness of thermal traps and pipe insulation. One reference concludes that pipe insulation is ~30% more effective than thermal traps on electric water heaters.[2] Another states that pipe insulation yields lower energy savings than thermal traps.[3] (disturbing in that both papers were written by the same authors)
- The magnitude of the savings from thermal traps on gas water heaters is less than the variability of the stand-by losses of the tank.[5] Therefore, thermal trap savings are too small to be directly measured on gas water heaters. Based on tests with a water heater simulator, however, check valve type thermal traps on both the inlet and outlet were shown to save an average of 28 Watts on a typical gas water heater.
- Power savings from thermal traps on electric water heaters are approximately 0.081 Watts/°F.[2]

These test results indicate that energy savings from thermal traps are very small - too small to measure in the case of gas water heaters. Given the small savings reported in these references, and the lack of more comprehensive data, thermal trap savings should not be considered in the voluntary standard.

References

1. Biemer, Jon R., Auburg, C. Douglas and Ek, Calvin. "Domestic Water Heating - Summary Research Findings for Conventional Systems", presented at "Conservation in Buildings: Northwest Perspective," Conference, Butte, Montana, May 1985.

2. Ek, Calvin and Auburg, C. Douglas. "Electric Water Heater Standby Losses: Comparison of Conservation Strategies and Their Energy Savings", Bonneville Power Administration.

3. Auburg, P.E., Ek, Calvin and Thor, P.W. "Electric Water Heater Energy Retrofits - Safety and Energy Savings", AC-83-01 No. 3. (ASHRAE paper)

4. Cromer, Charles J. and Cromer, William R. "Test of Heat-Traps and Valves to Prevent Nighttime Back-Siphoning", Proceedings of the 1984 Annual Meeting American Solar Energy Society, Inc. June 5-7, 1984, Anaheim, CA.

5. National Bureau of Standards, "Test Results and A Recommended Test Procedure for Heat Traps", March 1984, NBSIR 84-2851.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #8-4

Title: INSTANTANEOUS WATER HEATERS

Statement of Issue: How should instantaneous water heaters be treated in the standard?

Resolution: Instantaneous water heaters should not be used as an option in the standard. The standard will allow instantaneous water heaters but no credit will be given to them.

Discussion:

The committee feels there are insufficient data to document the potential savings of instantaneous water heaters. There are some instances where the distance from the water heater to the point of use will make a difference in energy consumption due to heat loss in the pipes. The standard will allow instantaneous water heaters but no credit will be given to them.

The probable coincident use at peak load may cause peak load increases which will be counterproductive, especially in summer peaking localities. The interrelationship with peak load increases further cloud the issue and make it difficult for a clear documentation of savings to be credited to instantaneous water heaters.

The water that remains in the tank of an instantaneous water heater, which is heated at each use, will cool before the next use and, therefore, is lost energy. In some installations, this loss can be of an equal or greater than the heat loss of the water stored in the tank of a standard water heater.

Instantaneous water heaters are made and can be installed which do not conflict with safety or health requirements.

The lack of data for documentation of savings and the absence of strategies which clearly indicate substantial energy reductions by the use of instantaneous water heaters, have led to the conclusion that they should not be included as options to be considered in the standard at this time. Increase of data and documentation in the future and development of strategies which clearly show methods of savings energy using instantaneous water heaters could be a justification to re-examine this position in the future.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #8-5

Title: PASSIVE AND ACTIVE SOLAR WATER HEATING

Statement of Issue: How should passive and active solar water heating be treated in the standard?

Resolution: A simplified method will be developed for the points path and a detailed method for the performance path.

Discussion:

Two major solar water heating technologies exist: passive systems and active systems. Both of these techniques will have a simplified method which can be used for a point path and a detailed method that will be used in the performance path.

The detailed method for the passive system will use the following input parameters to calculate the solar savings factor: 1) Qsav, which is the energy saved by the system under the SRCC test conditions or other nationally recognized test laboratories; 2) L, which is the night loss by the system; 3) A, which is the solar aperture; and 4) Nt, which is the number of units tested. All of these parameters are available from SRCC, the Solar Rating and Certification Corporation. In addition, the Energy Factor (EF) for the backup water heater, obtained from GAMA, is used.

If the input parameters are not available for a system, a simplified procedure has been developed. In the simplified procedure for passive systems the above parameters have been assumed at a conservative level based on the particular system type.

The detailed method for active solar collectors is based on the f-chart method. It is available in a book or a microcomputer program which is used to provide solar savings fractions (SSF) for different collectors in different locations.

The simplified method for active solar collectors will also be based on the f-chart method, but will assume conservative input parameters which are derived from sensitivity studies.

For both simplified methods, a water usage of 64.3 gal/day and a storage tank capacity of 40 gallons will be assumed. These values were confirmed from most of the data sources.

There is no impact on life or safety issues from the use of properly designed and installed solar water collectors.

In conclusion, the method outlined above will provide a sound basis for the development of a point path and a performance path for active and passive solar water heating. The calculation techniques and data are described in the appended support document.

SOLAR DOMESTIC HOT WATER TECHNICAL SUPPORT DOCUMENT

1.0 INTRODUCTION

Compliance-related options affecting the domestic hot water (DHW) energy use are confined to the levels of efficiency in the equipment and solar energy related options. The DHW position paper establishes the baseline performance for DHW equipment and is not subject to further technical analysis. Alternate equipment can be specified under the three compliance paths (see discussion on compliance paths).

Credit can be received for specifying the passive and solar options. The technical basis for establishing the credit for the active and the passive solar options is described in the following sections.

2.0 PASSIVE SOLAR DOMESTIC HOT WATER ENERGY CONSERVATION OPTION ANALYSIS

This section describes the procedure for estimating the credits allowed if the user of the standard specifies a passive solar hot water system. Such systems fall into two broad categories: thermosyphon water heaters and integral collectors (also referred to as batch heaters). Thermosyphon systems heat potable water directly and use natural convection to transport it from the collector to the storage tank. In a thermosyphon system, the storage tank must be elevated above the collectors. Conversely, as their name indicates, in an integral collector, the storage tank is integrated into the collector assembly.

2.1 SAVINGS CALCULATION PROCEDURES

Two methods are provided to receive credit for passive solar DHW systems in the voluntary standard. The methods are simply designated as "Detailed" and "Simplified." The simplified path is intended for users who do not know the specifics of the solar DHW system to be installed, but wish to get the credit for installing such a system.

The detailed path is intended for a user who knows in advance the characteristics of the system to be installed (Q_{sav}, Loss Coefficient) and wants to run a detailed analysis in order to calculate more accurately the credit for the specific system.

The output for the detailed and simplified path analysis will be given in terms of a Solar Savings Fraction (SSF), which is defined as the ratio of the annual solar energy collected with the installed units, divided by the annual energy required for domestic hot water heating.

2.1.1 The Detailed Estimation Procedure Path

The user who wants to use the detailed path analysis must know in advance the specific system he will install since the manufacturer's system test values for the following parameters will need to be specified: 1) the energy saved by the solar system under the SRCC test conditions (Q_{sav}), 2) the rate of heat lost from the system during the night (L), and 3) the total net aperture area of the tested (Nt). The above parameters are provided to the manufacturers by the Solar Rating & Certification Corporation (SRCC). This information should be available in the catalog of the purchased water heater. The user must also specify the number of units he will install with the above characteristics (N).

In addition to the above parameters, the user must also provide some information about the backup water heater to be installed as a supplement to the solar water system. The user must specify the water heater's efficiency, known as Energy Factor (EF). The EF can be obtained from the Gas Appliance Manufacturers Association (GAMA) Directory.

A second and simpler method for deriving the EF is from the Energy Guide label that is attached to the water heater or available directly from the manufacturer. The user must locate the National Average Unit Cost of Fuel and the Estimate Annual Operating Cost on the Energy Guide label of his water heater. Then, depending on the energy use, he can calculate the EF using one of the following equations:

Gas $$EF = \frac{1.743 \times \text{cents/therm}^{(a)}}{\text{Estimated Annual Operating Cost}}$$

Electric $$EF = \frac{51.058 \times \text{cents/KWh}^{(a)}}{\text{Estimated Annual Operating Cost}}$$

LP-Gas $$EF = \frac{1.915 \times \text{cents/gallon}^{(a)}}{\text{Estimated Annual Operating Cost}}$$

Oil $$EF = \frac{125.82 \times \text{dollars/gallon}^{(a)}}{\text{Estimated Annual Operating Cost}}$$

Using the above information and the calculation procedure explained in Section 2, the Solar Savings Fraction for a specific system can be calculated.

(a) This information can be obtained directly from the Energy Guide label.

2.1.2 The Simplified Estimation Procedure

The user of the simplified path does not need to know any specific information about the system to be used. However, a selection will need to be made as to the type of system to be installed and the approximate collector area.

The estimate of the SSF is made by assuming the following values are assigned to selected variables within the calculation procedure (see Section 3 for details on the selection procedure of these values).

Thermosyphon System

One Unit System	Two Unit System
Qsav = 14900 Btu/day	Qsav = 26600 Btu/day
L = 3.2 Btu/h.F	L = 5.2 Btu/h.F
Area = 22 sq. ft	Area = 40 sq. ft

Integral Collector System

One Unit System	Two Unit System
Qsav = 12000 Btu/day	Qsav = 22000 Btu/day
L = 13 Btu/h.F	L = 20 Btu/h.F
Area = 20 sq. ft	Area = 40 sq. ft

In addition to the above information the computer program will use the following relationships in order to determine the Energy Factor for the backup water heaters (see DHW position paper for details):

Water Heater Type	Energy Factor
Gas	0.62 - 0.00175V
LP-Gas	0.63 - 0.00175V
Oil	0.61 - 0.00175V
Electric	0.94 - 0.001V

where V = volume of the storage tank (gal).

The output of the microcomputer program is an SSF for each system type at the two collector areas indicated above. Other values for variables are assigned per the procedure described below.

The user of the standard will first select the energy type to be used for the backup water heater (gas, electric, oil etc.). Then, the type of solar system will be designated (thermosyphon or integral) and the number of units. If the area is approximately 20 square feet, one unit is selected. If the area is about 40 square feet, then the two unit system is designated. This information is required to determine the number of points for a passive solar system, (see Table 8 of section V.B on the Points Compliance Path).

2.2 CALCULATION PROCEDURE

In order to calculate the SSF for any of the 45 locations the following procedure is followed:

Part 1: Determine the annual solar energy collected (Ref. 2)

Calculate the daily water use per unit.

$$w = Wd / N \tag{2.1}$$

where w = the per unit daily hot water use (gal/day/unit)
N = the number of solar units to be installed
Wd = the expected daily hot water use (gal/day)
= 64.3 gal/day

In order to adjust the water usage to match the test conditions solve for Wt:

$$Wt = w * Nt \tag{2.2}$$

where Nt = the number of units tested

Convert the result of equation (2.2) into units of thermal mass:

$$D = Wt * C_p \tag{2.3}$$

where D = the thermal mass in (Btu/day/
C_p = the thermal capacity of the water
= 8.33 (Btu/gal-°F)

Calculate a loss coefficient factor (LC) based on the system type:

$$LC = 18 * L \tag{2.4}$$

for integral collector/storage water heaters (batch water heaters) or

$$LC = 16 * A \tag{2.5}$$

for thermosyphon systems

where L = the rate of heat loss from the system (Btu/hr-°F)
A = the total net aperture area of the system tested (sq. ft)

Determine Q_i, Q_{sav} adjusted to account for changes in irradiation and draw.

$$Q_i = \{1-[(LC * (833-D))/(833 * (D+LC))]\} * Qsav * (Ht/1500) \tag{2.6}$$

where Q_{sav} = the net daily amount of energy provided by the solar system during the test (Btu/day)
HT = the annual average daily insolation on a surface tilted above the horizontal plane at an angle equal to the collector tilt angle (btu/sq. ft/day) (see Table 2.1).

Solve for Q_t, the Q_i value adjusted for differences in environmental temperature from those assumed in the test:

$$Q_t = Q_i + 24 * L * (T_a - T_m) \tag{2.7}$$

TABLE 2.1. Climatic Data for the 45 locations (Ref. 1)

Location	Latitude	Te	Tm	Ht1	Ht2
Albuquerque, NM	35	57	62	2023	1911
Atlanta, GA	34	61	65	1426	1337
Birmingham, AL	34	62	62	1420	1331
Bismark, ND	47	41	42	1434	1331
Boise, ID	44	51	52	1659	1531
Boston, MD	42	51	50	1194	1104
Brownsville, TX	26	74	75	1584	1487
Buffalo, NY	43	47	47	1067	970
Burlington, VT	44	43	47	1080	988
Charleston, SC	33	65	65	1427	1342
Cheynne, WY	41	46	46	1722	1624
Chicago, IL	42	51	52	1312	1212
Cincinatti, OH	39	55	55	1222	1129
Denver, Co	40	49	50	1795	1694
El Paso, TX	32	63	65	2062	1951
Fort Worth, TX	33	65	67	1563	1467
Fresno, CA	37	62	72	1823	1688
Great Falls, MT	47	42	42	1447	1338
Honolulu, HI	21	76	80	1989	1870
Jacksonville, FL	30	69	71	1521	1436
Juneau, AK		40	40	N/A	N/A
Kansas City, MO	39	55	55	1461	1363
Lake Charles, LA	30	67	67	1418	1331
Las Vegas, NV	36	65	73	2074	1954
Los Angeles, CA	34	62	65	1730	1632
Medford, OR	42	53	53	1428	1303
Memphis, TN	35	62	62	1448	1344
Miami, FL	26	75	78	1542	1468
Minneapolis, MN	45	44	44	1296	1198
Nashville, TN	36	60	55	1330	1233
New York, NY	41	54	52	1271	1182
Oklahoma City, OK	35	60	62	1579	1483
Omaha, NE	41	49	49	1461	1361
Philadelphia, PA	40	53	53	1260	1172
Phoenix, AZ	33	69	67	2031	1913
Pittsburgh, PA	40	50	52	1113	1022
Portland, ME	44	45	47	1141	1054
Portland, OR	46	53	50	1121	1019
Reno, NV	39	48	52	1984	1859
Salt Lake, UT	41	51	52	1781	1657
San Antonio, TX	30	69	67	1568	1477
San Diego, CA	33	62	66	1727	1642
San Francisco, CA	38	57	60	1681	1566

TABLE 2.1. (contd)

Location	Latitude	Te	Tm	Ht1	Ht2
Seattle, Wa	47	51	52	1098	990
Washington, DC	39	57	57	1294	1202

L = Latitude angle for each location
Ta = annual average ambient air temperature in °F
Tm = annual average water main temperature in °F
Ht1 = average annual daily radiation on a surface tilted at an angle equal to the Latitude (Btu/sq. ft/day)
Ht2 = average annual daily radiation on a surface tilted at an angle equal to the latitude plus 15 degrees.

where Q_t = an adjustment to the differences in the environmental and the inlet water temperature (Btu/sq. ft/day)

T_a = the average annual temperature in °F (see Table 2.1)

T_m = the annual average mains temperature in (see Table 2.1)

Calculate Q_c, an adjustment to Q_{sav} to account for the number of units installed at the site:

$$Q_c = Q_t * (N / Nt) \qquad (2.8)$$

Calculate Q_s, the annual solar energy collected with the units installed:

$$Q_s = Q_c * 365 \qquad (2.9)$$

Part 2: Calculation of the Annual Domestic Hot Water Energy Consumption

Calculate Q_a, the annual energy consumption for DHW:

$$Q_a = (Wd * 8.33 * (T_s - T_m) * 365) / EF$$

where Q_a = annual energy consumption (Btu/yr)

T_s = backup water heater setpoint temperature

= 140 °F

EF = backup water heater energy factor

Part 3: Calculate the Solar Savings Factor

$$SSF = Q_s / Q_a \tag{2.10}$$

where SSF = Solar Savings Fraction

Notes: The above calculation procedure is valid only for residential applications.

For calculated Solar Savings Fractions greater than 0.60, use the following approximation:

$$CSSF = SSF - ((SSF - 0.60)/s) \tag{2.11}$$

where CSSF = corrected Solar Savings Fraction for values higher than 0.60

2.3 DEVELOPMENT OF SSFS FOR THE SIMPLIFIED PATH

In an effort to determine reasonable assumptions for use in determining SSF values in the simplified passive solar procedure a series of sensitivities were conducted (see Tables 2.2 to 2.7). Specifically, the objective of this work was to determine conservative values of Q_{sav}, L and collector area, to be held constant for all subsequent SSF calculations (see Section 1.b). In addition, this analysis utilized the following input parameters:

Daily water usage = 64.3 gal/day
Storage tank volume = 40 gal

These values were assumed in the calculation of the SSFs for a single-story detached house for six different locations: Miami, Florida; Albuquerque, New Mexico; Oklahoma City, Oklahoma; San Antonio, Texas;

Washington D.C.; and Denver, Colorado. The actual values, by house type, will be used by the computer in determining SSF in the standard.

TABLE 2.2. Passive Solar Savings Fractions for Miami, Florida

Location	Annual Insolat. (Btu/sq. ft/day)	Average Annual Ambient Temp (F)	Average Annual Water In Temp (F)	Water Usage (Gal./day)	Storage Tank Volume (Gal.)	Annual Energy Consumption (MBtu/yr) Gas	Electric	Oil	LP-Gas
Miami, Fl	1468	75	78	64.3	40	22.04	13.47	22.45	21.64

THERMOSYPHON SYSTEMS

Manufacturer	Q_{sav} (Btu/Day)	L (Btu/hrRF)	Tested Net Area (sq. ft)	System Loss Coeff.	Number of Units Test	Inst.	Ther. Mass (Btu/DayRF)	Annual Solar Ener. Coll (MBtu/yr)	Solar Savings Fractions Gas	Electric	Oil	LP-Gas
AMCOR Group, LTD												
(i) SOLON 120 (p. 47)	21400	2.70	23.20	371.20	1	1	535.62	6.4563	0.293	0.479	0.288	0.298
(ii) SOLON 240 (p. 47)	21400	5.30	46.00	736.00	2	2	535.62	6.9255	0.269	0.440	0.264	0.274
Environment Co												
RM-40 (p. 51)	19500	4.20	32.00	512.00	1	1	535.62	6.6399	0.256	0.419	0.251	0.261
Solcoor Inc.												
(i) Syphon D-28 (p. 52)	17400	2.40	20.10	321.60	1	1	535.62	5.3200	0.241	0.395	0.237	0.246
(ii) Syphon F-34 (p. 54)	17100	2.40	20.10	321.60	1	1	535.62	5.2272	0.237	0.388	0.233	0.241
Solahart U.S.A.												
(i) SHW 300JD (p. 55)	26600	5.20	40.20	643.20	2	2	535.62	7.5143	0.341	0.558	0.335	0.347
(ii) SHW 300JK (p. 56)	31400	5.10	40.20	643.20	2	2	535.62	8.8976	0.404	0.661	0.396	0.411
(iii) SHW 300JK (p. 57)	28700	5.10	40.20	643.20	2	2	535.62	8.1210	0.368	0.603	0.362	0.375
(iv) SHW 300JK (p. 58)	39100	4.70	40.20	643.20	2	2	535.62	11.1229	0.505	0.826	0.496	0.514
(v) SHW 80GE (p. 59)	28000	6.60	40.20	643.20	2	2	535.62	7.8802	0.358	0.585	0.351	0.364
Sun Resourse												
SR-SSR-28 (p. 61)	21700	2.40	22.00	352.00	1	1	535.62	6.5910	0.299	0.489	0.294	0.305
URJA, Inc.												
SSII (p. 65)	14900	3.20	22.40	352.00	1	1	535.62	4.4766	0.203	0.332	0.199	0.207
American Solar												
ATS	20200	1.44	23.02	358.40	1	1	535.62	6.1282	0.278	0.455	0.273	0.283
COLT Inc.												
(i) PC-101	14700	4.08	22.00	352.00	1	1	535.62	4.4004	0.200	0.327	0.196	0.203
(ii) TS-101	19300	3.03	22.00	352.00	1	1	535.62	5.8385	0.265	0.434	0.260	0.270
Recommended Thermosyphon System												
One Unit System	14900	3.20	22.00	352.00	1	1	535.62	4.4849	0.204	0.333	0.200	0.207
Two Unit System	26600	5.20	40.20	643.20	2	2	535.62	7.5143	0.341	0.558	0.335	0.347

TABLE 2.2. (contd)

INTEGRAL COLLECTOR / STORAGE SYSTEMS

Manufacturer	Q_{sav} (Btu/Day)	L (Btu/hrRF)	Tested Net Area (sq. ft)	System Loss Coeff.	Number of Units Test	Number of Units Inst.	Ther. Mass (Btu/DayRF)	Annual Solar Ener. Coll (MBtu/yr)	Solar Savings Fractions Gas	Electric	Oil	LP-Gas
GULF THERMAL CO PT-40 (p. 41)(a)	16700	11.80	17.40	212.40	1	1	535.619	5.0506	0.229	0.375	0.225	0.233
Solway Energy CO HPS-200 (p. 43)	15700	9.70	21.90	174.60	1	1	535.619	4.8611	0.221	0.361	0.217	0.225
Sun Systems, Inc. SS-1500 (p. 44)	20300	25.00	21.00	450.00	1	1	535.619	5.4125	0.246	0.402	0.241	0.250
Fafco, Inc.	26000	20.39	40.00	367.02	2	2	535.619	7.4035	0.336	0.550	0.330	0.342
COYNE SOLAR	11000	8.31	15.00	149.58	1	1	535.619	3.4047	0.154	0.253	0.152	0.157
Recommended Integral Collector Storage Systems												
One Unit System	12000	13.00	20.00	234.00	1	1	535.619	3.4796	0.158	0.258	0.155	0.161
Two Unit System	22000	20.00	40.00	360.00	2	2	535.619	6.2054	0.282	0.461	0.276	0.287

(a) NOTE: Page numbers are referenced to Directory of SRCC Certified Solar Water Heating System Ratings (Feb. 1987).

TABLE 2.3. Passive Solar Savings Fractions for Albuquerque, New Mexico

Location	Annual Insolat. (Btu/sq. ft/day)	Average Annual Ambient Temp (F)	Average Annual Water In Temp (F)	Water Usage (Gal./day)	Storage Tank Volume (Gal.)	Annual Energy Consumption (MBtu/yr) Gas	Electric	Oil	LP-Gas
Albuquerque, NM	1911	57	62	64.3	40	27.3	16.94	28.24	27.23

THERMOSYPHON SYSTEMS

Manufacturer	Qsav (Btu/Day)	L (Btu/hrRF)	Tested Net Area (sq. ft)	System Loss Coeff.	Number of Units Test	Inst.	Ther. Mass (Btu/DayRF)	Annual Solar Ener. Coll (MBtu/yr)	Solar Savings Fractions Gas	Electric	Oil	LP-Gas
AMCOR Group, LTD												
(i) SOLON 120 (p. 47)	21400	2.70	23.20	371.20	1	1	535.62	8.3787	0.302	0.495	0.297	0.308
(ii) SOLON 240 (p. 47)	21400	5.30	46.00	736.00	2	2	535.62	7.6629	0.276	0.452	0.271	0.281
Environment Co												
RM-40 (p. 51)	19500	4.20	32.00	512.00	1	1	535.62	7.3016	0.263	0.431	0.259	0.268
Solcoor Inc.												
(i) Syphon D-28 (p. 52)	17400	2.40	20.10	321.60	1	1	535.62	6.9024	0.249	0.407	0.244	0.253
(ii) Syphon F-34 (p. 54)	17100	2.40	20.10	321.60	1	1	535.62	6.7815	0.245	0.400	0.240	0.249
Solahart U.S.A.												
(i) SHW 300JD (p. 55)	26600	5.20	40.20	643.20	2	2	535.62	9.7321	0.351	0.574	0.345	0.357
(ii) SHW 300JK (p. 56)	31400	5.10	40.20	643.20	2	2	535.62	11.5337	0.416	0.681	0.408	0.424
(iii) SHW 300JK (p. 57)	28700	5.10	40.20	643.20	2	2	535.62	10.5228	0.380	0.621	0.373	0.386
(iv) SHW 300JK (p. 58)	39100	4.70	40.20	643.20	2	2	535.62	14.4344	0.521	0.852	0.511	0.530
(v) SHW 80GE (p. 59)	28000	6.60	40.20	643.20	2	2	535.62	10.1950	0.368	0.602	0.361	0.374
Sun Resourse												
SR-SSR-28 (p. 61)	21700	2.40	22.00	352.00	1	1	535.62	8.5570	0.309	0.505	0.303	0.314
URJA, Inc.												
SSII (p. 65)	14900	3.20	22.40	358.40	1	1	535.62	5.7969	0.209	0.342	0.205	0.213
American Solar												
ATS	20200	1.44	23.02	368.32	1	1	535.62	7.9638	0.287	0.470	0.282	0.292
COLT Inc												
(i) PC-101	14700	4.08	22.00	352.00	1	1	535.62	5.6892	0.205	0.336	0.201	0.209
(ii) TS-101	19300	3.03	22.00	352.00	1	1	535.62	7.5714	0.273	0.447	0.268	0.278
Recommended Thermosyphon System												
One Unit System	14900	3.20	22.00	352.00	1	1	535.62	5.8076	0.209	0.343	0.206	0.213
Two Unit System	26600	5.20	40.20	643.20	2	2	535.62	9.7321	0.351	0.574	0.345	0.357

TABLE 2.3. (contd)

INTEGRAL COLLECTOR / STORAGE SYSTEMS

Manufacturer	Qsav (Btu/Day)	L (Btu/hrRF)	Tested Net Area (sq. ft)	System Loss Coeff.	Number of Units Test	Number of Units Inst.	Ther. Mass (Btu/DayRF)	Annual Solar Ener. Coll (MBtu/yr)	Solar Savings Fractions: Gas	Solar Savings Fractions: Electric	Solar Savings Fractions: Oil	Solar Savings Fractions: LP-Gas
GULF THERMAL CO PT-40 (p. 41)[(a)]	16700	11.80	17.40	212.40	1	1	535.619	6.4616	0.233	0.381	0.229	0.237
Solway Energy CO HPS-200 (p. 43)	17000	9.70	21.90	174.60	1	1	535.619	6.2351	0.225	0.368	0.221	0.229
Sun Systems, Inc. SS-1500 (p. 44)	20300	25.00	21.00	450.00	1	1	535.619	6.8061	0.245	0.402	0.241	0.250
Fafco, Inc.	26000	20.39	40.00	367.02	2	2	535.619	9.4422	0.341	0.557	0.334	0.347
COYNE SOLAR	11000	8.31	15.00	149.58	1	1	535.619	4.3525	0.157	0.257	0.154	0.160
Recommended Integral Collector Storage System												
One Unit System	12000	13.00	20.00	234.00	1	1	535.619	4.4050	0.159	0.260	0.156	0.162
Two Unit System	22000	20.00	40.00	360.00	2	2	535.619	7.8862	0.284	0.465	0.279	0.290

(a) NOTE: Page numbers are referenced to Directory of SRCC Certified Solar Water Heating System Ratings (Feb. 1987).

TABLE 2.4. Passive Solar Savings Fractions for Oklahoma City, Oklahoma

Location	Annual Insolat. (Btu/sq. ft/day)	Average Annual Ambient Temp (F)	Average Annual Water In Temp (F)	Water Usage (Gal./day)	Storage Tank Volume (Gal.)	Annual Energy Consumption (MBtu/yr) Gas	Electric	Oil	LP-Gas
Oklahoma City, OK	1463	60	62	64.3	40	27.73	16.94	28.24	27.23

THERMOSYPHON SYSTEMS

Manufacturer	Qsav (Btu/Day)	L (Btu/hrRF)	Tested Net Area (sq. ft)	System Loss Coeff.	Number of Units Test	Inst.	Ther. Mass (Btu/DayRF)	Annual Solar Ener. Coll (MBtu/yr)	Solar Savings Fractions Gas	Electric	Oil	LP-Gas
AMCOR Group, LTD												
(i) SOLON 120 (p. 47)	21400	2.70	23.20	371.20	1	1	535.62	6.5466	0.236	0.386	0.232	0.240
(ii) SOLON 240 (p. 47)	21400	5.30	46.00	736.00	2	2	535.62	6.0339	0.216	0.356	0.214	0.222
Environment Co												
RM-40 (p. 51)	19500	4.20	32.00	512.00	1	1	535.62	5.7355	0.207	0.339	0.203	0.211
Solcoor Inc.												
(i) Syphon D-28 (p. 52)	17400	2.40	20.10	321.60	1	1	535.62	5.3960	0.195	0.318	0.191	0.198
(ii) Syphon F-34 (p. 54)	17100	2.40	20.10	321.60	1	1	535.62	5.3022	0.191	0.313	0.188	0.195
Solahart U.S.A.												
(i) SHW 300JD (p. 55)	26600	5.20	40.20	643.20	2	2	535.62	7.6381	0.275	0.451	0.270	0.280
(ii) SWHS 300JK (p. 56)	31400	5.10	40.20	643.20	2	2	535.62	9.0346	0.326	0.533	0.320	0.332
(iii) SWH 300JK (p. 57)	28700	5.10	40.20	643.20	2	2	535.62	8.2500	0.298	0.487	0.292	0.303
(iv) SHS 300JK (p. 58)	39100	4.70	40.20	643.20	2	2	535.62	11.2790	0.407	0.666	0.399	0.414
(v) SWS 80GE	28000	6.60	40.20	643.20	2	2	535.62	8.0203	0.289	0.473	0.284	0.295
Sun Resourse												
SR-SSR-28 (p. 61)	21700	2.40	22.00	352.00	1	1	535.62	6.6801	0.241	0.394	0.237	0.245
URJA, Inc.												
SSII (p. 65)	14900	3.20	22.40	358.40	1	1	535.62	4.5513	0.164	0.269	0.161	0.167
American Solar												
ATS	20200	1.44	23.02	368.32	1	1	535.62	6.2039	0.224	0.366	0.220	0.228
COLT Inc												
(i) PC-101	14700	4.08	22.00	352.00	1	1	535.62	4.4822	0.162	0.265	0.159	0.165
(ii) TS-101	19300	3.03	22.00	352.00	1	1	535.62	5.9256	0.214	0.350	0.210	0.218
Recommended Thermosyphon System												
One Unit System	14900	3.20	22.00	352.00	1	1	535.62	4.5595	0.164	0.269	0.161	0.167
Two Unit System	26600	5.20	40.20	643.20	1	1	535.62	7.6381	0.275	0.451	0.270	0.280

TABLE 2.4. (contd)

INTEGRAL COLLECTOR / STORAGE SYSTEMS

Manufacturer	Q_{sav} (Btu/Day)	L (Btu/hrRF)	Tested Net Area (sq. ft)	System Loss Coeff.	Number of Units Test	Number of Units Inst.	Ther. Mass (Btu/DayRF)	Annual Solar Ener. Coll (MBtu/yr)	Solar Savings Fractions Gas	Electric	Oil	LP-Gas
GULF THERMAL CO PT-40 (p. 41)[(a)]	16700	11.80	17.40	212.40	1	1	535.619	5.2088	0.188	0.307	0.184	0.191
Solway Energy CO HPS-200 (p. 43)	15700	9.70	21.90	174.60	1	1	535.619	4.9984	0.180	0.295	0.177	0.184
Sun Systems, Inc. SS-1500 (p. 44)	20300	25.00	21.00	450.00	1	1	535.619	5.6935	0.205	0.336	0.202	0.209
Fafco, Inc.	26000	20.39	40.00	367.02	2	2	535.619	7.6633	0.276	0.452	0.271	0.281
COYNE SOLAR	11000	8.31	15.00	149.58	1	1	535.619	3.5145	0.127	0.207	0.124	0.129
Recommended Integral Collector Storage System												
One Unit System	12000	13.00	20.00	234.00	1	1	535.619	3.6326	0.131	0.214	0.129	0.133
Two Unit System	22000	20.00	40.00	360.00	2	2	535.619	6.4494	0.233	0.381	0.228	0.237

(a) NOTE: Page numbers are referenced to Directory of SRCC Certified Solar Water Heating System Ratings (Feb. 1987).

TABLE 2.5. Passive Solar Savings Fractions for San Antonio, Texas

Location	Annual Insolat. (Btu/sq. ft/day)	Average Annual Ambient Temp (F)	Average Annual Water In Temp (F)	Water Usage (Gal./day)	Storage Tank Volume (Gal.)	Annual Energy Consumption (MBtu/yr) Gas	Electric	Oil	LP-Gas
San Antonio, TX	1477	69	67	64.3	40	25.95	15.86	26.43	25.48

THERMOSYPHON SYSTEMS

Manufacturer	Qsav (Btu/Day)	L (Btu/hrRF)	Tested Net Area (sq. ft)	System Loss Coeff.	Number of Units Test	Inst.	Ther. Mass (Btu/DayRF)	Annual Solar Ener. Coll (MBtu/yr)	Solar Savings Fractions Gas	Electric	Oil	LP-Gas
AMCOR Group, LTD												
(i) SOLON 120 (p. 47)	21400	2.70	23.20	371.20	1	1	535.62	6.6146	0.255	0.417	0.250	0.260
(ii) SOLON 240 (p. 47)	21400	5.30	46.00	736.00	2	2	535.62	6.1949	0.239	0.391	0.234	0.243
Environment Co												
RM-40 (p. 51)	19500	4.20	32.00	512.00	1	1	535.62	5.8592	0.226	0.369	0.222	0.230
Solcoor Inc.												
(i) Syphon D-28 (p. 52)	17400	2.40	20.10	321.60	1	1	535.62	5.4581	0.210	0.344	0.207	0.214
(ii) Syphon F-34 (p. 54)	17100	2.40	20.10	321.60	1	1	535.62	5.3647	0.207	0.338	0.203	0.211
Solahart U.S.A.												
(i) SHW 300JD (p. 55)	26600	5.20	40.20	643.20	2	2	535.62	7.7890	0.300	0.491	0.295	0.306
(ii) SWHS 300JK (p. 56)	31400	5.10	40.20	643.20	2	2	535.62	9.1764	0.354	0.579	0.347	0.360
(iii) SWH 300JK (p. 57)	28700	5.10	40.20	643.20	2	2	535.62	8.3950	0.324	0.529	0.318	0.329
(iv) SHS 300JK (p. 58)	39100	4.70	40.20	643.20	2	2	535.62	11.3977	0.439	0.719	0.431	0.447
(v) SWS 80GE	28000	6.60	40.20	643.20	2	2	535.62	8.2187	0.317	0.518	0.311	0.322
Sun Resourse												
SR-SSR-28 (p. 61)	21700	2.40	22.00	352.00	1	1	535.62	6.7370	0.260	0.425	0.255	0.264
URJA, Inc.												
SSII (p. 65)	14900	3.20	22.40	358.40	1	1	535.62	4.6448	0.179	0.293	0.176	0.182
American Solar												
ATS	20200	1.44	23.02	368.32	1	1	535.62	6.2291	0.240	0.393	0.236	0.244
COLT Inc												
(i) PC-101	14700	4.08	22.00	352.00	1	1	535.62	4.6067	0.178	0.291	0.174	0.181
(ii) TS-101	19300	3.03	22.00	352.00	1	1	535.62	6.0075	0.232	0.379	0.227	0.236
Recommended Thermosyphon System												
One Unit System	14900	3.20	22.00	352.00	1	1	535.62	4.6530	0.179	0.293	0.176	0.183
Two Unit System	26600	5.20	40.20	643.20	1	1	535.62	7.7890	0.300	0.491	0.295	0.306

TABLE 2.5. (contd)

INTEGRAL COLLECTOR / STORAGE SYSTEMS

Manufacturer	Qsav (Btu/Day)	L (Btu/hrRF)	Tested Net Area (sq. ft)	System Loss Coeff.	Number of Units Test	Number of Units Inst.	Ther. Mass (Btu/DayRF)	Annual Solar Ener. Coll (MBtu/yr)	Solar Savings Fractions Gas	Electric	Oil	LP-Gas
GULF THERMAL CO PT-40 (p. 41)[(a)]	16700	11.80	17.40	212.40	1	1	535.619	5.6003	0.216	0.353	0.212	0.220
Solway Energy CO HPS-200 (p. 43)	15700	9.70	21.90	174.60	1	1	535.619	5.3174	0.205	0.335	0.201	0.220
Sun Systems, Inc. SS-1500 (p. 44)	20300	25.00	21.00	450.00	1	1	535.619	6.5447	0.252	0.413	0.248	0.257
Fafco, Inc.	26000	20.39	40.00	367.02	2	2	535.619	8.3453	0.322	0.526	0.316	0.327
COYNE SOLAR	11000	8.31	15.00	149.58	1	1	535.619	3.7909	0.146	0.239	0.143	0.149
Recommended Integral Collector Storage System												
One Unit System	12000	13.00	20.00	234.00	1	1	535.619	4.0725	0.157	0.257	0.154	0.160
Two Unit System	22000	20.00	40.00	360.00	2	2	535.619	7.1226	0.274	0.449	0.270	0.279

(a) NOTE: Page numbers are referenced to Directory of SRCC Certified Solar Water Heating System Ratings (Feb. 1987).

TABLE 2.6. Passive Solar Savings Fractions for Washington D.C.

Location	Annual Insolat. (Btu/sq. ft/day)	Average Annual Ambient Temp (F)	Average Annual Water In Temp (F)	Water Usage (Gal./day)	Storage Tank Volume (Gal.)	Annual Energy Consumption (MBtu/yr) Gas	Electric	Oil	LP-Gas
Washington D.C.	1202	57	57	64.3	40	29.50	18.03	30.05	28.98

THERMOSYPHON SYSTEMS

Manufacturer	Qsav (Btu/Day)	L (Btu/hrRF)	Tested Net Area (sq. ft)	System Loss Coeff.	Number of Units Test	Inst.	Ther. Mass (Btu/DayRF)	Annual Solar Ener. Coll (MBtu/yr)	Solar Savings Fractions Gas	Electric	Oil	LP-Gas
AMCOR Group, LTD												
(i) SOLON 120 (p. 47)	21400	2.70	23.20	371.20	1	1	535.62	5.3445	0.181	0.296	0.178	0.184
(ii) SOLON 240 (p. 47)	21400	5.30	46.00	736.00	2	2	535.62	4.9659	0.168	0.275	0.165	0.171
Environment Co												
RM-40 (p. 51)	19500	4.20	32.00	512.00	1	1	535.62	4.7084	0.160	0.261	0.157	0.162
Solcoor Inc.												
(i) Syphon D-28 (p. 52)	17400	2.40	20.10	321.60	1	1	535.62	4.4076	0.149	0.244	0.147	0.152
(ii) Syphon F-34 (p. 54)	17100	2.40	20.10	321.60	1	1	535.62	4.3316	0.147	0.240	0.144	0.149
Solahart U.S.A.												
(i) SHW 300JD (p. 55)	26600	5.20	40.20	643.20	2	2	535.62	6.2646	0.212	0.347	0.208	0.216
(ii) SWHS 300JK (p. 56)	31400	5.10	40.20	643.20	2	2	535.62	7.3951	0.251	0.410	0.246	0.255
(iii) SWH 300JK (p. 57)	28700	5.10	40.20	643.20	2	2	535.62	6.7592	0.229	0.375	0.225	0.233
(iv) SHS 300JK (p. 58)	39100	4.70	40.20	643.20	2	2	535.62	9.2086	0.312	0.511	0.306	0.318
(v) SWS 80GE	28000	6.60	40.20	643.20	2	2	535.62	6.5944	0.224	0.366	0.219	0.228
Sun Resourse												
SR-SSR-28 (p. 61)	21700	2.40	22.00	352.00	1	1	535.62	5.4484	0.185	0.302	0.181	0.188
URJA, Inc.												
SSII (p. 65)	14900	3.20	22.40	358.40	1	1	535.62	3.7343	0.127	0.207	0.124	0.129
American Solar												
ATS	20200	1.44	23.02	368.32	1	1	535.62	5.0488	0.171	0.280	0.168	0.174
COLT Inc												
(i) PC-101	14700	4.08	22.00	352.00	1	1	535.62	3.6908	0.125	0.205	0.123	0.127
(ii) TS-101	19300	3.03	22.00	352.00	1	1	535.62	4.8458	0.164	0.269	0.161	0.167
Recommended Thermosyphon System												
One Unit System	14900	3.20	22.00	352.00	1	1	535.62	3.7411	0.127	0.207	0.124	0.129
Two Unit System	26600	5.20	40.20	643.20	1	1	535.62	6.2646	0.212	0.347	0.208	0.216

TABLE 2.6. (contd)

INTEGRAL COLLECTOR / STORAGE SYSTEMS

Manufacturer	Q_{sav} (Btu/Day)	L (Btu/hrRF)	Tested Net Area (sq. ft)	System Loss Coeff.	Number of Units Test	Number of Units Inst.	Ther. Mass (Btu/DayRF)	Annual Solar Ener. Coll (MBtu/yr)	Solar Savings Fractions Gas	Electric	Oil	LP-Gas
GULF THERMAL CO PT-40 (p. 41)[a]	16700	11.80	17.40	212.40	1	1	535.619	4.3894	0.149	0.243	0.146	0.151
Solway Energy CO HPS-200 (p. 43)	15700	9.70	21.90	174.60	1	1	535.619	4.1890	0.142	0.232	0.139	0.145
Sun Systems, Inc. SS-1500 (p. 44)	20300	25.00	21.00	450.00	1	1	535.619	4.9697	0.168	0.276	0.165	0.172
Fafco, Inc.	26000	20.39	40.00	367.02	2	2	535.619	6.5003	0.220	0.361	0.216	0.224
COYNE SOLAR	11000	8.31	15.00	149.58	1	1	535.619	2.9666	0.101	0.165	0.099	0.102
Recommended Integral Collector Storage System												
One Unit System	12000	13.00	20.00	234.00	1	1	535.619	3.1289	0.106	0.174	0.104	0.108
Two Unit System	22000	20.00	40.00	360.00	2	2	535.619	5.5113	0.187	0.306	0.183	0.190

(a) NOTE: Page numbers are referenced to Directory of SRCC Certified Solar Water Heating System Ratings (Feb. 1987).

TABLE 2.7. Passive Solar Savings Fractions for Denver, Colorado

Location	Annual Insolat. (Btu/sq. ft/day)	Average Annual Ambient Temp (F)	Average Annual Water In Temp (F)	Water Usage (Gal./day)	Storage Tank Volume (Gal.)	Annual Energy Consumption (MBtu/yr) Gas	Electric	Oil	LP-Gas
Denver, CO	1694	49	50	64.3	40	31.99	19.55	32.58	31.42

THERMOSYPHON SYSTEMS

Manufacturer	Qsav (Btu/Day)	L (Btu/hrRF)	Tested Net Area (sq. ft)	System Loss Coeff.	Number of Units Test	Inst.	Ther. Mass (Btu/DayRF)	Annual Solar Ener. Coll (MBtu/yr)	Solar Savings Fractions Gas	Electric	Oil	LP-Gas
AMCOR Group, LTD												
(i) SOLON 120 (p. 47)	21400	2.70	23.20	371.20	1	1	535.62	7.5085	0.235	0.384	0.230	0.239
(ii) SOLON 240 (p. 47)	21400	5.30	46.00	736.00	2	2	535.62	6.9521	0.217	0.356	0.213	0.221
Environment Co												
RM-40 (p. 51)	19500	4.20	32.00	512.00	1	1	535.62	6.5988	0.206	0.338	0.203	0.210
Solcoor Inc.												
(i) Syphon D-28 (p. 52)	17400	2.40	20.10	321.60	1	1	535.62	6.1907	0.194	0.317	0.190	0.197
(ii) Syphon F-34 (p. 54)	17100	2.40	20.10	321.60	1	1	535.62	6.0836	0.190	0.311	0.187	0.194
Solahart U.S.A.												
(i) SHW 300JD (p. 55)	26600	5.20	40.20	643.20	2	2	535.62	8.7833	0.275	0.449	0.270	0.280
(ii) SWHS 300JK (p. 56)	31400	5.10	40.20	643.20	2	2	535.62	10.3774	0.324	0.531	0.318	0.330
(iii) SWH 300JK (p. 57)	28700	5.10	40.20	643.20	2	2	535.62	9.4812	0.296	0.485	0.291	0.302
(iv) SHS 300JK (p. 58)	39100	4.70	40.20	643.20	2	2	535.62	12.9366	0.404	0.662	0.397	0.412
(v) SWS 80GE	28000	6.60	40.20	643.20	2	2	535.62	9.2357	0.289	0.472	0.283	0.294
Sun Resourse												
SR-SSR-28 (p. 61)	21700	2.40	22.00	352.00	1	1	535.62	7.6575	0.239	0.392	0.235	0.244
URJA, Inc.												
SSII (p. 65)	14900	3.20	22.40	358.40	1	1	535.62	5.2348	0.164	0.268	0.161	0.167
American Solar												
ATS	20200	1.44	23.02	368.32	1	1	535.62	7.1027	0.222	0.363	0.218	0.226
COLT Inc												
(i) PC-101	14700	4.08	22.00	352.00	1	1	535.62	5.1658	0.161	0.264	0.159	0.164
(ii) TS-101	19300	3.03	22.00	352.00	1	1	535.62	6.8027	0.213	0.348	0.209	0.217
Recommended Thermosyphon System												
One Unit System	14900	3.20	22.00	352.00	1	1	535.62	5.2443	0.164	0.268	0.161	0.167
Two Unit System	26600	5.20	40.20	643.20	1	1	535.62	8.7833	0.275	0.449	0.270	0.280

TABLE 2.7. (contd)

INTEGRAL COLLECTOR / STORAGE SYSTEMS

Manufacturer	Q_{sav} (Btu/Day)	L (Btu/hrRF)	Tested Net Area (sq. ft)	System Loss Coeff.	Number of Units Test	Number of Units Inst.	Ther. Mass (Btu/DayRF)	Annual Solar Ener. Coll (MBtu/yr)	Solar Savings Fractions Gas	Electric	Oil	LP-Gas
GULF THERMAL CO PT-40 (p. 41) *	16700	11.80	17.40	212.40	1	1	535.619	6.0827	0.190	0.311	0.187	0.194
Solway Energy CO HPS-200 (p. 43)	15700	9.70	21.90	174.60	1	1	535.619	5.8187	0.182	0.298	0.179	0.185
Sun Systems, Inc. SS-1500 (p. 44)	20300	25.00	21.00	450.00	1	1	535.619	6.7849	0.212	0.347	0.208	0.216
Fafco, Inc.	26000	20.39	40.00	367.02	2	2	535.619	8.9830	0.281	0.459	0.276	0.286
COYNE SOLAR	11000	8.31	15.00	149.58	1	1	535.619	4.1081	0.128	0.210	0.126	0.131
Recommended Integral Collector Storage System												
One Unit System	12000	13.00	20.00	234.00	1	1	535.619	4.2957	0.134	0.220	0.132	0.137
Two Unit System	22000	20.00	40.00	360.00	2	2	535.619	7.5920	0.237	0.388	0.233	0.242

(a) NOTE: Page numbers are referenced to Directory of SRCC Certified Solar Water Heating System Ratings (Feb. 1987).

The recommended defau alues for Q_{sav}, L, and area, based on the results for the six locati are shown at the end of each table (see Tables 3.2 to 3.7). These ues were selected because they result in conservative, although not minimum, SSfs.

2.3.1 Discussion

With the information ided above, Table 2.8 was developed as an example, summarizing the ting Solar Savings Fractions for each system for each of the six locati The computer program will develop the Solar Savings Fractions for each ation for different housing prototypes (i.e. different storage tank vo and different hot water usage per day). This information will then be by the computer to develop the domestic hot water multipliers (see se V.B. of the TSD on Points Compliance Path).

TABLE 2.8. Passive Solar Savings Fractions for House Prototype: Single-Story Detached

Location		Gas		Electric		Oil		LP-Gas	
		Thermosyphon	Integral	Thermosyphon	Integral	Thermosyphon	Integral	Thermosyphon	Integral
Miami	One Unit	0.204	0.158	0.333	0.258	0.200	0.155	0.207	0.161
	Two Units	0.341	0.282	0.558	0.461	0.335	0.276	0.347	0.287
Albuquerque	One Unit	0.209	0.159	0.343	0.260	0.206	0.156	0.213	0.162
	Two Units	0.351	0.451	0.574	0.465	0.345	0.279	0.357	0.290
Oklahoma City	One Units	0.164	0.131	0.269	0.214	0.161	0.129	0.167	0.133
	Two Units	0.275	0.233	0.451	0.381	0.270	0.228	0.280	0.237
San Antonio	One Unit	0.179	0.157	0.293	0.257	0.176	0.154	0.183	0.160
	Two Units	0.300	0.274	0.491	0.449	0.295	0.270	0.306	0.279
Washington D.C.	One Unit	0.127	0.106	0.207	0.174	0.124	0.104	0.129	0.108
	Two Units	0.212	0.187	0.347	0.306	0.208	0.183	0.216	0.190
Denver	One Unit	0.164	0.134	0.268	0.220	0.161	0.132	0.167	0.137
	Two Units	0.275	0.237	0.449	0.388	0.270	0.233	0.280	0.280

3.0 ACTIVE SOLAR DOMESTIC HOT WATER ENERGY CONSERVATION OPTION ANALYSIS

This section describes the procedure for estimating the credits allowed if the user of the standard specifies an active solar hot water system. Such systems are characterized by the need to move the heat transfer fluid (typically water or air) with the assistance of pumps or fans (forced circulation). Active systems for DHW heating are typically provided in either a one or two panel configuration with each panel about twenty square feet in area. Collectors are typically glazed with one layer of plastic or glass.

3.1 SAVINGS CALCULATION PROCEDURES

An accepted but tedious method for predicting the performance of an active solar system is provided by the f-Chart computer program. The f-Chart method is the technical basis for the solar analysis procedures referenced in the standard.

As in the passive solar procedure two levels of analysis are provided. The simplified procedure which was developed to avoid the necessity of elaborate computer simulations in the design of typical active solar systems. The simple path is the result of selecting typical solar designs and setting values for most of the variables found in the f-Chart analysis. The assumptions made are fairly conservative. The simple path would also be used when the solar collector system engineering data is not available.

As an alternate users have the option of running the f-Chart computer program and substituting design specific information. In general, use of the equipment specific date will yield a higher energy savings estimates.

The output information for both paths should be given in terms of the Solar Savings Fraction (SSF) rather than the f-factor derived from the f-Chart. The SSF is defined as the ratio of the annual solar energy collected with the installed units, divided by the annual energy required for domestic hot water heating.

3.1.1 The Detailed Estimation Procedure Path

The user of this method must have access to the f-Chart procedure and know in advance the characteristics of the system to be installed. Once the f-factor is determined using this procedure, Parts 5 through 7 of section 2, described below, are followed.

3.1.2 The Simplified Calculation Procedure

In the simplified calculation procedure the f-Chart method is followed with most of the input parameters predetermined. The values for the design data were determined by gauging the performance of a number of solar collectors and selecting characteristics representative of some of the worst performers. The analysis and selection of data is discussed in Section 3 below.

3.2 CALCULATION PROCEDURE FOR THE SIMPLIFIED PATH

The analysis procedure outlined below is used by the microcomputer program to determine the SSFs for the locations under consideration. The program is designed to compute an SSF value for each location for two collector areas. (The committee decided not to include double glazed solar collectors in the simplified analysis, due to their lack of popularity).

The f-Chart method was altered slightly to allow the use of monthly annual average weather (environmental, water mains temperatures) and solar insolation conditions. This approach was used by DOE (Ref. 3) and results in a somewhat lower, hence more conservative, estimate of savings than provided by the f-Chart. The procedure is in seven parts as follows:

Part 1: Determine the Reference Collector Loss to the Total Heating Load (Ref. 4)

$$X = (F_R * U_L) * (F'_R/F_R) * (Tref - Ta) * (Dt/QL) * A \qquad (3.1)$$

where X = the ratio of a reference collector total energy loss to the total heating load during the period Dt

A = net collector area (sq. ft)

F_R = collector heat removal factor

U_L = collector heat loss coefficient (Btu/hr-ft^2-°F)

F'_R/F_R = correction factor for the collector / storage heat exchanger

Tref = reference temperature
= 212 °F (Ref. 7)

Te = average annual ambient temperature (see Table 2.1)

Dt = time in hours for a month
= 720 hr/month

QL = monthly hot water load (Btu/month)

The following collector area will be used for this simplified analysis:

1 panel = 22 sq. ft
2 panels = 44 sq. ft

These values were found to be representative of a substantial portion of all the tested collectors included in the SRCC directory (See Table 3.1).

The value of (F_R*U_L) is provided in the SRCC directory (Ref. 5) for various collectors. Using the 22 sq.ft collector as the basis the F_R*Y_L = 0.90 Btu/hr-ft^2-°F was selected for single glazed collector.

A typical value for the ratio (F'_R/F_R) is 0.95 (see Table 3.1). This ratio can be stated as the inefficiency in collector performance associated with the heat exchanger.

The following equation is used to calculate the monthly load in hot water:

$$Q_L = 8.33 * W_d * (T_w - T_m) * N \qquad (3.2)$$

where W_d = the expected daily hot water use

T_w = outlet water temperature
= 140 °F

T_m = the annual average mains water temperature (see Table 3.1)

N = number of days in a month

= 30 days

TABLE 3.1. Active Solar Savings Fractions for Miami, Florida

Location	Annual Insolat. (Btu/sq. ft/day)	Average Annual Ambient Temp. (RF)	Average Annual Water In Temp. (RF)	Water Usage (Gal./day)	Storage Tank Volume (Gal.)	Monthly DHW load (Btu/mth) QL	Annual Energy Consumption (MBtu/yr) Gas	Electric	Oil	LP-Gas
Miami, FL	1468	75	78	64.3	40	996251	22.04	13.47	22.45	21.64

Absorp.-Transm. Ratio (TA/TAn) = 0.94

Manufacturer	Flow Rate (gpm)	Slope (FR*UL)	Y-Interc (FR*TAn)	Net Area (sq. ft)	Heat Exch. Corr. Fact (F'R/FR)	Xc	Y	f-Factor	Ann. Solar Load Suppl. (MBtu/yr)	Solar Savings Fraction Gas	Electric	Oil	LP-Gas
Allstate Solar	0.65	0.746	0.709	22.00	0.9788	2.6321	0.6344	0.4020	4.8056	0.218	0.357	0.214	0.222
(p. 34)	0.65	0.748	0.709	44.00	0.9584	5.1547	1.2424	0.6612	7.9041	0.359	0.587	0.352	0.365
B&H Refrigerat	0.64	1.203	0.738	21.90	0.9669	4.1587	0.6487	0.3321	3.9701	0.180	0.295	0.177	0.183
(p. 38)	0.64	1.203	0.738	43.80	0.9341	5.3727	1.2835	0.6729	8.0448	0.365	0.597	0.358	0.372
Calwest Energy	0.66	0.777	0.730	22.10	0.9789	2.6551	0.6724	0.4289	5.1273	0.233	0.365	0.219	0.227
(p. 43)	0.66	0.777	0.780	14.20	0.9573	5.3727	1.2835	0.6729	8.0448	0.365	0.597	0.358	0.372
Calwest Energy	0.66	0.751	0.746	22.10	0.9789	2.6551	0.5724	0.4289	5.1273	0.233	0.381	0.228	0.237
(p. 49)	0.66	0.751	0.748	44.20	0.9587	5.2004	1.3170	0.6983	8.3477	0.379	0.620	0.372	0.686
Cole Solar	0.54	0.864	0.732	22.70	0.9698	3.1083	0.6696	0.4021	0.8067	0.218	0.357	0.214	0.222
(p. 57)	0.54	0.864	0.732	45.40	0.9414	6.0345	1.3000	0.6521	7.7958	0.354	0.579	0.347	0.380
Cole Solar	0.52	0.798	0.762	22.00	0.9719	2.7883	0.6770	0.4249	5.0796	0.230	0.377	0.226	0.235
(p. 60)	0.52	0.798	0.762	44.00	0.9453	5.4240	1.3170	0.6880	8.2246	0.373	0.611	0.366	0.330
Cole Solar	0.65	1.118	0.713	22.00	0.9686	3.8932	0.6313	0.3325	3.9754	0.180	0.295	0.177	0.184
(p. 62)	0.65	1.118	0.713	44.00	0.9391	7.5492	1.2242	0.5505	6.5808	0.299	0.489	0.293	0.304
Dell Solar In	0.50	0.798	0.713	21.90	0.9709	3.8932	0.6313	0.3909	4.6731	0.212	0.347	0.208	0.216
(p. 68)	0.50	0.798	0.713	43.80	0.9435	5.3890	1.2243	0.6406	7.6588	0.348	0.569	0.341	0.354
General Energy (p. 72)	0.66	0.822	0.748	38.80	0.9602	5.0047	1.1580	0.6218	7.4337	0.337	0.552	0.331	0.343
Intersolar	0.63	1.429	0.819	21.50	0.9599	4.6194	0.7023	0.3391	4.0539	0.184	0.301	0.181	0.187
(p. 81)	0.63	1.429	0.819	43.00	0.9228	9.2669	1.3505	0.5569	6.6573	0.302	0.494	0.297	0.308
Intersolar	0.63	1.170	0.816	21.50	0.9669	3.9748	0.7049	0.3825	4.5724	0.207	0.340	0.204	0.211
(p. 83)	0.63	1.170	0.816	43.00	0.9359	7.6949	1.3645	0.6182	7.3900	0.335	0.549	0.329	0.341
Lordan/Solcoor	0.60	0.873	0.705	20.30	0.9753	2.6246	0.5800	0.3501	4.185	0.190	0.311	0.186	0.163
(p. 89)	0.60	0.873	0.705	40.50	0.9548	6.5130	1.1321	0.5837	6.9780	0.317	0.518	0.311	0.322
Mor-Flo Indust	0.66	0.775	0.746	22.00	0.9783	2.7259	0.6672	0.4211	5.0346	0.228	0.374	0.224	0.233
(p. 92)	0.66	0.775	0.746	44.00	0.9576	5.3363	1.3061	0.6864	8.2054	0.372	0.609	0.366	0.379

TABLE 3.1. (contd)

Manufacturer	Flow Rate (gpm)	Slope (FR*UL)	Y-Interc (FR*TAn)	Net Area (sq. ft)	Heat Exch. Corr. Fact (F'R/FR)	Xc	Y	f-Factor	Ann. Solar Load Suppl. (MBtu/yr)	Solar Savings Fraction: Gas	Electric	Oil	LP-Gas
Mor-Flo Indust (p. 96)	0.66	0.775	0.746	39.60	0.9617	4.8231	1.1805	0.6430	7.6867	0.349	0.571	0.342	0.355
Mor-Flo Indust	0.66	0.846	0.728	22.00	0.9764	2.9698	0.6498	0.3949	4.7214	0.214	0.351	0.210	0.218
(p. 98)	0.66	0.846	0.728	44.00	0.9539	5.8026	1.2697	0.6463	7.7270	0.351	0.574	0.344	0.357
Novan Energy (p. 109)	1.09	0.762	0.789	43.70	0.9745	5.3029	1.3962	0.7333	8.7669	0.398	0.651	0.391	0.405
Radco Prod. (p. 116)	0.88	0.769	0.737	45.60	0.9670	5.5413	1.3504	0.6997	8.3645	0.380	0.621	0.373	0.386
Ramada Energy	0.55	0.994	0.695	21.60	0.9673	3.4255	0.6090	0.3399	4.0639	0.184	0.302	0.181	0.183
(p. 122)	0.55	0.994	0.695	43.60	0.9367	6.6342	1.1795	0.5620	6.7191	0.305	0.499	0.299	0.310
Raynolds Metal (p. 125)	0.82	0.926	0.720	44.10	0.9591	6.4003	1.2654	0.6184	7.3925	0.335	0.549	0.329	0.342
Solar Age Ind	0.50	0.751	0.628	21.60	0.9729	2.5792	0.5484	0.3391	4.0539	0.184	0.301	0.181	0.187
(p. 129)	0.50	0.751	0.628	43.20	0.9473	6.0225	1.0679	0/5690	6.8024	0.309	0.505	0.303	0.314
Solar Transiti (p. 137)	0.68	0.960	0.751	44.50	0.9501	6.7024	1.3332	0.6411	7.6642	0.348	0.669	0.341	0.187
Sun Devil	0.68	0.905	0.767	22.10	0.9754	3.1881	0.6870	0.4105	4.9078	0.223	0.364	0.219	0.227
(p. 148)	0.68	0.905	0.767	44.20	0.9520	6.2231	1.3411	0.6651	7.9512	0.361	0.590	0.354	0.367
Sun Source	0.66	0.822	0.748	22.20	0.9766	2.9131	0.6740	0.4159	4.9720	0.226	0.369	0.222	0.230
(p. 153)	0.66	0.822	0.748	44.40	0.9547	5.6944	1.3176	0.6796	8.1241	0.369	0.603	0.362	0.375
Sun Source	0.66	0.763	0.730	22.20	0.9785	2.7085	0.6589	0.4160	4.9731	0.226	0.369	0.222	0.230
(p. 159)	0.66	0.763	0.730	44.40	0.9579	5.3029	1.2901	0.6796	8.1241	0.369	0.603	0.362	0.375
Terra Light	0.65	0.975	0.757	21.90	0.9726	3.3938	0.6700	0.3871	4.6283	0.210	0.344	0.206	0.214
(p. 181)	0.65	0.975	0.757	43.80	0.9467	6.6068	1.3043	0.6302	7.5336	0.342	0.559	0.336	0.348
Thermax Solar	0.68	0.847	0.722	21.40	0.0759	2.8908	0.6266	0.3819	4.5654	0.207	0.339	0.203	0.244
(p. 188)	0.63	0.847	0.722	42.30	0.9630	5.6457	1.2237	0.6287	7.6163	0.341	0.558	0.335	0.347
U.S. Solar	0.70	0.791	0.760	23.30	0.9779	2.9454	0.7196	0.4471	5.3452	0.243	0.397	0.238	0.247
(p. 191)	0.70	0.791	0.760	46.60	0.9568	5.7636	1.4061	0.7184	8.5885	0.390	0.638	0.383	0.397
Recommended Active Solar System													
One Panel System		0.900	0.700	22.00	0.95	0.0739	0.6079	0.3579	4.2781	0.194	0.318	0.191	0.198
Two Panel System		0.900	0.700	44.00	0.95	6.1478	1.2159	0.6025	7.2025	0.827	0.515	0.321	0.333

NOTE: Page numbers are referenced to Directory of SRCC Certified Solar Collector Ratings (1986)

Part 2: Determine the Ratio of Absorbed Solar Energy to the Heating Load

$$Y = (F_R{*}\gamma\alpha_n) * (F'_R/F_R) * (\gamma\alpha/\gamma\alpha_n) * N * A * (Ht/Q_L) \quad (3.3)$$

where Y = the ratio of the total absorbed solar energy divided by the total heating load

N = number of days in a month

Ht = the annual average daily insolation on a surface tilted above the horizonal plane, at an angle equal to the collector tilt angle (Table 3.1)

$\gamma\alpha$ = the product of the transmittance/absorbance values of the solar collector

$\gamma\alpha$ = the product of the transmittance/absorbance values of the solar collector at normal incidence

The value of $(F_R{*}\gamma\alpha)$ is provided in the SRCC directory for different collectors. Using the 22 sq. ft area collector as the basis the following value was obtained (see Table 3.1):

$F_R{*}\gamma\alpha$ = 0.7 for single glazed collectors

Suggested typical value for the ratio of the average transmittance/ absorbance product divided by that at normal incidence is given below (Ref. 1):

$\gamma\alpha/\gamma\alpha_n$ = 0/94 for single glazed collectors

Part 3. Estimate the Correction Facing for the DHW Use

The f-chart procedure for liquid-based systems using only service water (no space heating), requires the use of the following correction factor (Ref. 1):

$$X_C = X * (-66.16 + 1.18\ Tw + 3.86\ Tm - 2.32\ Ta) / (212 - Ta) \quad (3.4)$$

where X_C = DHW heating correction factor.

Part 4: Calculate the f-factor

The value of the f-factor is given by the following equation:

$$F = 1.029\ Y - 0.065\ Xc\ Y^2 + 0.245\ Y^2 + 0.0016\ Xc^2 + 0.0251\ Y^3 \quad (3.5)$$

The above procedure is valid only for liquid based systems for the following range of values for X and Y:

$$0 < Y < 3$$
$$0 < X < 18$$

Part 5: Calculate the Annual Load Supplied by the Solar

The annual load supplied by the solar collectors is estimated as follows:

$$Q_S\ (Btu/yr) = (f * QL) * 12 \quad (3.6)$$

Part 6: Calculate the Annual DHW Energy Consumption

In order to calculate the annual energy consumption for DHW solve for Qa as follows:

$$Q_a = (W_d * 8.33 * (T_s - T_m) * 365) / EF$$

(See Section 2 of the Passive Solar discussion for details).

Part 7: Calculate the Solar Savings Fraction of the Active Solar System

The solar savings fraction is given by the ratio of annual solar energy collected to the annual DHW energy consumption as follows:

$$SSF = Q_s / Q_a$$

3.3 DEVELOPMENT OF SSFS FOR THE SIMPLIFIED PATH

In an effort to determine reasonable assumptions for use in determining SSF values in the simplified active solar procedure, a series of sensitivities were conducted (see Tables 3.1 to 3.6). Specifically, the objective of this analysis was to determine values of ($F_R{}^*\gamma\alpha_n$), (F'_R/F_R), and ($F_R{}^*U_L$) for single glazed solar collectors. These values are held constant for all subsequent SSF calculators. In addition this analysis utilized a 64.3 gal/day for the expected daily hot water use, and a 40 gallons storage tank volume (these values change by house type). The Energy Factors were calculated using the information specified in the Passive Solar DHW analysis section.

Examining the results of Tables 3.1 to 3.6 the following values were selected to be held constant for all subsequent SSF calculations:

Single glazed collectors: $F_R{}^*U_L = 0.9$
$\gamma\alpha/\gamma\alpha_n = 0.94$
$F_R{}^* = 0.7$
$F'_R/F_R = 0.95$

The above values were selected because they result in conservative, although not the minimum, SSFs.

As an illustrative example, by keeping the above values constant for each of the six locations, the resulting SSFs for each energy type are shown at the end of Tables 3.1 through 3.6. A summary of these SSFs is shown in Table 3.7.

TABLE 3.2. Active Solar Savings Fractions for Albuquerque, New Mexico

Location	Annual Insolat. (Btu/sq. ft/day)	Average Annual Ambient Temp. (RF)	Average Annual Water In Temp. (RF)	Water Usage (Gal./day)	Storage Tank Volume (Gal.)	Monthly DHW load (Btu/mth) QL	Annual Energy Consumption (MBtu/yr) Gas	Electric	Oil	LP-Gas
Albuqerque, NM	1911	57	62	64.3	40	1253348	27.73	16.94	28.24	27.23

Absorp.-Transm. Ratio (TA/TAn) = 0.94

Manufacturer	Flow Rate (gpm)	Slope (FR*UL)	Y-Interc (FR*TAn)	Net Area (sq. ft)	Heat Exch. Corr. Fact (F'R/FR)	Xc	Y	f-Factor	Ann. Solar Load Suppl. (MBtu/yr)	Solar Savings Fraction Gas	Electric	Oil	LP-Gas
Allstate Solar	0.65	0.748	0.709	22.00	0.9788	1.9071	0.6564	0.4596	6.9121	0.249	0.403	0.245	0.254
(p. 34)	0.65	0.748	0.709	44.00	0.9584	3.7349	1.2855	0.7536	11.3342	0.409	0.669	0.401	0.416
B&H Refrigerat	0.64	1.203	0.738	21.90	0.9659	3.0132	0.6712	0.4084	6.1423	0.222	0.363	0.218	0.226
(p. 38)	0.64	1.203	0.738	43.80	0.9341	5.8278	1.2982	0.6602	9.9296	0.358	0.586	0.352	0.365
Calwest Energy	0.66	0.777	0.730	22.10	0.9789	1.9889	0.6785	0.4711	7.0854	0.256	0.418	0.251	0.260
(p. 43)	0.66	0.777	0.780	14.20	0.9573	3.8929	1.3281	0.7675	11.5435	0.416	0.681	0.409	0.424
Calwest Energy	0.66	0.751	0.746	22.10	0.9789	1.9238	0.6958	0.4874	7.3309	0.264	0.433	0.260	0.269
(p. 49)	0.66	0.751	0.748	44.20	0.9587	3.7680	1.3628	0.7915	11.9038	0.429	0.703	0.422	0.437
Cole Solar	0.54	0.864	0.732	22.70	0.9698	2.2522	0.6929	0.4664	7.0154	0.253	0.414	0.248	0.258
(p. 57)	0.54	0.864	0.732	45.40	0.9414	4.3724	1.3452	0.7522	11.3125	0.403	0.668	0.401	0.415
Cole Solar	0.52	0.798	0.762	22.00	0.9719	2.0203	0.7005	0.4853	7.2985	0.263	0.431	0.258	0.268
(p. 60)	0.52	0.798	0.762	44.00	0.9453	3.9301	1.3627	0.7831	11.7786	0.425	0.595	0.417	0.433
Cole Solar	0.65	1.118	0.713	22.00	0.9686	2.8209	0.6533	0.4056	6.1006	0.220	0.360	0.216	0.224
(p. 62)	0.65	1.118	0.713	44.00	0.9391	5.4699	1.2667	0.6597	9.9215	0.358	0.586	0.351	0.364
Dell Solar In	0.50	0.798	0.713	21.90	0.9709	2.0091	0.6519	0.4503	6.7723	0.244	0.400	0.240	0.249
(p. 68)	0.50	0.798	0.713	43.80	0.9435	3.9047	1.2669	0.7351	11.0555	0.399	0.652	0.391	0.406
General Energy (p. 72)	0.66	0.822	0.748	38.80	0.9602	3.6263	1.1982	0.7124	10.7142	0.386	0.632	0.379	0.393
Intersolar	0.63	1.429	0.819	21.50	0.9599	3.4919	0.7267	0.4230	6.3623	0.229	0.376	0.225	0.234
(p. 81)	0.63	1.429	0.819	43.00	0.9228	6.7145	1.3974	0.6727	10.1177	0.365	0.597	0.358	0.234
Intersolar	0.63	1.170	0.816	21.50	0.9669	2.8800	0.7294	0.4577	6.8833	0.248	0.406	0.244	0.253
(p. 83)	0.63	1.170	0.816	43.00	0.9359	5.5755	1.4120	0.7287	10.9598	0.395	0.647	0.388	0.402
Lordan/Solcoor	0.60	0.873	0.705	20.30	0.9753	2.0466	0.6002	0.4093	6.1552	0.222	0.363	0.218	0.226
(p. 89)	0.60	0.873	0.705	40.50	0.9548	3.9946	1.1714	0.6786	10.2063	0.368	0.602	0.361	0.375
Mor-Flo Indust	0.66	0.775	0.746	22.00	0.9783	1.9751	0.6904	0.4805	7.2272	0.261	0.427	0.256	0.265
(p. 92)	0.66	0.775	0.746	44.00	0.9576	3.8665	1.3515	0.7807	11.7423	0.424	0.693	0.416	0.431

TABLE 3.2. (contd)

Manufacturer	Flow Rate (gpm)	Slope (FR*UL)	Y-Interc (FR*TAn)	Net Area (sq. ft)	Heat Exch. Corr. Fact (F'R/FR)	Xc	Y	f-Factor	Ann. Solar Load Suppl. (MBtu/yr)	Solar Savings Fraction Gas	Electric	Oil	LP-Gas
Mor-Flo Indust (p. 96)	0.66	0.775	0.746	39.60	0.9617	3.4947	1.2215	0.7320	11.0087	0.397	0.650	0.390	0.404
Mor-Flo Indust (p. 98)	0.66	0.846	0.728	22.00	0.9764	2.1518	0.6724	0.4572	6.8766	0.248	0.406	0.214	0.253
	0.66	0.846	0.728	44.00	0.9539	4.2044	1.3138	0.7445	11.1967	0.404	0.661	0.396	0.411
Novan Energy (p. 109)	1.09	0.762	0.789	43.70	0.9745	3.8423	1.4447	0.8277	12.4494	0.449	0.735	0.441	0.457
Radco Prod. (p. 116)	0.88	0.769	0.737	45.60	0.9670	4.0150	1.3973	0.7960	11.9717	0.432	0.707	0.424	0.440
Ramada Energy (p. 122)	0.55	0.994	0.695	21.60	0.9673	2.4820	0.6302	0.4072	6.1242	0.221	0.361	0.217	0.225
	0.55	0.994	0.695	43.60	0.9367	4.8069	1.2205	0.6657	10.0121	0.361	0.591	0.355	0.368
Raynolds Metal (p. 125)	0.82	0.926	0.720	44.10	0.9591	4.6374	1.3093	0.7209	10.8427	0.391	0.640	0.384	0.398
Solar Age Ind (p. 129)	0.50	0.751	0.628	21.60	0.9729	1.8688	0.5675	0.3944	5.9323	0.214	0.350	0.210	0.216
	0.50	0.751	0.628	43.20	0.9473	3.6391	1.1050	0.6591	9.9126	0.358	0.585	0.351	0.364
Solar Transiti (p. 137)	0.68	0.960	0.751	44.50	0.9501	4.8563	1.3795	0.7460	11.2195	0.405	0.662	0.397	0.412
Sun Devil (p. 146)	0.68	0.905	0.767	22.10	0.9754	2.3100	0.7109	0.4762	7.1618	0.258	0.423	0.254	0.263
	0.68	0.905	0.767	44.20	0.9520	4.5091	1.3877	0.7667	11.5316	0.416	0.681	0.408	0.423
Sun Source (p. 153)	0.66	0.822	0.748	22.20	0.9766	2.1107	0.6975	0.4778	7.1869	0.259	0.424	0.255	0.264
	0.66	0.822	0.748	44.40	0.9547	4.1259	1.3634	0.7736	11.6346	0.420	0.687	0.412	0.427
Sun Source (p. 159)	0.66	0.763	0.730	22.20	0.9785	1.9625	0.6818	0.4750	7.1443	0.258	0.422	0.253	0.262
	0.66	0.763	0.730	44.40	0.9579	3.8423	1.3349	0.7736	11.6345	0.420	0.687	0.412	0.427
Terra Light (p. 181)	0.65	0.975	0.757	21.90	0.9726	2.4591	0.6933	0.4550	6.8440	0.247	0.404	0.242	0.251
	0.65	0.975	0.757	43.80	0.9467	4.7870	1.3495	0.7343	11.0440	0.398	0.652	0.391	0.404
Thermax Solar (p. 188)	0.68	0.847	0.722	21.40	0.0759	2.0946	0.6483	0.4428	6.6591	0.240	0.393	0.236	0.245
	0.63	0.847	0.722	42.30	0.9630	4.0907	1.2662	0.7253	10.9066	0.393	0.644	0.386	0.401
U.S. Solar (p. 191)	0.70	0.791	0.760	23.30	0.9779	2.1341	0.7446	0.5102	7.6734	0.277	0.453	0.272	0.280
	0.70	0.791	0.760	46.60	0.9568	4.1761	1.4570	0.8167	12.2840	0.443	0.725	0.435	0.451
Recommended Active Solar System													
One Panel System		0.900	0.700	22.00	0.95	2.2273	0.6290	0.4207	6.3281	0.228	0.373	0.224	0.232
Two Panel System		0.900	0.700	44.00	0.95	4.4545	1.2681	0.7029	10.5725	0.361	0.624	0.374	0.388

NOTE: Page numbers are referenced to Directory of SRCC Certified Solar Collector Ratings (1986).

TABLE 3.3. Active Solar Savings Fractions for Oklahoma City, Oklahoma

Location	Annual Insolat. (Btu/sq. ft/day)	Average Annual Ambient Temp. (RF)	Average Annual Water In Temp. (RF)	Water Usage (Gal./day)	Storage Tank Volume (Gal.)	Monthly DHW load (Btu/mth) QL	Annual Energy Consumption (MBtu/yr) Gas	Electric	Oil	LP-Gas
Oklahoma City, OK	1483	60	62	64.3	40	1253348	27.73	16.94	28.24	27.23

Absorp.-Transm. Ratio (TA/TAn) = 0.94

Manufacturer	Flow Rate (gpm)	Slope (FR*UL)	Y-Interc (FR*TAn)	Net Area (sq. ft)	Heat Exch. Corr. Fact (F'R/FR)	Xc	Y	f-Factor	Ann. Solar Load Suppl. (MBtu/yr)	Solar Savings Fraction Gas	Electric	Oil	LP-Gas
Allstate Solar	0.65	0.748	0.709	22.00	0.9788	1.6427	0.5094	0.3503	5.2679	0.190	0.311	0.187	0.193
(p. 34)	0.65	0.748	0.709	44.00	0.9584	3.6088	0.9976	0.5965	18.9716	0.324	0.530	0.318	0.329
B&H Refrigerat	0.64	1.203	0.738	21.90	0.9659	2.9115	0.5209	0.2991	4.4984	0.162	0.265	0.159	0.165
(p. 38)	0.64	1.203	0.738	43.80	0.9341	5.6310	1.0075	0.5047	7.5914	0.274	0.448	0.269	0.279
Calwest Energy	0.66	0.777	0.730	22.10	0.9789	1.9218	0.5266	0.3593	5.4040	0.195	0.319	0.191	0.296
(p. 43)	0.66	0.777	0.780	14.20	0.9573	3.7615	1.0307	0.6087	19.1556	0.330	0.540	0.324	0.336
Calwest Energy	0.66	0.751	0.746	22.10	0.9789	1.8568	0.5399	0.3735	5.6179	0.203	0.332	0.199	0.206
(p. 49)	0.66	0.751	0.748	44.20	0.9587	3.6408	1.0576	0.6311	9.4922	0.342	0.560	0.336	0.349
Cole Solar	0.54	0.864	0.732	22.70	0.9698	2.1761	0.5377	0.3534	5.3157	0.192	0.314	0.188	0.195
(p. 57)	0.54	0.864	0.732	45.40	0.9414	4.2247	1.0439	0.5933	18.9226	0.322	0.527	0.316	0.328
Cole Solar	0.52	0.798	0.762	22.00	0.9719	1.9521	0.5436	0.3710	5.5799	0.201	0.329	0.198	0.205
(p. 60)	0.52	0.798	0.762	44.00	0.9453	3.7974	1.0575	0.6230	19.3702	0.338	0.553	0.332	0.344
Cole Solar	0.65	1.118	0.713	22.00	0.9686	2.7256	0.5070	0.2982	4.4845	0.162	0.265	0.159	0.165
(p. 62)	0.65	1.118	0.713	44.00	0.9391	5.2852	0.9830	0.5054	7.6008	0.274	0.449	0.269	0.279
Dell Solar In	0.50	0.798	0.713	21.90	0.9709	1.9413	0.5059	0.3417	5.1390	0.185	0.303	0.182	0.189
(p. 68)	0.50	0.798	0.713	43.80	0.9435	3.7728	0.9831	0.5791	8.7094	0.314	0.514	0.308	0.320
General Energy (p. 72)	0.66	0.822	0.748	38.80	0.9602	3.5038	0.9299	0.5595	18.4165	0.304	0.497	02989	0.309
Intersolar	0.63	1.429	0.819	21.50	0.9599	3.3740	0.5640	0.3081	4.6336	0.167	0.273	0.164	0.170
(p. 81)	0.63	1.429	0.819	43.00	0.9228	6.4877	1.0844	0.5138	17.7281	0.279	0.456	0.274	0.284
Intersolar	0.63	1.170	0.816	21.50	0.9669	2.7827	0.3660	0.3416	5.1370	0.185	0.303	0.182	0.489
(p. 83)	0.63	1.170	0.816	43.00	0.9359	5.3872	1.0958	0.5685	18.5600	0.308	0.505	0.303	0.314
Lordan/Solcoor	0.60	0.873	0.705	20.30	0.9753	1.9753	0.4657	0.3071	4.6195	0.167	0.273	0.164	0.170
(p. 89)	0.60	0.873	0.705	40.50	0.9548	3.8597	0.9090	0.5277	17.9372	0.286	0.468	0.281	0.291

TABLE 3.4. Active Solar Savings Fractions for San Antonio, Texas

Location	Annual Insolat. (Btu/sq. ft/day)	Average Annual Ambient Temp. (RF)	Average Annual Water In Temp. (RF)	Water Usage (Gal./day)	Storage Tank Volume (Gal.)	Monthly DHW load (Btu/mth) QL	Annual Energy Consumption (MBtu/yr) Gas	Electric	Oil	LP-Gas
San Antonio, TX	1477	69	67	64.3	40	1173006	25.95	15.86	26.43	25.48

Absorp.-Transm. Ratio (TA/TAn) = 0.94

Manufacturer	Flow Rate (gpm)	Slope (FR*UL)	Y-Interc (FR*TAn)	Net Area (sq. ft)	Heat Exch. Corr. Fact (F'R/FR)	Xc	Y	f-Factor	Ann. Solar Load Suppl. (MBtu/yr)	Solar Savings Fraction Gas	Electric	Oil	LP-Gas
Allstate Solar	0.65	0.748	0.709	22.00	0.9788	1.9533	0.5421	0.3697	5.2042	0.201	0.328	0.197	0.204
(p. 34)	0.65	0.748	0.709	44.00	0.9584	3.8254	1.0616	0.6240	8.7837	0.339	0.554	0.332	0.345
B&H Refrigerat	0.64	1.203	0.738	21.90	0.9659	3.0862	0.5543	0.3159	4.4472	0.171	0.280	0.168	0.175
(p. 38)	0.64	1.203	0.738	43.80	0.9341	5.9690	1.0721	0.5287	7.4417	0.287	0.469	0.282	0.292
Calwest Energy	0.66	0.777	0.730	22.10	0.9789	2.0371	0.5604	0.3792	5.3370	0.206	0.397	0.202	0.209
(p. 43)	0.66	0.777	0.780	14.20	0.9573	3.9872	1.0968	0.6364	8.9586	0.345	0.565	0.339	0.351
Calwest Energy	0.66	0.751	0.746	22.10	0.9789	1.9704	0.5746	0.3940	5.5466	0.214	0.350	0.210	0.215
(p. 49)	0.66	0.751	0.748	44.20	0.9587	3.8593	1.1254	0.6595	9.2831	0.358	0.585	0.351	0.361
Cole Solar	0.54	0.864	0.732	22.70	0.9698	2.3068	0.5722	0.3729	5.2493	0.202	0.331	0.199	0.206
(p. 57)	0.54	0.864	0.732	45.40	0.9414	4.4783	1.1109	0.6202	8.7295	0.336	0.551	0.330	0.343
Cole Solar	0.52	0.798	0.762	22.00	0.9719	2.0692	0.5785	0.3914	5.5089	0.212	0.347	0.208	0.216
(p. 60)	0.52	0.798	0.762	44.00	0.9453	4.0253	1.1254	0.6510	19.1639	0.353	0.578	0.347	0.360
Cole Solar	0.65	1.118	0.713	22.00	0.9686	2.8892	0.5395	0.3150	4.4339	0.171	0.280	0.168	0.174
(p. 62)	0.65	1.118	0.713	44.00	0.9391	5.6024	1.0461	0.5294	7.4519	0.287	0.470	0.282	0.292
Dell Solar In	0.50	0.798	0.713	21.90	0.9709	2.0578	0.5383	0.3607	5.0775	0.196	0.320	0.192	0.190
(p. 68)	0.50	0.798	0.713	43.80	0.9435	3.9993	1.0462	0.6060	8.5296	0.329	0.538	0.323	0.365
General Energy (p. 72)	0.66	0.822	0.748	38.80	0.9602	3.7141	0.9895	0.5861	8.2496	0.318	0.520	0.312	0.329
Intersolar	0.63	1.429	0.819	21.50	0.9599	3.5765	0.6002	0.3253	4.5789	0.767	0.289	0.173	0.180
(p. 81)	0.63	1.429	0.819	43.00	0.9228	6.8771	1.1540	0.5379	7.5715	0.292	0.477	0.286	0.297
Intersolar	0.63	1.170	0.816	21.50	0.9669	2.9497	0.6023	0.3603	5.0721	0.195	0.320	0.192	0.199
(p. 83)	0.63	1.170	0.816	43.00	0.9359	5.7105	1.1661	0.5941	8.3623	0.322	0.527	0.316	0.328
Lordan/Solcoor	0.60	0.873	0.705	20.30	0.9753	2.0962	0.4956	0.3245	4.5681	0.176	0.288	0.173	0.179
(p. 89)	0.60	0.873	0.705	40.50	0.9548	4.0913	0.9674	0.5531	17.7850	0.300	0.491	0.295	0.305
Mor-Flo Indust	0.66	0.775	0.746	22.00	0.9783	2.0230	0.5701	0.3876	5.4553	0.210	0.344	0.206	0.214
(p. 92)	0.66	0.775	0.746	44.00	0.9576	3.9601	1.1161	0.6490	9.1352	0.352	0.576	0.346	0.358

TABLE 3.4. (contd)

Manufacturer	Flow Rate (gpm)	Slope (FR*UL)	Y-Interc (FR*TAn)	Net Area (sq. ft)	Heat Exch. Corr. Fact (F'R/FR)	Xc	Y	f-Factor	Ann. Solar Load Suppl. (MBtu/yr)	Solar Savings Fraction Gas	Electric	Oil	LP-Gas
Mor-Flo Indust (p. 96)	0.66	0.775	0.746	39.60	0.9617	3.5793	1.0085	0.6049	8.5143	0.328	0.537	0.322	0.334
Mor-Flo Indust	0.66	0.846	0.728	22.00	0.9764	2.2039	0.5553	0.3656	5.1466	0.198	0.325	0.195	0.202
(p. 98)	0.66	0.846	0.728	44.00	0.9539	4.3062	1.0850	0.6136	8.6364	0.333	0.545	0.327	0.339
Novan Energy (p. 109)	1.09	0.762	0.789	43.70	0.9745	3.9354	1.1931	0.6936	9.7636	0.376	0.616	0.369	0.383
Radco Prod. (p. 116)	0.88	0.769	0.737	45.60	0.9670	4.1123	1.1539	0.6629	9.3306	0.360	0.588	0.353	0.366
Ramada Energy	0.55	0.994	0.695	21.80	0.9673	2.5421	0.5204	0.3191	4.4914	0.173	0.283	0.170	0.176
(p. 122)	0.55	0.994	0.695	43.60	0.9367	4.9234	1.0079	0.6376	7.5666	0.292	0.477	0.286	0.297
Raynolds Metal (p. 125)	0.82	0.926	0.720	44.10	0.9591	4.7498	1.0813	0.5898	8.3022	0.320	0.524	0.314	0.325
Solar Age Ind	0.50	0.751	0.628	21.60	0.9729	1.9141	0.4686	0.3132	4.4083	0.170	0.278	0.167	0.173
(p. 129)	0.50	0.751	0.628	43.20	0.9473	3.7373	0.9126	0.5368	7.5562	0.291	0.477	0.286	0.296
Solar Transiti (p. 137)	0.68	0.960	0.751	44.50	0.9501	4.9739	1.1393	0.6127	8.6237	0.332	0.644	0.326	0.338
Sun Devil	0.68	0.905	0.767	22.10	0.9754	2.3659	0.5871	0.3810	5.3635	0.207	0.338	0.203	0.210
(p. 148)	0.68	0.905	0.767	44.20	0.9520	4.6183	1.1460	0.6334	8.9165	0.344	0.562	0.337	0.350
Sun Source	0.66	0.822	0.748	22.20	0.9766	2.1619	0.5760	0.3841	5.4066	0.208	0.341	0.205	0.212
(p. 153)	0.66	0.822	0.748	44.40	0.9547	4.2259	1.1259	0.6413	9.0265	0.348	0.569	0.342	0.354
Sun Source	0.66	0.763	0.730	22.20	0.9785	2.0100	0.5631	0.3828	5.3885	0.208	0.340	0.204	0.211
(p. 159)	0.66	0.763	0.730	44.40	0.9579	3.9354	1.1024	0.6423	9.0414	0.348	0.570	0.342	0.355
Terra Light	0.65	0.975	0.757	21.90	0.9726	2.5186	0.5725	0.3613	5.0850	0.196	0.321	0.192	0.200
(p. 181)	0.65	0.975	0.757	43.80	0.9467	4.9030	1.1146	0.6019	8.4719	0.326	0.534	0.321	0.332
Thermax Solar	0.68	0.847	0.722	21.40	0.0759	2.1453	0.5354	0.3534	4.9746	0.192	0.314	0.188	0.195
(p. 188)	0.63	0.847	0.722	42.30	0.9630	4.1898	1.0457	0.5961	8.3904	0.323	0.529	0.317	0.329
U.S. Solar	0.70	0.791	0.760	23.30	0.9779	2.1858	0.6149	0.4125	5.8058	0.244	0.366	0.220	0.228
(p. 191)	0.70	0.791	0.760	46.60	0.9568	4.2773	1.2033	0.6821	9.6008	0.370	0.605	0.363	0.377
Recommended Active Solar System													
One Panel System		0.900	0.700	22.00	0.95	2.2812	0.5195	0.3330	4.6879	0.181	0.296	0.177	0.184
Two Panel System		0.900	0.700	44.00	0.95	4.5624	1.0390	0.5737	8.0754	0.311	0.309	0.306	0.317

NOTE: Page numbers are referenced to Directory of SRCC Certified Solar Collector Ratings (1986).

TABLE 3.5. Active Solar Savings Fractions for Washington D.C.

Location	Annual Insolat. (Btu/sq. ft/day)	Average Annual Ambient Temp. (RF)	Average Annual Water In Temp. (RF)	Water Usage (Gal./day)	Storage Tank Volume (Gal.)	Monthly DHW load (Btu/mth) QL	Annual Energy Consumption (MBtu/yr) Gas	Electric	Oil	LP-Gas
Washington D.C.	1202	57	57	64.3	40	1333691	29.50	18.03	30.05	28.98

Absorp.-Transm. Ratio (TA/TAn) = 0.94

Manufacturer	Flow Rate (gpm)	Slope (FR*UL)	Y-Interc (FR*TAn)	Net Area (sq. ft)	Heat Exch. Corr. Fact (F'R/FR)	Xc	Y	f-Factor	Ann. Solar Load Suppl. (MBtu/yr)	Solar Savings Fraction Gas	Electric	Oil	LP-Gas
Allstate Solar	0.65	0.748	0.709	22.00	0.9788	1.6244	0.3880	0.2630	4.2092	0.143	0.233	0.140	0.145
(p. 34)	0.65	0.748	0.709	44.00	0.9584	3.1813	0.7599	0.4629	7.4083	0.251	0.411	0.247	0.256
B&H Refrigerat	0.64	1.203	0.738	21.90	0.9659	2.5666	0.3968	0.2163	3.4618	0.117	0.192	0.115	0.119
(p. 38)	0.64	1.203	0.738	43.80	0.9341	4.9639	0.7674	0.3784	6.0561	0.205	0.336	0.202	0.209
Calwest Energy	0.66	0.777	0.730	22.10	0.9789	1.6941	0.4011	0.2700	4.3207	0.146	0.240	0.144	0.149
(p. 43)	0.66	0.777	0.780	14.20	0.9573	3.3158	0.7850	0.4732	7.5736	0.257	0.420	0.252	0.261
Calwest Energy	0.66	0.751	0.746	22.10	0.9789	1.6386	0.4113	0.2818	4.5105	0.153	0.250	0.150	0.136
(p. 49)	0.66	0.751	0.748	44.20	0.9587	3.2095	0.8055	0.4930	7.8897	0.267	0.438	0.263	0.272
Cole Solar	0.54	0.864	0.732	22.70	0.9698	1.9183	0.4096	0.2640	4.2251	0.143	0.234	0.141	0.146
(p. 57)	0.54	0.864	0.732	45.40	0.9414	3.7242	0.7951	0.4588	7.3427	0.249	0.407	0.244	0.253
Cole Solar	0.52	0.798	0.762	22.00	0.9719	1.7208	0.4141	0.2793	4.4706	0.152	0.248	0.149	0.164
(p. 60)	0.52	0.798	0.762	44.00	0.9453	3.3475	0.8055	0.4856	7.7717	0.263	0.431	0.259	0.268
Cole Solar	0.65	1.118	0.713	22.00	0.9686	2.4027	0.3861	0.2165	3.4645	0.117	0.192	0.115	0.120
(p. 62)	0.65	1.118	0.713	44.00	0.9391	4.6591	0.7488	0.3799	6.0799	0.206	0.337	0.202	0.210
Dell Solar In	0.50	0.798	0.713	21.90	0.9709	1.7113	0.3853	0.2556	4.0904	0.139	0.227	0.136	0.141
(p. 68)	0.50	0.798	0.713	43.80	0.9435	3.3259	0.7488	0.4474	7.1610	0.243	0.397	0.238	0.247
General Energy (p. 72)	0.66	0.822	0.748	38.80	0.9602	3.0887	0.7083	0.4312	6.9017	0.234	0.383	0.230	0.208
Intersolar	0.63	1.429	0.819	21.50	0.9599	2.9743	0.4296	0.2214	3.5434	0.120	0.197	0.118	0.122
(p. 81)	0.63	1.429	0.819	43.00	0.9228	5.7192	0.8260	0.3841	6.1468	0.208	0.341	0.205	0.212
Intersolar	0.63	1.170	0.816	21.50	0.9669	2.4531	0.4311	0.2515	4.0249	0.136	0.223	0.134	0.109
(p. 83)	0.63	1.170	0.816	43.00	0.9359	4.7490	0.8346	0.4347	6.9568	0.236	0.386	0.232	0.240
Lordan/Solcoor	0.60	0.873	0.705	20.30	0.9753	1.7432	0.3548	0.2275	3.6408	0.123	0.202	0.121	0.126
(p. 89)	0.60	0.873	0.705	40.50	0.9548	3.4024	0.6924	0.4030	16.4504	0.219	0.358	0.215	0.223
Mor-Flo Indust	0.66	0.775	0.746	22.00	0.9783	1.6823	0.4081	0.2766	4.4262	0.150	0.245	0.147	0.153
(p. 92)	0.66	0.775	0.746	44.00	0.9576	3.2933	0.7989	0.4839	7.7449	0.263	0.430	0.258	0.267

TABLE 3.5. (contd)

Manufacturer	Flow Rate (gpm)	Slope (FR*UL)	Y-Interc (FR*TAn)	Net Area (sq. ft)	Heat Exch. Corr. Fact (F'R/FR)	Xc	Y	f-Factor	Ann. Solar Load Suppl. (MBtu/yr)	Solar Savings Fraction Gas	Electric	Oil	LP-Gas
Mor-Flo Indust (p. 96)	0.66	0.775	0.746	39.60	0.9617	2.9766	0.7220	0.4472	7.1565	0.243	0.397	0.238	0.247
Mor-Flo Indust	0.66	0.846	0.728	22.00	0.9764	1.8328	0.3974	0.2588	4.1413	0.140	0.230	0.138	0.143
(p. 98)	0.66	0.846	0.728	44.00	0.9539	3.5811	0.7766	0.4534	7.2564	0.246	0.402	0.241	0.250
Novan Energy (p. 109)	1.09	0.762	0.789	43.70	0.9745	3.2727	0.8539	0.5222	8.3580	0.283	0.464	0.278	0.288
Radco Prod. (p. 116)	0.88	0.769	0.737	45.60	0.9670	3.4198	0.8259	0.4957	7.9327	0.269	0.440	0.264	0.274
Ramada Energy	0.55	0.994	0.695	21.60	0.9673	2.1141	0.3725	0.2212	3.5406	0.120	0.196	0.118	0.122
(p. 122)	0.55	0.994	0.695	43.60	0.9367	4.0944	0.7214	0.3883	6.2143	0.211	0.345	0.207	0.214
Raynolds Metal (p. 125)	0.82	0.926	0.720	44.10	0.9591	3.9500	0.7740	0.4326	6.9237	0.235	0.384	0.230	0.239
Solar Age Ind	0.50	0.751	0.628	21.60	0.9729	1.5918	0.3354	0.2196	3.5151	0.119	0.195	0.117	0.121
(p. 129)	0.50	0.751	0.628	43.20	0.9473	3.0997	0.6532	0.3904	6.2482	0.212	0.347	0.208	0.216
Solar Transiti (p. 137)	0.68	0.960	0.751	44.50	0.9501	4.1364	0.8154	0.4517	7.2294	0.245	0.401	0.241	0.249
Sun Devil	0.68	0.905	0.767	22.10	0.9754	1.9676	0.4202	0.2701	4.3224	0.147	0.240	0.144	0.149
(p. 148)	0.68	0.905	0.767	44.20	0.9520	3.8407	0.8203	0.4700	7.5215	0.255	0.417	0.250	0.260
Sun Source	0.66	0.822	0.748	22.20	0.9766	1.7978	0.4123	0.2733	4.3740	0.148	0.243	0.146	0.151
(p. 153)	0.66	0.822	0.748	44.40	0.9547	3.5143	0.8059	0.4771	7.6352	0.259	0.423	0.254	0.264
Sun Source	0.66	0.763	0.730	22.20	0.9785	1.6716	0.4030	0.2729	4.3681	0.148	0.242	0.145	0.151
(p. 159)	0.66	0.763	0.730	44.40	0.9579	3.2727	0.7891	0.4783	7.6545	0.259	0.425	0.255	0.264
Terra Light	0.65	0.975	0.757	21.90	0.9726	2.0945	0.4098	0.2540	4.0655	0.138	0.225	0.135	0.140
(p. 181)	0.65	0.975	0.757	43.80	0.9467	4.0774	0.7978	0.4426	7.0837	-.240	0.393	0.236	0.244
Thermax Solar	0.68	0.847	0.722	21.40	0.0759	1.7841	0.3832	0.2495	3.9938	0.135	0.222	0.133	0.133
(p. 188)	0.63	0.847	0.722	42.30	0.9630	3.4843	0.7485	0.4388	7.0229	0.238	0.390	0.234	0.242
U.S. Solar	0.70	0.791	0.760	23.30	0.9779	1.8178	0.4401	0.2954	4.7271	0.160	0.262	0.157	0.163
(p. 191)	0.70	0.791	0.760	46.60	0.9568	3.5571	0.8612	0.5121	8.1957	0.278	0.455	0.272	0.283
Recommended Active Solar System													
One Panel System		0.900	0.700	22.00	0.95	1.8971	0.3718	0.2332	3.7321	0.127	0.207	0.124	0.129
Two Panel System		0.900	0.700	44.00	0.95	3.7942	0.7437	0.4193	6.7113	0.227	0.372	0.223	0.232

NOTE: Page numbers are referenced to Directory of SRCC Certified Solar Collector Ratings (1986).

TABLE 3.6. Active Solar Savings Fractions for Denver, Colorado

Location	Annual Insolat. (Btu/sq. ft/day)	Average Annual Ambient Temp. (RF)	Average Annual Water In Temp. (RF)	Water Usage (Gal./day)	Storage Tank Volume (Gal.)	Monthly DHW load (Btu/mth) QL	Annual Energy Consumption (MBtu/yr) Gas	Electric	Oil	LP-Gas
Denver, CO	1694	49	50	64.3	40	1446171	31.99	19.55	32.58	31.42

Absorp.-Transm. Ratio (TA/TAn) = 0.94

Manufacturer	Flow Rate (gpm)	Slope (FR*UL)	Y-Interc (FR*TAn)	Net Area (sq. ft)	Heat Exch. Corr. Fact (F'R/FR)	Xc	Y	f-Factor	Ann. Solar Load Suppl. (MBtu/yr)	Solar Savings Fraction Gas	Electric	Oil	LP-Gas
Allstate Solar	0.65	0.748	0.709	22.00	0.9788	1.4302	0.5043	0.3706	6.4306	0.201	0.329	0.197	0.205
(p. 34)	0.65	0.748	0.709	44.00	0.9584	2.8010	0.9876	0.6335	10.9943	0.344	0.562	0.337	0.350
B&H Refrigerat	0.64	1.203	0.738	21.90	0.9659	2.2597	0.5157	0.3312	5.7483	0.180	0.294	0.176	0.163
(p. 38)	0.64	1.203	0.738	43.80	0.9341	4.3705	0.9974	0.5578	9.6798	0.303	0.495	0.297	0.308
Calwest Energy	0.66	0.777	0.730	22.10	0.9789	1.4916	0.5213	0.3804	6.6021	0.206	0.338	0.203	0.210
(p. 43)	0.66	0.777	0.780	14.20	0.9573	1.0203	0.6471	0.4732	11.2296	0.351	0.574	0.345	0.357
Calwest Energy	0.66	0.751	0.746	22.10	0.9789	1.4427	0.5345	0.3938	6.8346	0.214	0.350	0.210	0.218
(p. 49)	0.66	0.751	0.748	44.20	0.9587	2.8258	1.0470	0.6683	11.5974	0.363	0.593	0.356	0.369
Cole Solar	0.54	0.864	0.732	22.70	0.9698	1.6890	0.5323	0.3776	6.5505	0.205	0.335	0.201	0.208
(p. 57)	0.54	0.864	0.732	45.40	0.9414	3.2790	1.0334	0.6357	11.0313	0.345	0.564	0.339	0.351
Cole Solar	0.52	0.798	0.762	22.00	0.9719	1.5151	0.5332	0.3924	6.8096	0.213	0.348	0.209	0.217
(p. 60)	0.52	0.798	0.762	44.00	0.9453	2.9473	1.0469	0.6616	11.4817	0.359	0.587	0.352	0.365
Cole Solar	0.65	1.118	0.713	22.00	0.9686	2.1155	0.5019	0.3284	5.6997	0.178	0.292	0.175	0.181
(p. 62)	0.65	1.118	0.713	44.00	0.9391	4.1021	0.9732	0.5561	9.6514	0.302	0.494	0.296	0.307
Dell Solar In	0.50	0.798	0.713	21.90	0.9709	1.5067	0.5008	0.3632	6.3025	0.197	0.322	0.193	0.201
(p. 68)	0.50	0.798	0.713	43.80	0.9435	2.9283	0.9733	0.6177	10.7188	0.335	0.548	0.329	0.341
General Energy (p. 72)	0.66	0.822	0.748	38.80	0.9602	2.7195	0.9206	0.5958	10.3388	0.323	0.529	0.317	0.329
Intersolar	0.63	1.429	0.819	21.50	0.9599	2.6188	0.5583	0.3466	5.9807	0.187	0.306	0.184	0.190
(p. 81)	0.63	1.429	0.819	43.00	0.9228	5.7192	0.8260	0.3841	6.1468	0.208	0.341	0.205	0.212
Intersolar	0.63	1.170	0.816	21.50	0.9669	2.4531	0.4311	0.2515	4.0249	0.136	0.223	0.134	0.109
(p. 83)	0.63	1.170	0.816	43.00	0.9359	4.7490	0.8346	0.4347	6.9568	0.236	0.386	0.232	0.240
Lordan/Solcoor	0.60	0.873	0.705	20.30	0.9753	1.7432	0.3548	0.2275	3.8408	0.123	0.202	0.121	0.126
(p. 89)	0.60	0.873	0.705	40.50	0.9548	3.4024	0.6924	0.4030	16.4504	0.219	0.358	0.215	0.223
Mor-Flor Indust	0.66	0.775	0.746	22.0	0.9783	1.4812	0.5304	0.3883	6.7379	0.211	0.345	0.207	0.214
(p. 92)	0.66	0.775	0.746	44.00	0.9576	2.8996	1.0383	0.6590	11.4368	0.357	0.585	0.351	0.364

TABLE 3.6. (contd)

Manufacturer	Flow Rate (gpm)	Slope (FR*UL)	Y-Interc (FR*TAn)	Net Area (sq. ft)	Heat Exch. Corr. Fact (F'R/FR)	Xc	Y	f-Factor	Ann. Solar Load Suppl. (MBtu/yr)	Solar Savings Fraction: Gas	Electric	Oil	LP-Gas
Mor-Flo Indust (p. 96)	0.66	0.775	0.746	39.60	0.9617	2.6208	0.9384	0.6126	10.6318	0.332	0.544	0.326	0.333
Mor-Flo Indust	0.66	0.846	0.728	22.00	0.9764	1.6137	0.5166	0.3694	6.4110	0.200	0.328	0.197	0.204
(p. 98)	0.66	0.846	0.728	44.00	0.9639	3.1530	1.0093	0.6278	10.8940	0.341	0.557	0.334	0.347
Novan Energy (p. 109)	1.09	0.762	0.789	43.70	0.9745	2.8815	1.1099	0.7022	12.1865	0.381	0.623	0.374	0.388
Radco Prod. (p. 116)	0.88	0.769	0.737	45.60	0.9670	3.0110	1.0735	0.6739	11.6954	0.366	0.598	0.359	0.372
Ramada Energy	0.55	0.994	0.695	21.80	0.9673	1.8614	0.4841	0.3288	5.7067	0.178	0.292	0.175	0.182
(p. 122)	0.55	0.994	0.695	43.60	0.9367	3.6049	0.9376	0.5592	9.7042	0.303	0.496	0.298	0.309
Raynolds Metal (p. 125)	0.82	0.926	0.720	44.10	0.9591	3.4778	1.0059	0.6084	10.5589	0.330	0.540	0.324	0.336
Solar Age Ind.	0.50	0.751	0.628	21.60	0.9729	1.4015	0.9460	0.3166	5.4935	0.172	0.281	0.169	0.175
(p. 129)	0.50	0.751	0.628	43.20	0.9473	2.7292	0.8489	0.5484	9.5163	0.297	0.487	0.292	0.303
Solar Transiti (p. 137)	0.68	0.960	0.751	44.50	0.9601	3.6420	1.0598	0.6324	10.9747	0.343	0.561	0.337	0.349
Sun Devil	0.68	0.905	0.767	22.10	0.9754	1.7324	0.5462	0.3858	6.6952	0.209	0.342	0.205	0.213
(p. 148)	0.68	0.905	0.767	44.20	0.9520	3.3816	1.0661	0.6498	11.2758	0.352	0.577	0.346	0.359
Sun Source	0.66	0.822	0.748	22.20	0.9768	1.5829	0.5358	0.3865	6.7074	0.210	0.343	0.206	0.216
(p. 153)	0.66	0.822	0.748	44.40	0.9547	3.0942	1.0474	0.6540	11.3467	0.355	0.580	0.348	0.361
Sun Source	0.66	0.763	0.730	22.20	0.9785	1.4718	0.5238	0.3836	6.6573	0.208	0.341	0.204	0.212
(p. 159)	0.66	0.822	0.748	44.404	0.9547	3.0942	1.0474	0.6540	11.3487	0.355	0.580	0.348	0.361
Terra Light	0.65	0.975	0.757	21.90	0.9726	1.8442	0.5326	0.3686	6.3969	0.200	0.327	0.196	0.201
(p. 181)	0.65	0.975	0.757	43.80	0.9467	3.5900	1.0369	0.6214	10.7831	0.337	0.552	0.331	0.341
Thermex Solar	0.63	0.847	0.722	21.40	0.9759	1.5708	0.4981	0.3572	6.1988	0.194	0.317	0.190	0.197
(p. 188)	0.63	0.847	0.722	42.80	0.9530	3.0678	0.9726	0.6098	10.5823	0.331	0.541	0.325	0.337
U.S. Solar	0.70	0.791	0.760	23.30	0.9779	1.6005	0.5720	0.4137	7.1799	0.224	0.367	0.220	0.229
(p. 191)	0.70	0.791	0.760	46.60	0.9568	3.1318	1.1194	0.6941	12.0460	0.377	0.616	0.370	0.383
Recommended Active Solar System													
One Panel System		0.900	0.700	22.00	0.95	1.6703	0.4833	0.3993	5.8890	0.184	0.301	0.181	0.187
Two Panel System		0.900	0.700	44.00	0.95	3.3406	0.9685	0.5913	10.2614	0.321	0.525	0.315	0.327

Note: Page numbers are referenced to Directory of SRCC Certified Solar Collector Ratings (1986).

TABLE 3.7. Active Solar Savings Fractions for House Prototype: Single-Story Detached

Location	Gas		Electric		Oil		LP-Gas	
	One Panel	Two Panel	One Panel	Two Panel	One Panel	Two Panel	One Panel	Two Panel
Miami, FL	0.194	0.327	0.318	0.535	0.191	0.321	0.198	0.333
Albuquerque, NM	0.228	0.381	0.373	0.616	0.224	0.374	0.232	0.388
Oklahoma City, OK	0.171	0.297	0.280	0.486	0.168	0.292	0.174	0.303
San Antonio, TX	0.181	0.311	0.296	0.509	0.177	0.306	0.184	0.317
Washington, D.C.	0.127	0.227	0.207	0.372	0.124	0.223	0.129	0.232
Denver, CO	0.184	0.321	0.301	0.525	0.181	0.315	0.187	0.327

4.0 REFERENCES

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3. Code of Federal Regulations. Energy Conservation Program for Consumer Products, 10 Part 430, Jan 1985.

4. Solar Energy Engineering, Jul Sheng Hsieh.

5. Directory of SRCC Certified Solar Collectors Ratings, Vol VI. Vol. 1, 1986.

6. Affordable Housing Through Energy Conservation - Technical Support Document, LBL-16342. Draft.

7. Solar Heating and Cooling, Revised first edition. Jan Kreider and Frank Kreith.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #9-1

Title: PACKAGES

Statement of Issue: What variety of packages should be offered and how should they be identified?

Resolution: The package approach should be provided for the basic heating and cooling fuel type combinations, with changes in components to be handled by the points and performance approaches.

Discussion:

The concept of packages was developed to try and retain some of the advantages of a prescriptive standard, namely a minimum amount of effort in determining compliance while enhancing the number of opportunities for compliance. The selection of packages would be based on covering as many standard building practices as possible. Although it is possible for this to get out of hand in the creation of tens of packages, it is important to have a number of packages which cover the majority of the designs in use. To assure this coverage, we would provide the codification agencies with the capability of identifying additional packages which are indigenous to the building practices in their areas. Past experience has shown that while the flexibility of the points and performance approaches is needed, a large majority just wants to be assured of compliance through an approach with minimal effort. The TEC has identified this as the package approach so there needs to be solid coverage by the packages of typical practices.

With this philosophy, the Committee has identified a basic set of packages which will be provided in each location. This set is comprised of an energy efficient, economically optimal frame construction residence with different fuel and equipment types. The following fuel/equipment types comprise the basic set:

1. Gas-fired Furnace with Direct Expansion Cooling
2. Oil-fired Furnace with Direct Expansion Cooling
3. LPG-fired Furnace with Direct Expansion Cooling
4. Electric Resistance Heating with Direct Expansion Cooling
5. Electric Heat Pump for Heating and Cooling

In addition to the basic set, local jurisdictions can create alternative packages. Each of these packages is derived by setting one or more features constant and deriving the rest of the ECM levels through the economic analysis. Some of these packages might include:

a. Superinsulated - Frame construction, basic package, high insulation levels and tighter infiltration measures. These would be traded off against lower equipment performance or more glazing.

b. Masonry or Mass Construction - Depending upon the results of the mass placement analysis, there might be two packages, one with the insulation on the outside and one with the insulation integral (as in log walls). The wall construction and associated insulation levels would be fixed with trade-offs against glazing, infiltration, and equipment options.

c. Sun-tempered - This is the package which allows for more south facing glazing without requiring interior mass. The increase in area will be traded off against a tighter envelope or other options as they are economically justified.

d. Alternative Mechanical System - In this package, the efficiencies of the equipment may be changed or alternative systems such as evaporative cooling may be set.

e. Infiltration - This would be a very tight package. The trade-off might be made against additional glazing area or reduced equipment performance.

f. Active Solar DHW - This would be an active solar DHW package which could trade hot water savings against additional glazing or reduced equipment performance. (Note discussion of equivalency.)

Equivalency on the packages would be based on a total dollar goal with blurred boundaries between heating, cooling, and DHW. This allows trade-offs across all the measures.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #9-2

Title: DEVELOPMENT OF POINTS COMPLIANCE PATH

Statement of Issue: What procedure(s) should be followed in demonstrating compliance with the standard using the Points Compliance Path?

Resolution: A technique has been developed that allows compliance to be demonstrated by combining points for individual energy-related conservation measures. Points represent the impact of energy measures on space heating, space cooling and domestic hot water energy consumption. The total points for a proposed design (i.e. Design Points) are the sum of the points for all the proposed energy measures. The Design Points must not exceed the total points for a predefined level of energy integrity (i.e. Target Points.)

Discussion:

Points are assigned to a wide range of energy conservation measures (ECMs) organized into categories. The corresponding points for each level within an ECM category in each location are calculated as a function of impact on energy use. Based upon the results of an economic analysis optimization procedure, target levels within an ECM Category (e.g. R-19 with the ceiling insulation category) will be developed for each location, each housing type, and each HVAC system type.

In demonstrating compliance, the desired levels of conservation are selected from each ECM category and the corresponding points are computed. To demonstrate compliance, the total points for the selected ECMs, when used with the proposed design, must be lower than the points estimated when the target ECM levels are applied to the proposed home. An example of the points compliance path is provided in Appendix A.

APPENDIX A

Development of the Points Compliance Path

1.0 Introduction

One of the methods that will allow the user to demonstrate compliance with the proposed standard is the Points Compliance Path. Relative to the Prescriptive Path, the Points Path provides a greater degree of flexibility in compliance but sacrifices simplicity in the process. The popularity and usability of the Points path has been demonstrated in the states of California and Florida.

Points are assigned to incremental levels of conservation within categories of energy conservation measures including ceiling, wall and foundation insulation levels, air infiltration rate, window layers, equipment efficiencies and solar domestic hot water options. The points can be translated into units of energy cost.

The economic analysis optimization procedure (see position paper on Economics Methodology) determines a "Target" set of conservation measures with an associated point total. In demonstrating compliance, the user selects a unique set of ECMs and adds up the corresponding points to determine the "Design" points. The Design points shall not exceed the Target points for compliance to be demonstrated. The total Target and the Design points can be translated into an estimated energy cost.

A separate set of points is provided for each of three housing types to reflect the differences in energy use patterns characteristic of changes in building configuration. The types are single-family detached, the multi-family attached, and manufactured or mobile homes. (See LBL TSD for further documentation regarding the selection of housing types and procedures for determining the point values.)

The generic name for the procedure for demonstrating compliance with the points path is the "parallel" method. In the parallel method the user must determine a unique point total for a home of the same configuration as the design, but with the optimized package of energy measures (i.e. Basic Prescriptive Package). In "parallel", a computation of the points for the proposed design is provided using a user-defined set of energy features. Consequently, each user's target and design point totals are unique.

The alternative to the parallel method is the linear method employed by the State of California. The linear method utilizes a static target and a single housing configuration. Only one calculation is performed and the user determines the number of points corresponding to a fixed home design with the desired conservation measures.

The advantage of the linear method is its simplicity. The parallel method has two important advantages. First, it is more accurate since the point estimates are based upon the actual configuration of the home and not a national average prototype; and, (2) the total points can be translated into an estimate of actual energy use for that particular design. The committee felt the trade-off of accuracy for a slight loss in simplicity to be justified.

2.0 Procedure for Using the Parallel Compliance Path

The following example will illustrate the process for using the Points compliance path:

Example

The example below is based upon a two story single-family detached home with 2504 square feet of floor area, 2088 square feet of opaque wall area and 248 square feet (50 north, 120 east, 25 south, and 53 west) of window area. The location assumed is South Bend, Indiana.

2.1. Development of the Total Target and Design Points

For the illustrative example we have assumed that the optimization analysis has yielded the following energy options as cost effective for homes with oil heating and electric cooling:

- R-30 ceiling insulation level
- R-23 wall insulation level
- R-30 unheated basement

- Air infiltration package "Average"
- Clear, triple glazed windows with thermal breaks
- 12 % fenestration area, equally distributed
- AFUE = 0.90 for gas heating
- SEER = 10.0 for A/C cooling
- DHW Equipment Efficiency - Federal Minimum

This set of energy conservation measures constitutes the compliance Target package. Separate target packages are generated for each location, housing type (attached, detached and manufactured) and HVAC system type as needed. When complying with the standard, the content of the target package is transparent, and only target points are provided.

In the first step of compliance the user computes points for each of the energy conservation measures, including the insulation, infiltration, and glazing type ECMs (see Table A.1). These are summed and combined with the points for glazing orientation. Next the number of points corresponding to the "base load" are estimated.

The base load points equate to the load of the home with the highest levels of space conditioning ECMs. Starting with the tightest home allows the point estimates for actual designs to be a result of only adding points (loads), simplifying compliance. The base load points are added to (or subtracted from) the composite points for the ECMs.

The result, a value that embodies the space load, is multiplied by the Equipment points. The result is the Total Space Heating and Cooling Points, which, when summed, yield the Total Space Conditioning Points. In the last step, the space conditioning and Domestic Hot Water points are combined to provide the Total Target Points. The same procedure is followed for calculating the Design points.

A precise description of the procedure for calculating the point totals is described in Volume I, Appendix B. While the user is able to select any energy type for space conditioning and domestic hot water point estimation, the energy type selected for the Target point computation must match the selection for the Design points.

The design package is assumed to have the following energy features:

- R-30 ceiling insulation
- R-13 wall insulation
- R-13 unheated basement
- Air infiltration package "Tight"
- Clear, double glazed windows without thermal breaks
- fenestration area as described above
- AFUE = 0.88 for gas heating
- SEER = 10.0 for A/C cooling
- A two panel active solar option

To demonstrate compliance, the number of Target points must be equal to or exceed the number of Design points. In this example, the design complies since the 103,069 target points exceeds the 90,046 points for the design (see Table A.1).

The 90,046 points represent an estimate of the cost in cents per year for space conditioning and domestic hot water used by a home built with the design package. In other words, this two story detached home in South Bend, IN with these energy features and design characteristics is expected to have an average utility bill of $900.46 in the first year of operation (excluding appliances).

3.0 Testing the Points Compliance System

In an effort to explore the trends in levels of conservation that might result from the utilization of the Points Compliance path, a series of sensitivity analyses was conducted. The objective of the analysis was to determine the sensitivity of the results to the level of HVAC equipment efficiency and the level of thermal integrity. The results indicate that for climates where heating loads predominate, the points system is more sensitive to the level of thermal integrity. Conversely, for climates where cooling loads predominate, the Points path showed higher sensitivity to the level of cooling equipment efficiency.

3.1. Procedure

Five locations, Albuquerque, Miami, Denver, Washington DC, and Minneapolis were selected for testing. In each location six packages of energy conservation measures were identified that represent reasonable gradations in the level of thermal integrity.

Each package includes ceiling, wall and foundation insulation levels, an air infiltration rate, and window layers. Package (1) corresponds to the lowest level of thermal integrity (i.e. highest energy consumption) and package (6) the highest level of thermal integrity (see Table 1.).

The Space Conditioning points were generated using data provided in raw form as generated using the DOE-2 computer model. The equivalent points (dollars) for both heating and cooling were calculated assuming natural gas fired heating equipment, and electric air conditioning. Also, for the heating equipment efficiencies, AFUEs ranging from 60% to 90% in steps of 5% were used, and the SEERs ranged from 8 to 12 in steps of 1.0 for cooling (see Table 2a). A 4% distribution loss was assumed to correct the system efficiency estimates.

The results of the analysis are tabulated on Tables 2.a through 2.e. The tabular data were then converted to graphic format for ease in assessing the results. Two sets of graphs are provided for each location. The first set of graphs in each set displays the points (in dollars) along the y-axis and the packages (identified by number) along the x-axis. Separate graphs are provided for heating and cooling and each curve corresponds to a level of equipment efficiency (AFUE or SEER).

The second set of graphs compares the points with the equipment efficiencies. The y-axis for this set shows the number of points (in dollars) and the x-axis displays the equipment efficiencies. The curves correspond to the six packages indicated as P1 through P6.

3.2. Summary of Results and Conclusions

The following observations can be made with regard to the results of this analysis:

- The heating analysis indicates that regardless of location the heating equipment efficiency curves converge as the level of thermal integrity increases. This implies that the Points compliance path becomes progressively less sensitive to the heating equipment efficiencies as the level of thermal integrity increases.
- Conversely, the Points path is very sensitive to the thermal integrity levels represented by the packages. For example, regardless of location, jumping from a lower thermal integrity package to a higher one (i.e. from P3 to P4) can result in considerable reduction in the number of points. This is especially true at the lower heating equipment efficiency levels. For all locations, changing the package level to a higher one results in more savings than going to the next higher level of AFUE.
- In cooling the reverse is true. A change in the cooling equipment efficiency will have a greater impact than selecting a higher thermal integrity level. This is especially true at the lower thermal integrity levels (Packages 1 and 2).
- The analysis confirmed the fact that changes in equipment efficiency will have a more profound effect as the level of thermal integrity is decreased. However, on a percentage basis the change is about the same regardless of thermal integrity level.

One general conclusion from this limited analysis is that in heating climates, it is more prudent to select a higher integrity level than higher heating equipment efficiency. On the other hand for locations where cooling loads are the primary concern, the better path is to select higher efficiency cooling equipment than to specify a high level of thermal integrity.

Table 1. Description of the Packages

1.	Ceiling Insul.	R-7	2.	Ceiling Insul.	R-11
	Wall Insul.	R-7		Wall Insul.	R-11
	Crawl Found.	R-11		Crawl Found.	R-19
	Air Infiltr.	High		Air Infiltr.	High
	Windows	One Pane		Windows	One Pane
3.	Ceiling Insul.	R-19	4.	Ceiling Insul.	R-30
	Wall Insul.	R-11		Wall Insul.	R-19
	Crawl Found.	R-19		Crawl Found.	R-19
	Air Infiltr.	Med		Air Infiltr.	Med
	Windows	One Pane		Windows	Two Pane
5.	Ceiling Insul.	R-38	6.	Ceiling Insul.	R-49
	Wall Insul.	R-27		Wall Insul.	R-27
	Crawl Found.	R-38		Crawl Found.	R-38
	Air Infiltr.	Med		Air Infiltr.	Low
	Windows	Two Pane		Windows	Three Pane

Energy Costs:

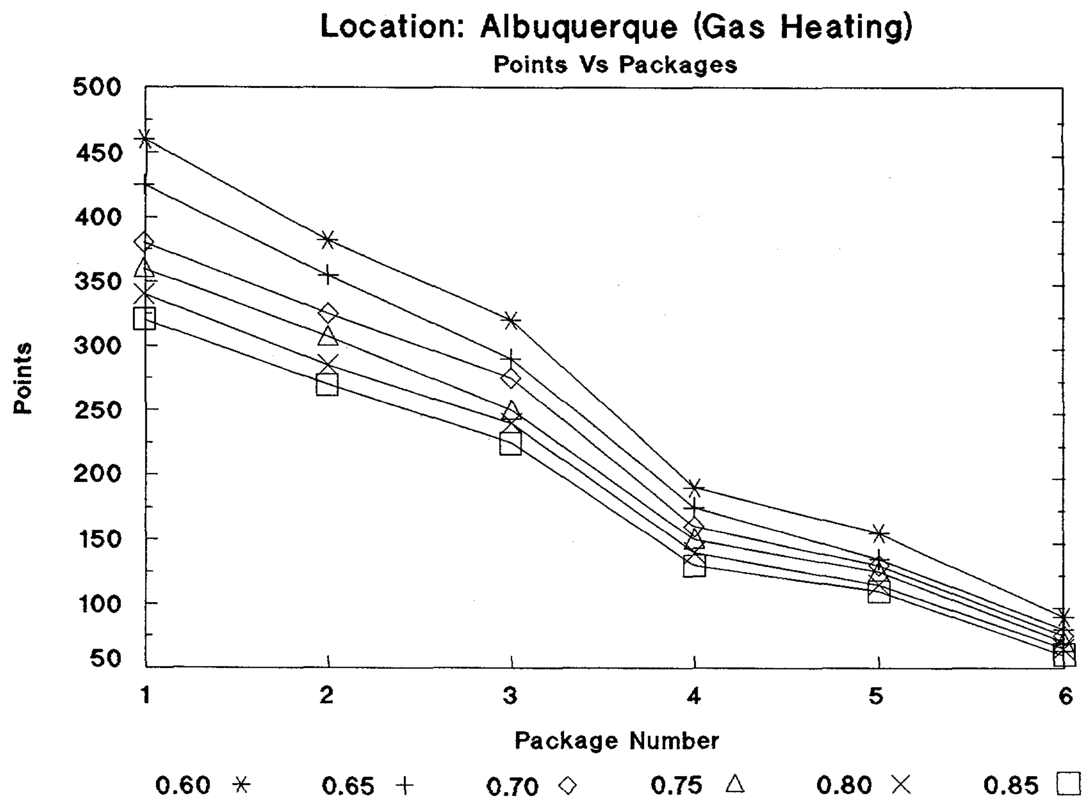
	GAS	ELECTRIC
Location	(Cents/ Therm)	(Cents/ KWH)
Albuquerque	50.30	9.64
Miami	25.40	8.26
Denver	38.70	6.50
Washing. DC	72.00	8.29
Minneapolis	53.60	7.23

Table 2a. Albuquerque

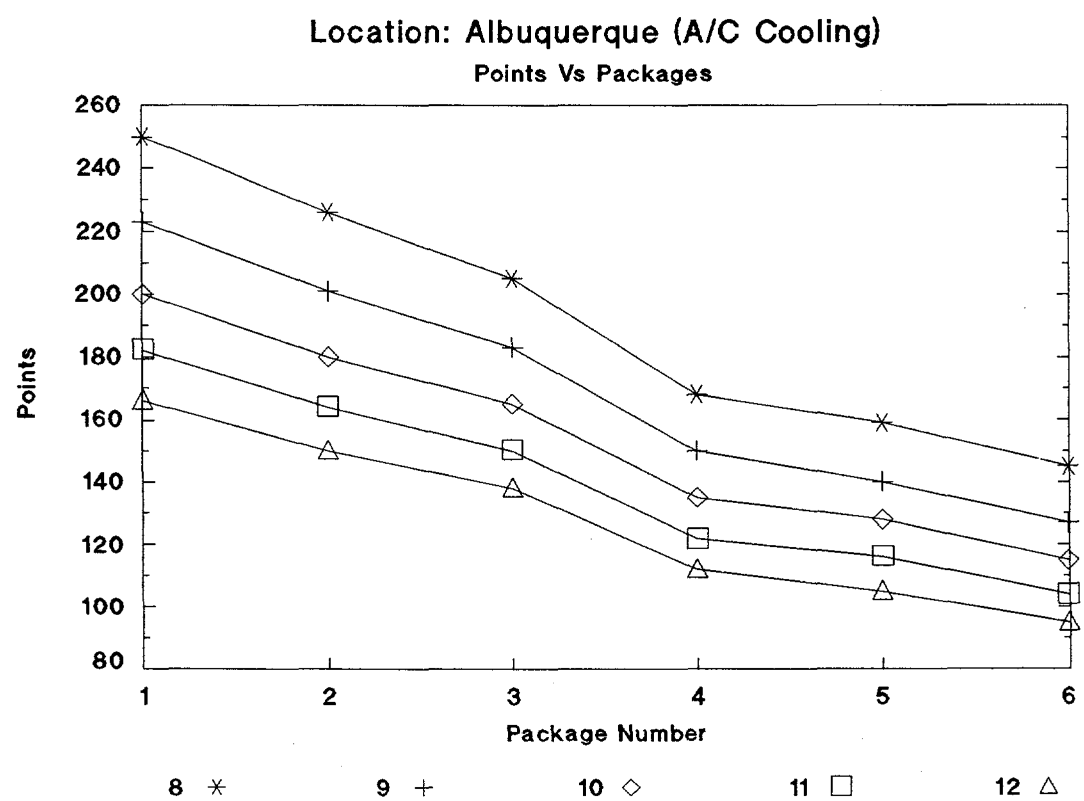
Date 03/26/87

Space Conditioning Points

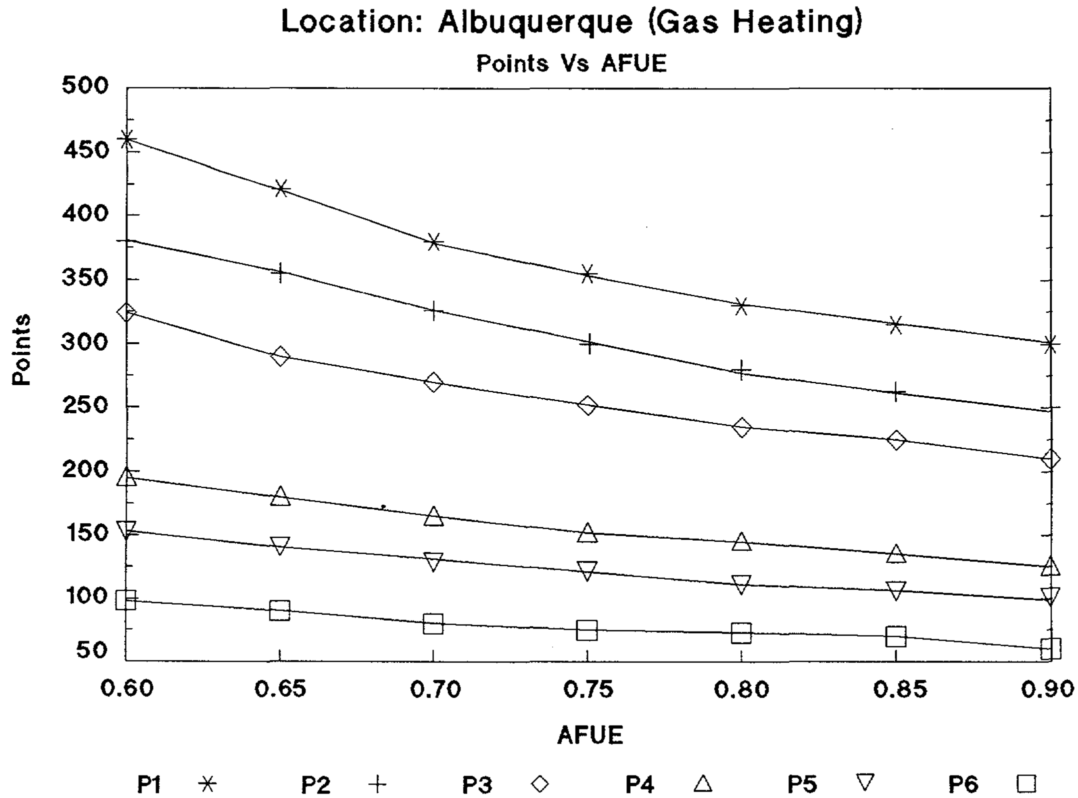
	Gas Efficiency (AFUE)							A/C Efficiency (SEER)				
	0.60	0.65	0.70	0.75	0.80	0.85	0.90	8.00	9.00	10.00	11.00	12.00
Package 1	460	422	390	363	339	318	299	251	223	200	182	166
Package 2	387	356	329	306	285	268	252	226	201	180	164	150
Package 3	320	294	272	253	236	221	209	207	183	165	150	137
Package 4	195	179	165	154	144	135	127	169	150	135	123	112
Package 5	154	141	131	122	114	107	100	159	141	127	115	105
Package 6	95	87	80	75	70	66	62	144	128	115	104	95



Location: Albuquerque (Gas Heating)
Points Vs Packages
Points
500
450
400
350
300
250
200
150
100
50
1
2
3
4
5
6
Package Number
0.60
0.65
0.70
0.75
0.80
0.85



Location: Albuquerque (A/C Cooling)
Points Vs Packages
Points
260
240
220
200
180
160
140
120
100
80
1
2
3
4
5
6
Package Number
8
9
10
11
12


Location: Albuquerque (Gas Heating)
Points Vs AFUE
500
450
400
350
300
250
200
150
100
50
Points
0.60
0.65
0.70
0.75
0.80
0.85
0.90
AFUE
P1
P2
P3
P4
P5
P6

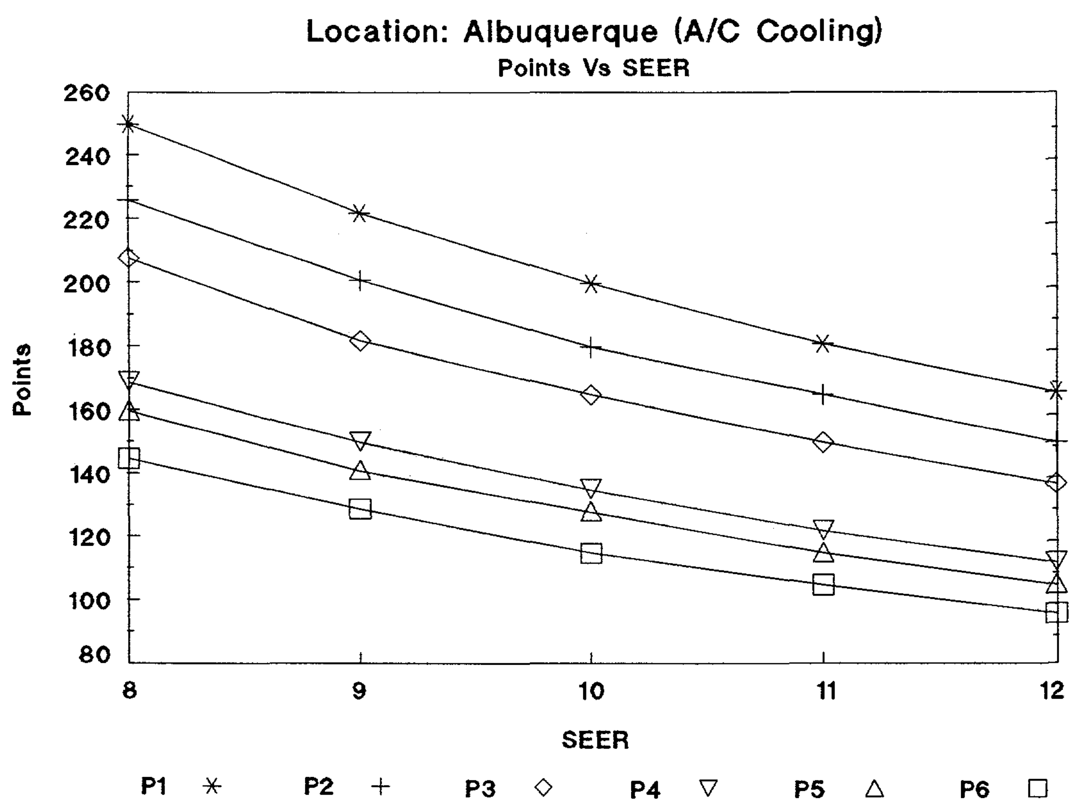
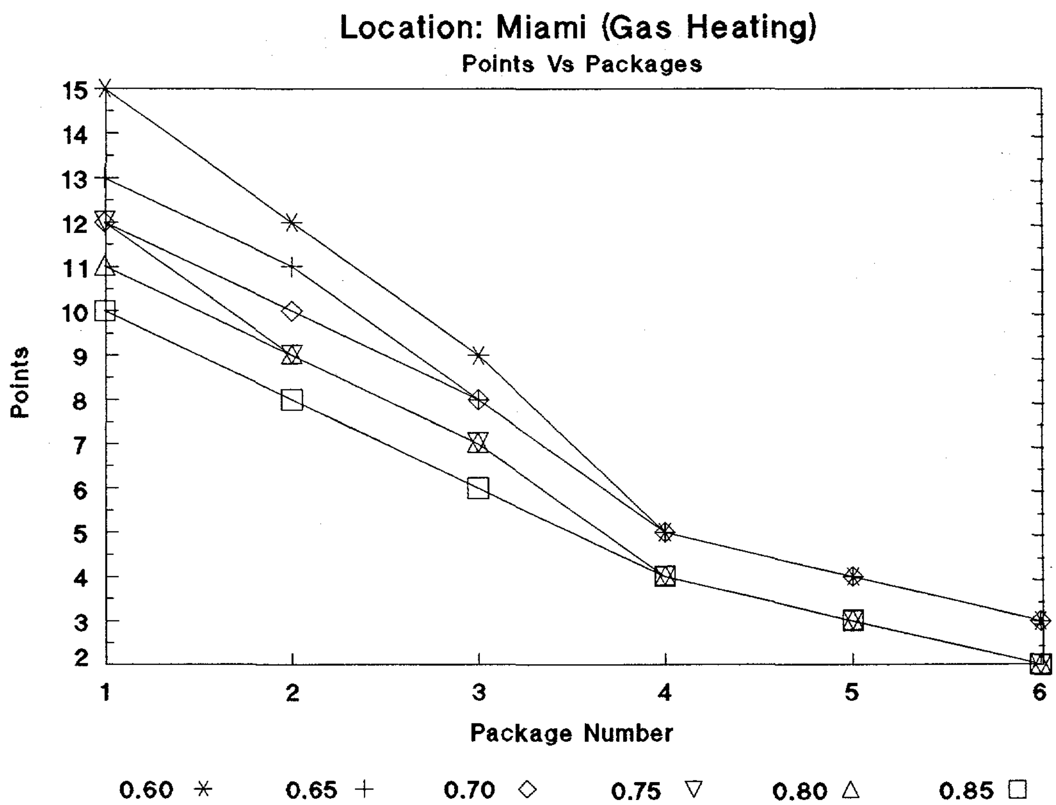

Location: Albuquerque (A/C Cooling)
Points Vs SEER
260
240
220
200
180
160
140
120
100
80
Points
8
9
10
11
12
SEER
P1
P2
P3
P4
P5
P6

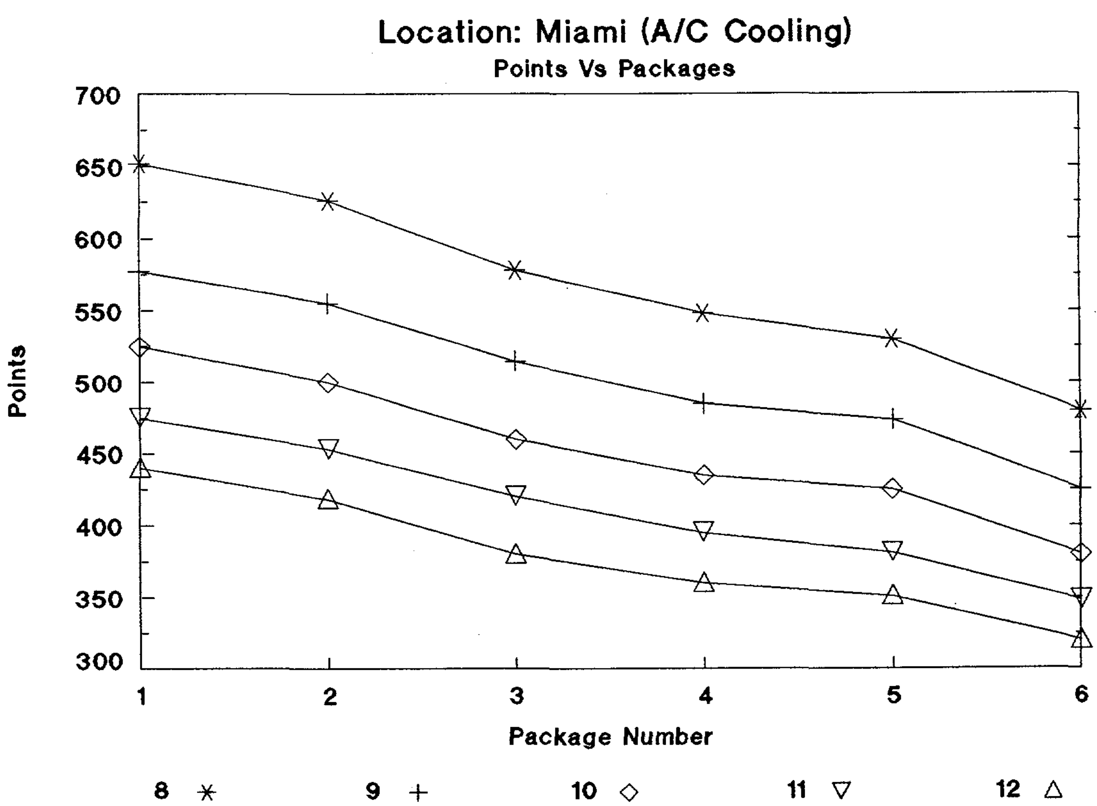
Table 2b. Miami

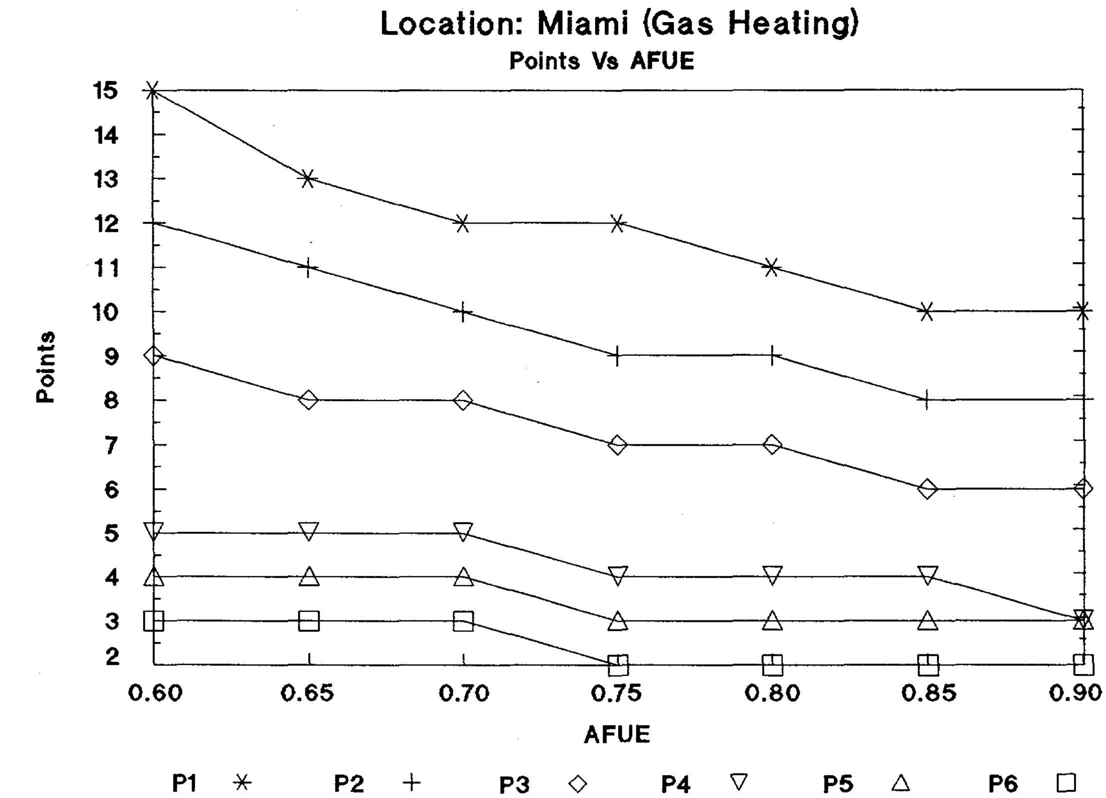
Date 03/26/87

Space Conditioning Points

	Gas Efficiency (AFUE)							A/C Efficiency (SEER)				
	0.60	0.65	0.70	0.75	0.80	0.85	0.90	8.00	9.00	10.00	11.00	12.00
Package 1	15	13	12	12	11	10	10	656	582	523	475	435
Package 2	12	11	10	9	9	8	8	626	555	499	453	415
Package 3	9	8	8	7	7	6	6	578	513	461	418	383
Package 4	5	5	5	4	4	4	3	544	483	434	394	361
Package 5	4	4	4	3	3	3	3	531	471	423	384	352
Package 6	3	3	3	2	2	2	2	480	426	382	347	318


Location: Miami (Gas Heating)
Points Vs Packages
Points
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
2
3
4
5
6
Package Number
0.60
0.65
0.70
0.75
0.80
0.85


Location: Miami (A/C Cooling)
Points Vs Packages
Points
700
650
600
550
500
450
400
350
300
1
2
3
4
5
6
Package Number
8
9
10
11
12


Location: Miami (Gas Heating)
Points Vs AFUE
Points
15
14
13
12
11
10
9
8
7
6
5
4
3
2
0.60
0.65
0.70
0.75
0.80
0.85
0.90
AFUE
P1
P2
P3
P4
P5
P6

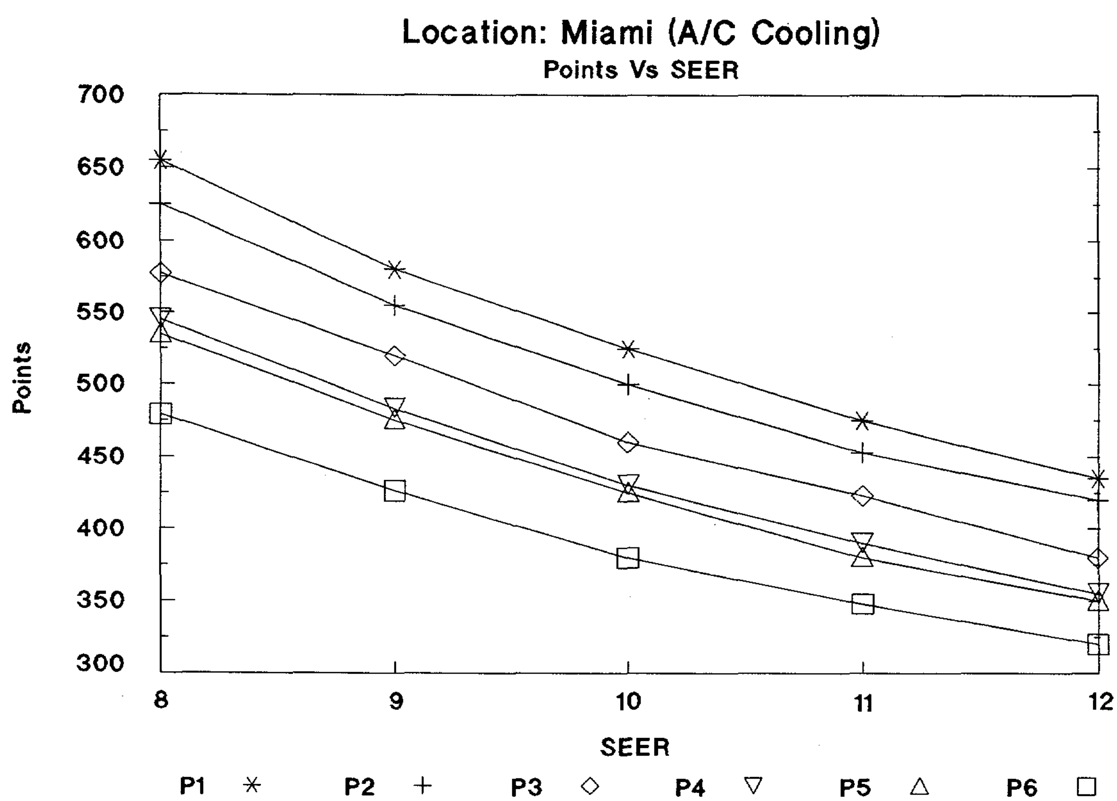
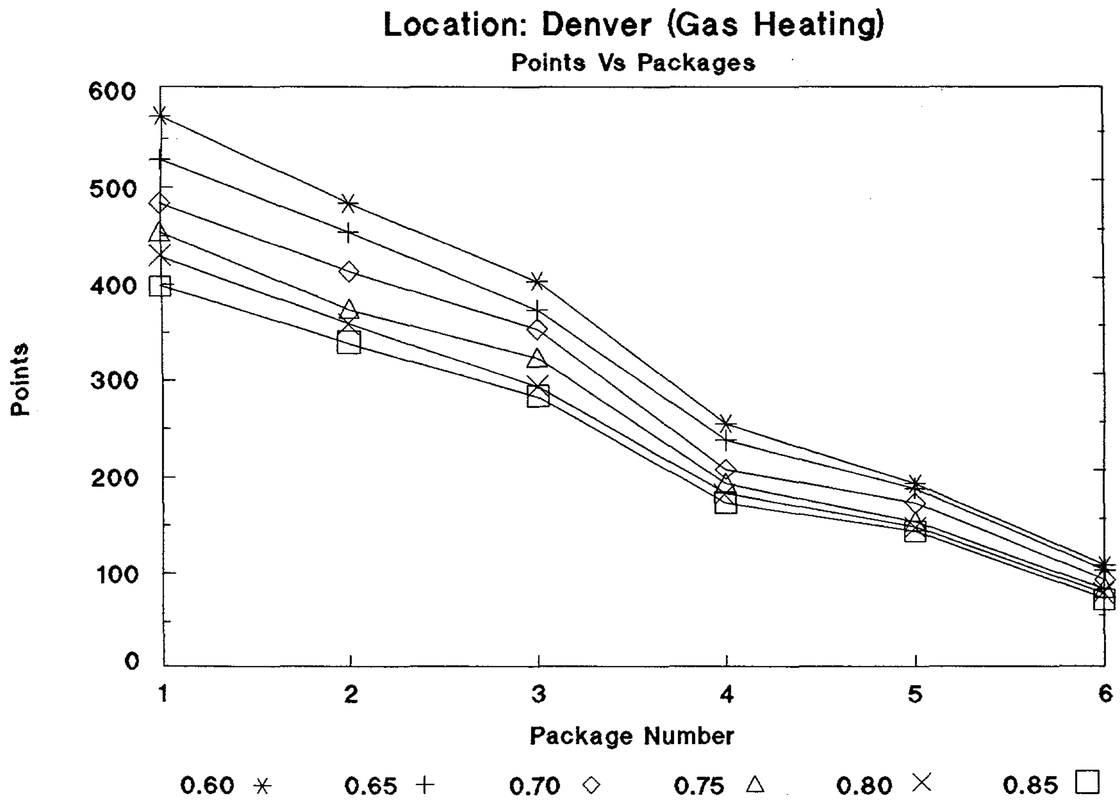

Location: Miami (A/C Cooling)
Points Vs SEER
Points
700
650
600
550
500
450
400
350
300
8
9
10
11
12
SEER
P1
P2
P3
P4
P5
P6

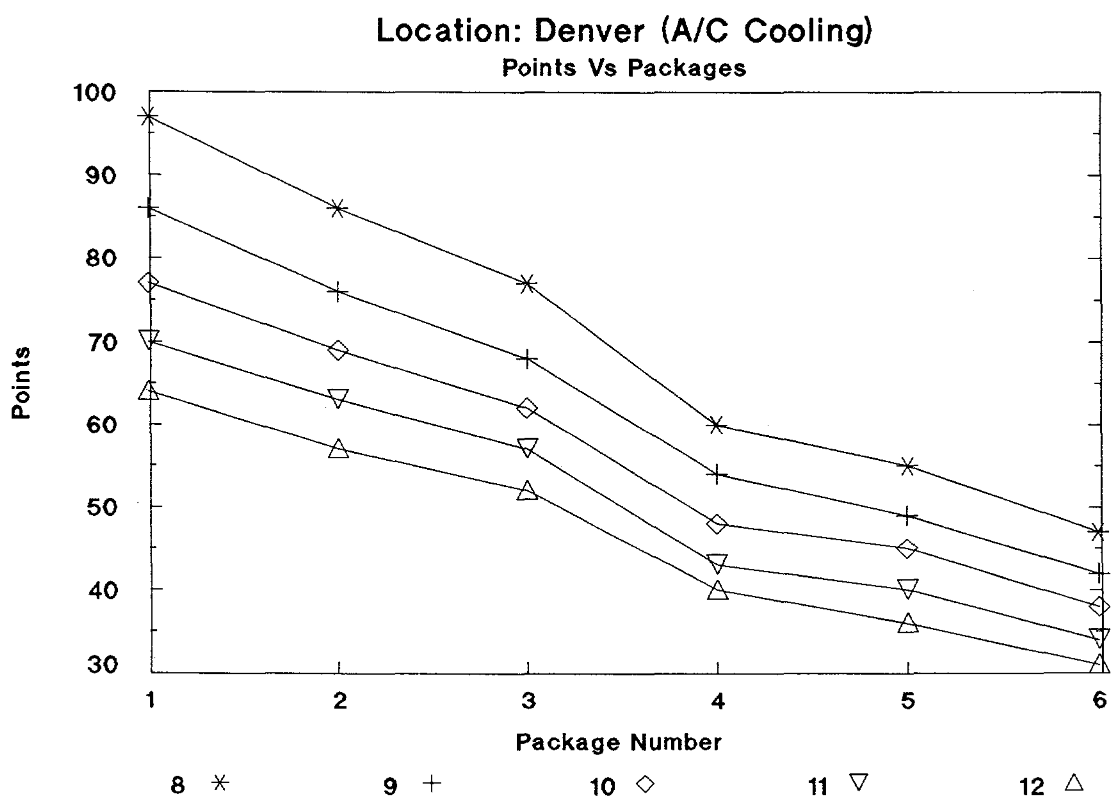
Table 2c. Denver

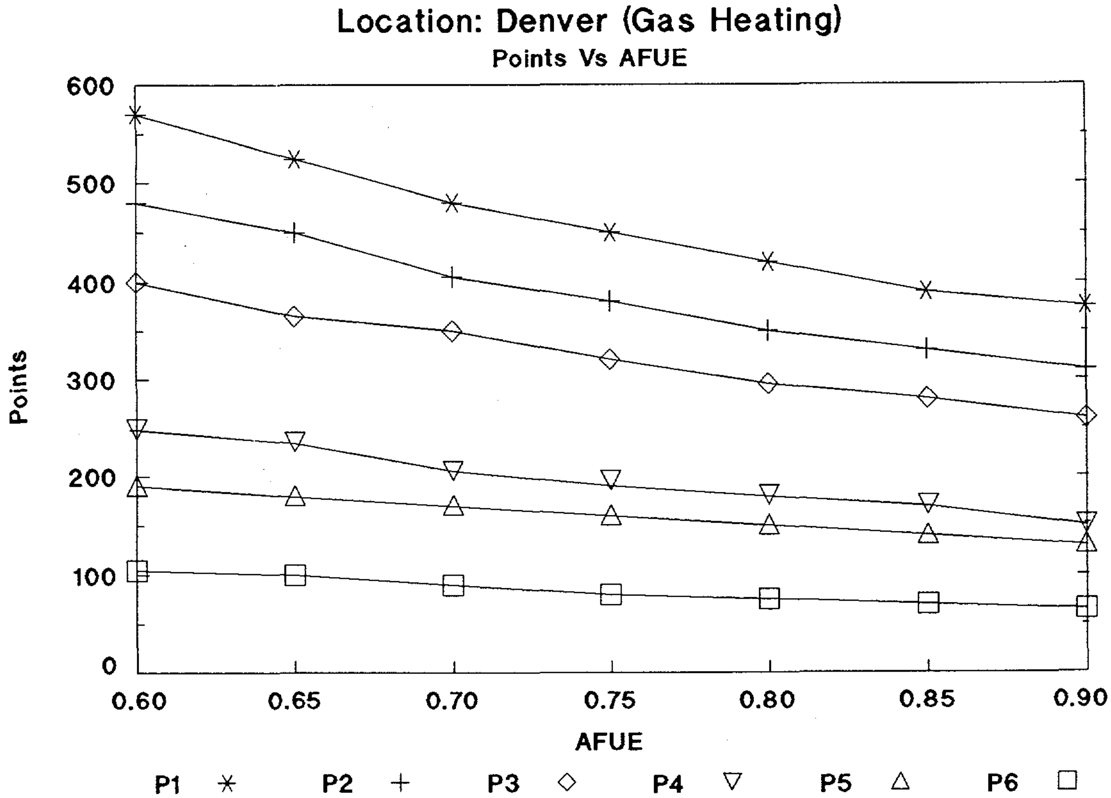
Date 03/25/87

Space Conditioning Points

	Gas Efficiency (AFUE)							A/C Efficiency (SEER)				
	0.60	0.65	0.70	0.75	0.80	0.85	0.90	8.00	9.00	10.00	11.00	12.00
Package 1	568	522	482	448	419	393	370	97	86	77	70	64
Package 2	480	441	408	379	354	332	313	86	76	69	62	57
Package 3	399	366	338	315	294	276	260	77	68	61	56	51
Package 4	243	223	206	192	179	168	158	60	53	48	43	40
Package 5	189	174	160	149	139	131	123	55	49	44	40	37
Package 6	107	98	91	84	79	74	70	47	42	38	34	31


Location: Denver (Gas Heating)
Points Vs Packages
Points
600
500
400
300
200
100
0
1
2
3
4
5
6
Package Number
0.60
0.65
0.70
0.75
0.80
0.85


Location: Denver (A/C Cooling)
Points Vs Packages
Points
100
90
80
70
60
50
40
30
1
2
3
4
5
6
Package Number
8
9
10
11
12


Location: Denver (Gas Heating)
Points Vs AFUE
Points
AFUE
0
100
200
300
400
500
600
0.60
0.65
0.70
0.75
0.80
0.85
0.90
P1
P2
P3
P4
P5
P6

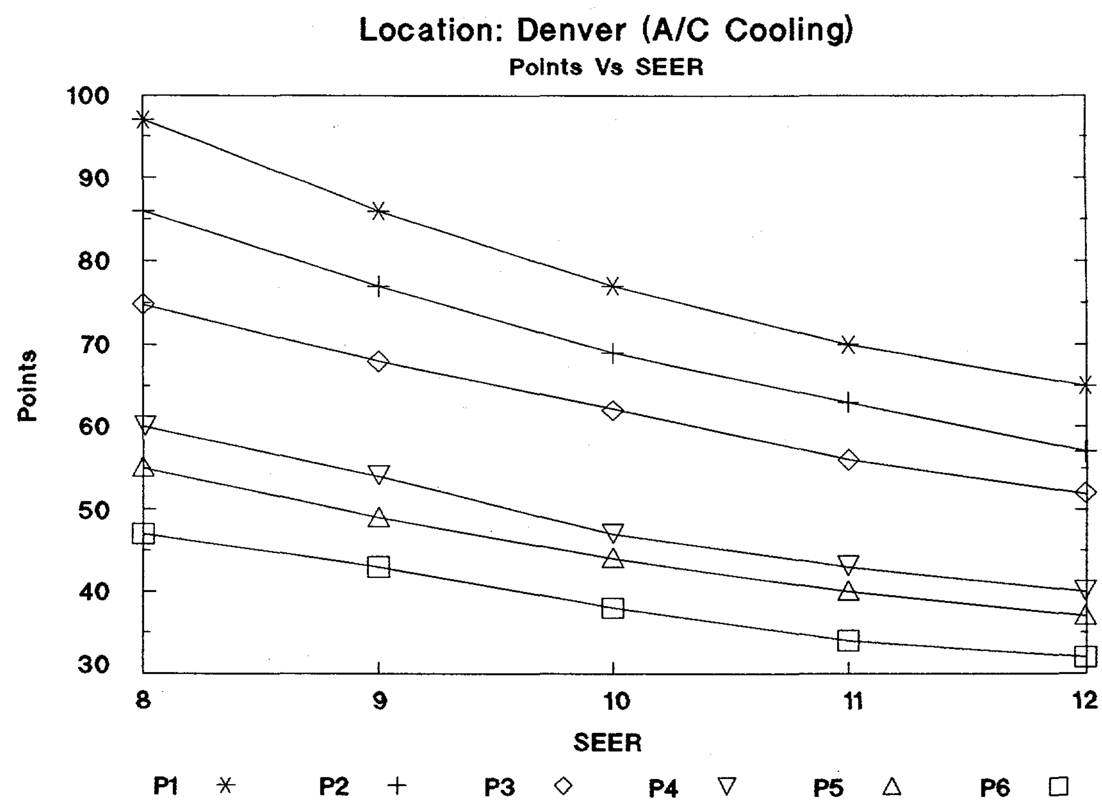
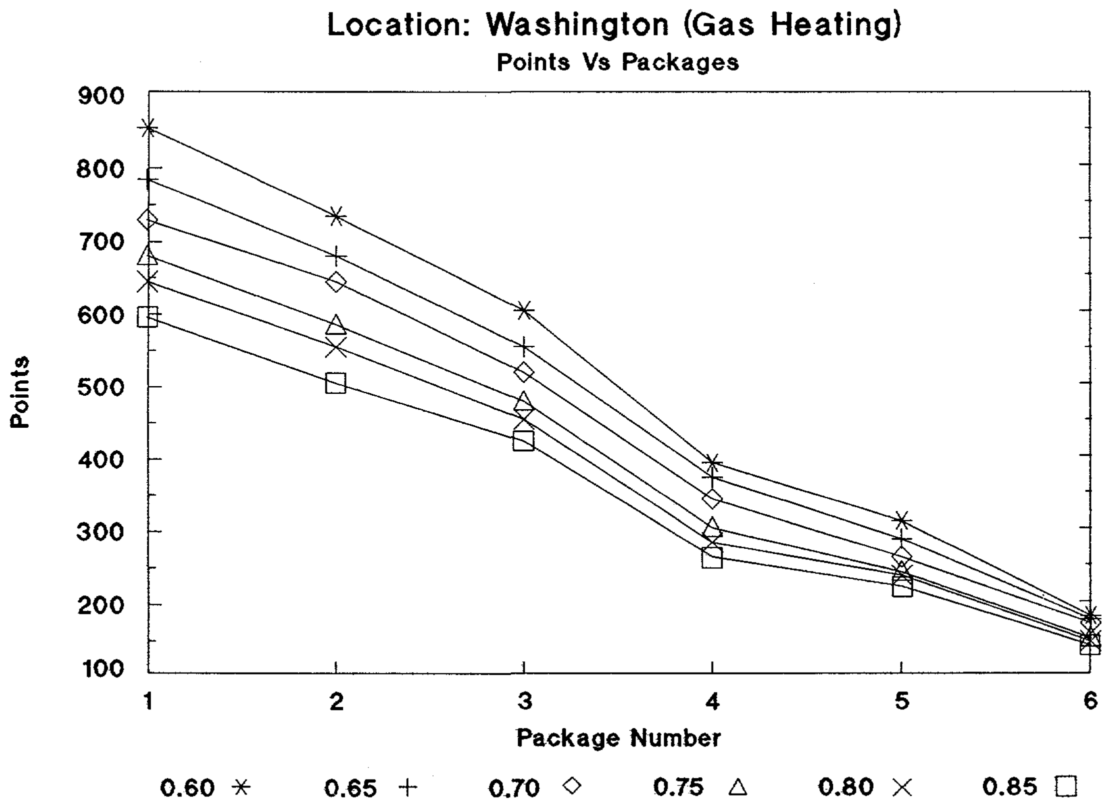

Location: Denver (A/C Cooling)
Points Vs SEER
Points
SEER
30
40
50
60
70
80
90
100
8
9
10
11
12
P1
P2
P3
P4
P5
P6

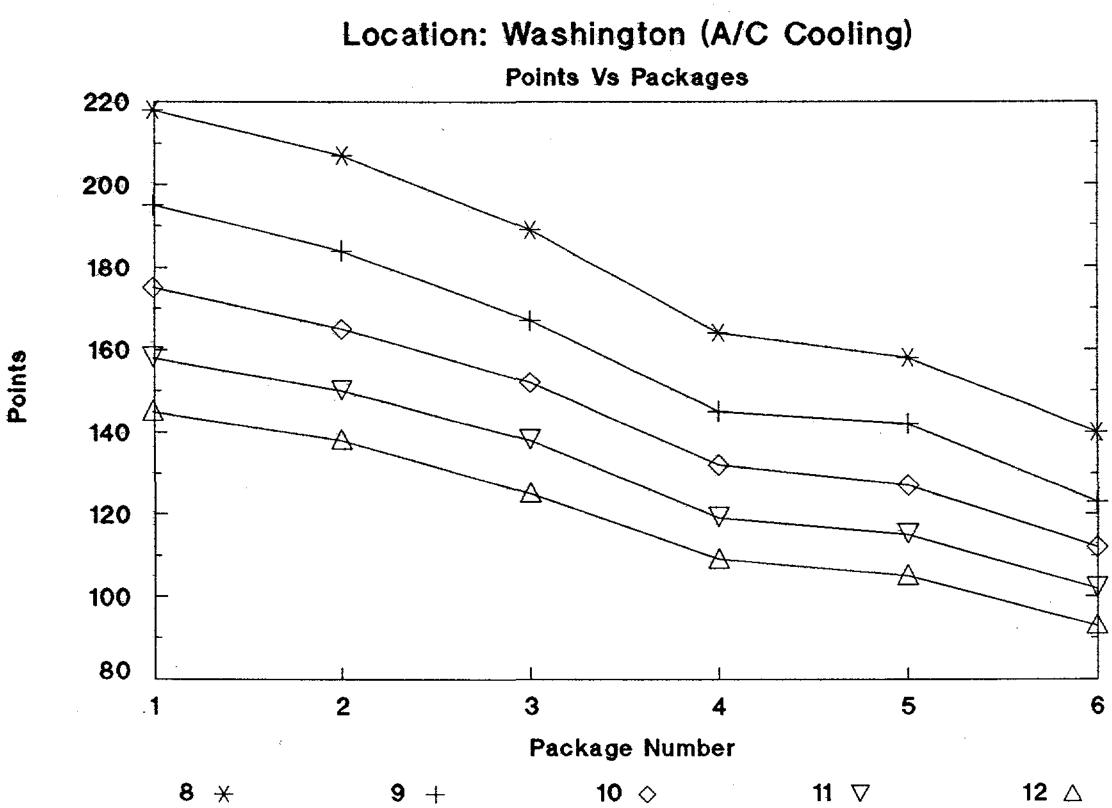
Table 2d. Washington DC

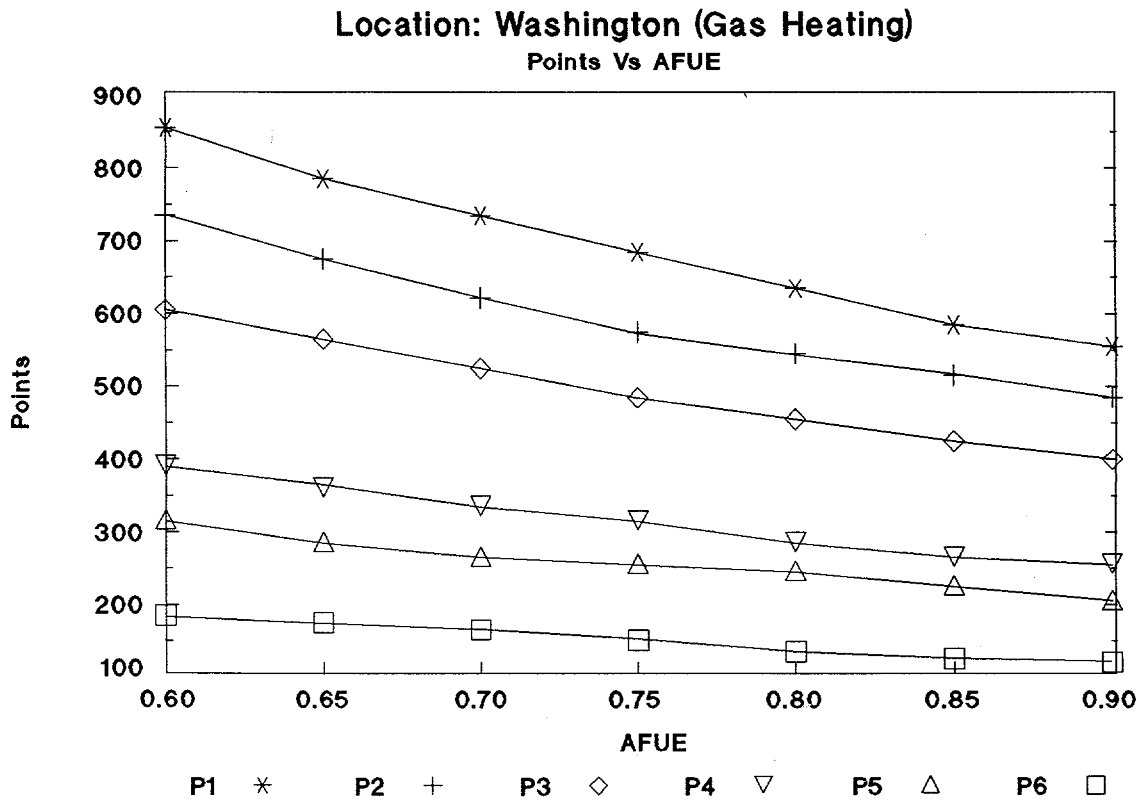
Date 03/26/87

Space Conditioning Points

	Gas Efficiency (AFUE)							A/C Efficiency (SEER)				
	0.60	0.65	0.70	0.75	0.80	0.85	0.90	8.00	9.00	10.00	11.00	12.00
Package 1	851	781	722	671	627	588	554	219	195	175	159	145
Package 2	728	669	618	575	537	504	474	207	184	165	150	137
Package 3	601	552	510	474	443	416	391	189	168	151	137	125
Package 4	386	355	328	305	285	267	252	164	145	131	119	109
Package 5	311	285	264	245	229	215	202	153	141	126	115	105
Package 6	179	165	152	142	132	124	117	140	124	112	102	93


Location: Washington (Gas Heating)
Points Vs Packages
Points
900
800
700
600
500
400
300
200
100
1
2
3
4
5
6
Package Number
0.60
0.65
0.70
0.75
0.80
0.85


Location: Washington (A/C Cooling)
Points Vs Packages
Points
220
200
180
160
140
120
100
80
1
2
3
4
5
6
Package Number
8
9
10
11
12


Location: Washington (Gas Heating)
Points Vs AFUE
900
800
700
600
500
400
300
200
100
Points
0.60
0.65
0.70
0.75
0.80
0.85
0.90
AFUE
P1
P2
P3
P4
P5
P6

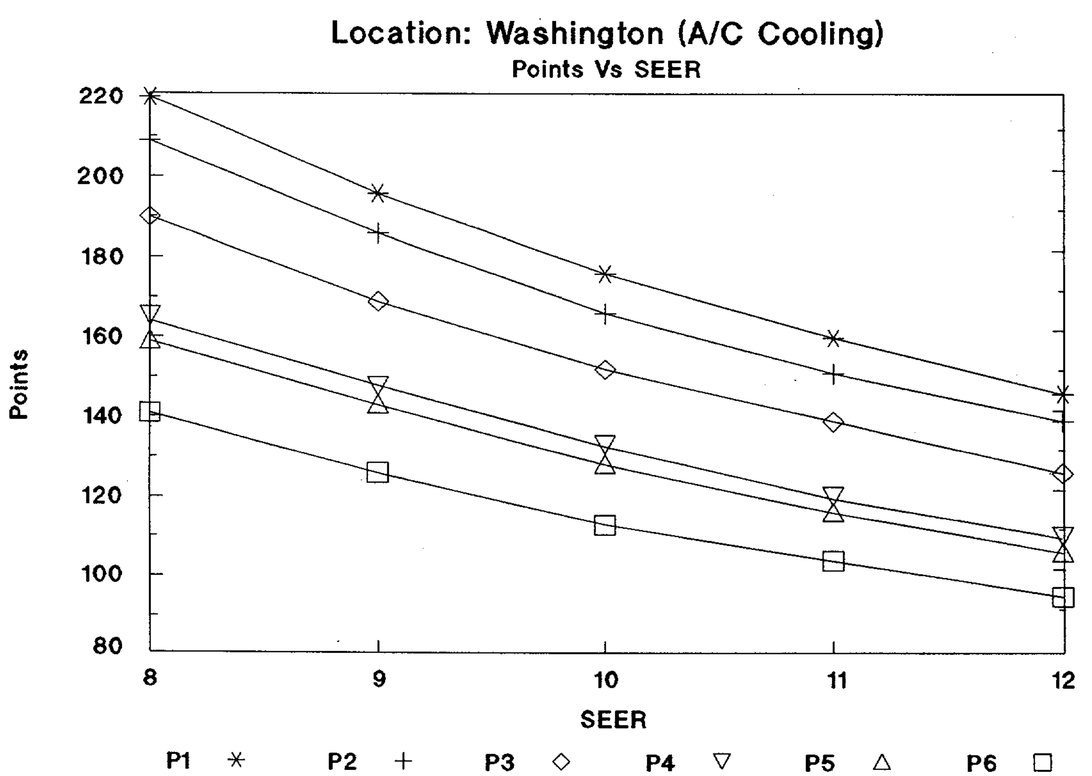

Location: Washington (A/C Cooling)
Points Vs SEER
220
200
180
160
140
120
100
80
Points
8
9
10
11
12
SEER
P1
P2
P3
P4
P5
P6

Table 2e. Minneapolis

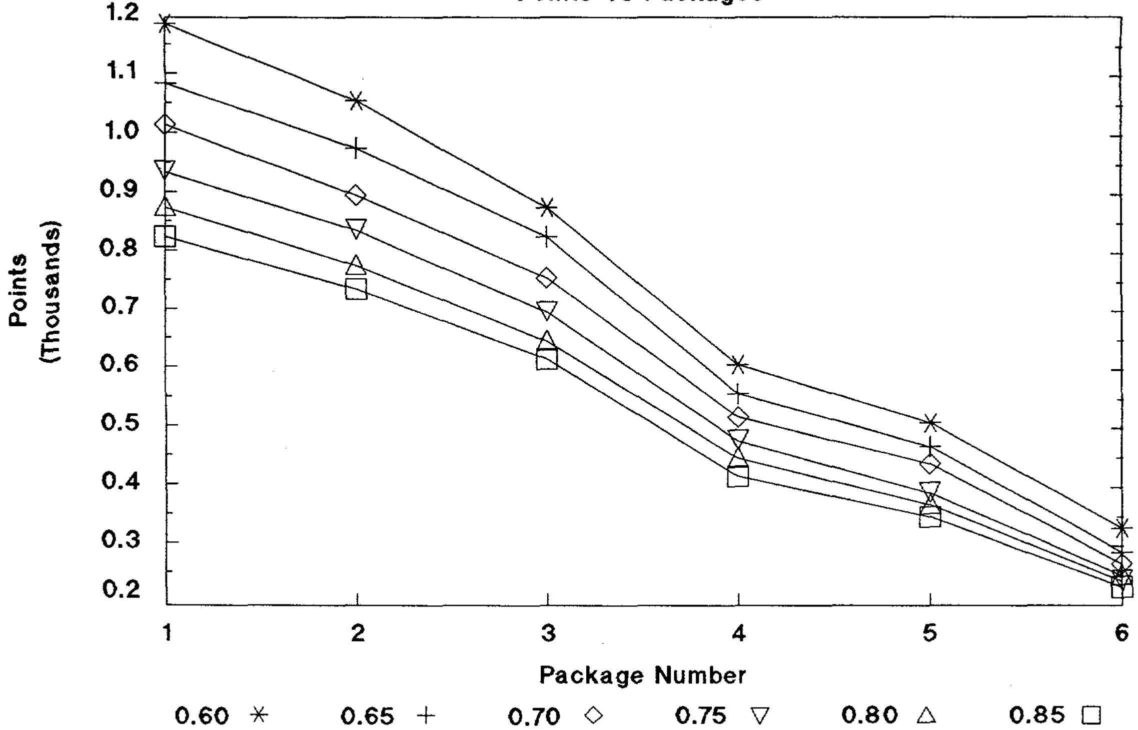
Date 03/26/87

Space Conditioning Points

	Gas Efficiency (AFUE)							A/C Efficiency (SEER)				
	0.60	0.65	0.70	0.75	0.80	0.85	0.90	8.00	9.00	10.00	11.00	12.00
Package 1	1191	1093	1010	939	877	823	775	109	97	87	79	73
Package 2	1060	973	899	836	781	733	690	103	92	82	75	69
Package 3	890	817	755	702	655	615	579	95	84	76	69	63
Package 4	607	558	515	479	448	420	396	80	71	63	58	53
Package 5	504	463	428	398	372	349	328	77	69	62	56	51
Package 6	322	295	273	254	237	222	210	68	61	54	49	45

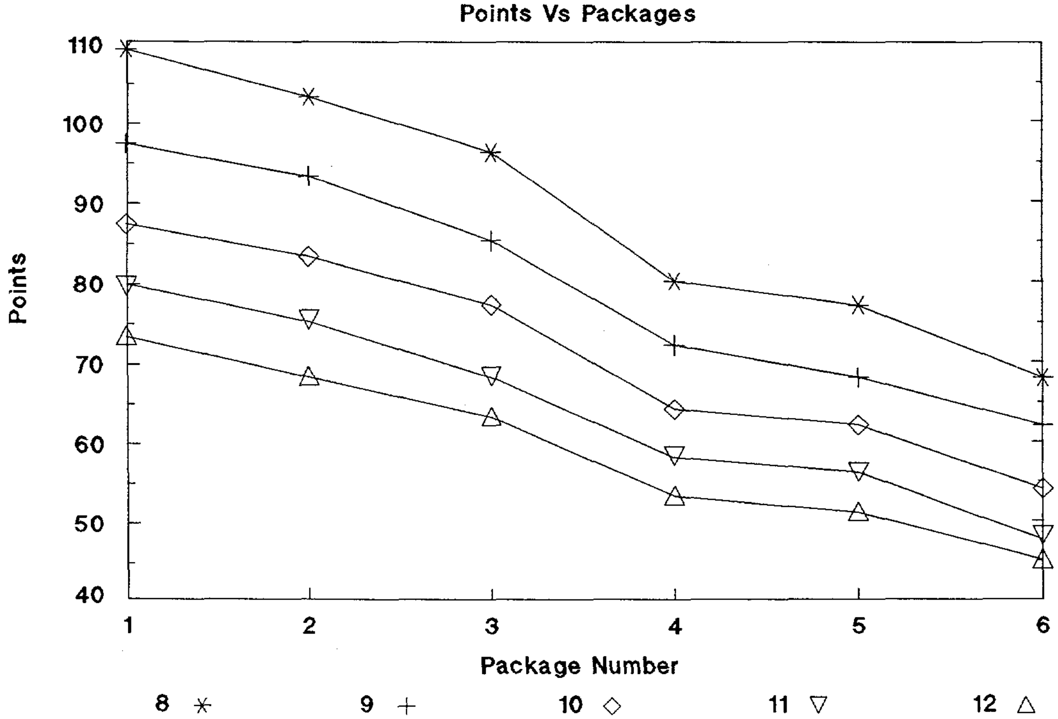
Location: Minneapolis (Gas Heating)

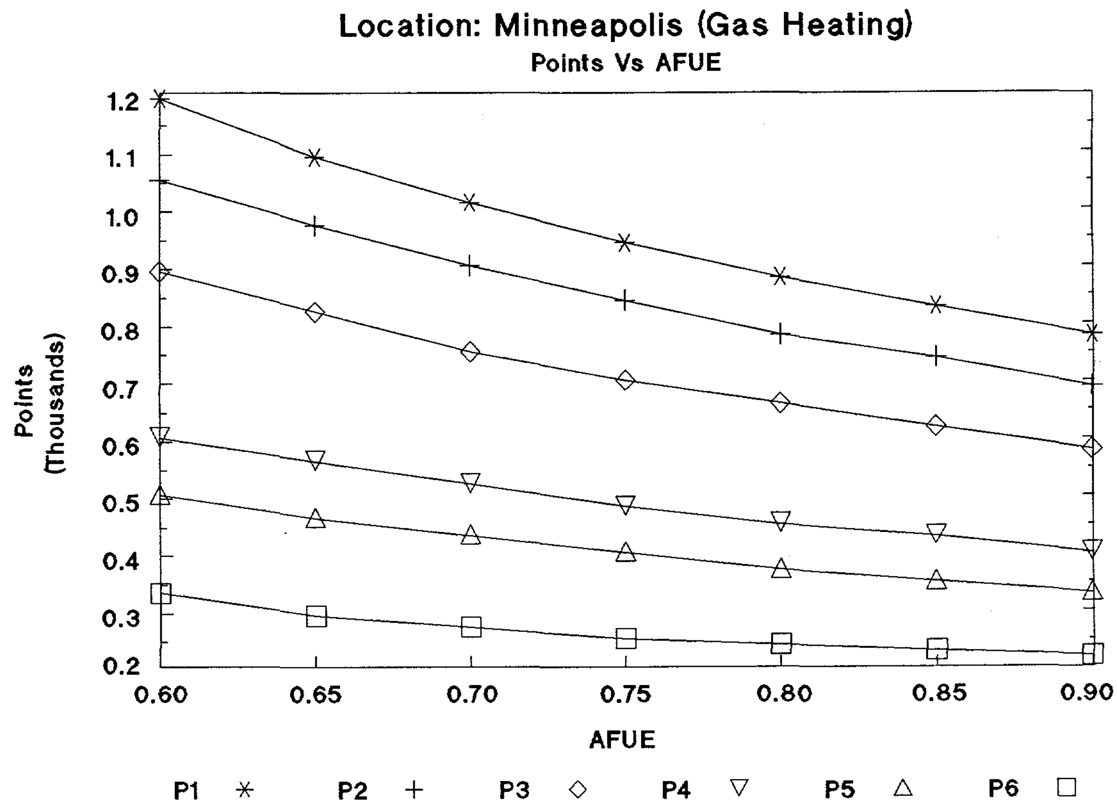
Points Vs Packages

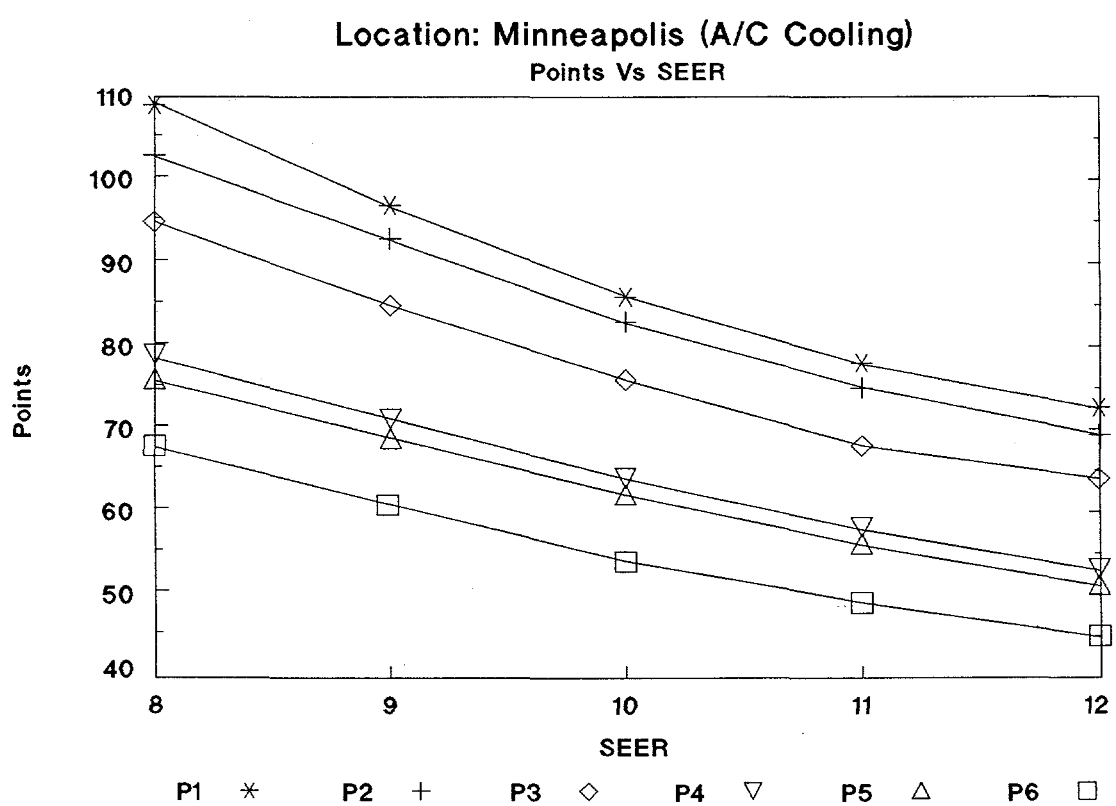


Location: Minneapolis (A/C Cooling)

Points Vs Packages




Location: Minneapolis (Gas Heating)
Points Vs AFUE
Points (Thousands)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.60
0.65
0.70
0.75
0.80
0.85
0.90
AFUE
P1
P2
P3
P4
P5
P6


Location: Minneapolis (A/C Cooling)
Points Vs SEER
Points
110
100
90
80
70
60
50
40
8
9
10
11
12
SEER
P1
P2
P3
P4
P5
P6

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #9-3

Title: PHILOSOPHY OF PERFORMANCE PATH

Statement of Issue: How should unusual or unique designs be handled in the standard?

Resolution: Performance path will be provided as an alternative compliance path. This will require side by side computer analysis of the proposed design and a complying prototype design.

Discussion:

The performance path is designed to allow compliance for designs which are atypical and do not easily fit under the packages or in the points path. For this reason, it must be the most flexible of the alternative paths allowing for a wide variety of ECMs and structure designs. At the same time, it must also assure equivalency in energy cost with the other paths so the energy target is used to represent the compliance standard.

Compliance through the performance path uses the prototype approach. This prototype represents a building in a specific generic group which meets the energy target when analyzed with the base set of assumptions including a standard set of schedules for appliance and lighting use, a standard schedule of occupancy and related heat gains, the basic HVAC system (the one with the same heating/cooling equipment and fuel as in the proposed design), the cost effective levels of those ECMs required in the energy target, and the same window areas and locations as used to generate the energy target. In fact, the prototype is precisely the model used to generate the energy target for a specific generic group.

Under the performance path, a user would comply a design as follows:

1. Utilizing the prototype approach to compliance, the reference dwelling unit for the appropriate category would be selected to compare with the proposed design.

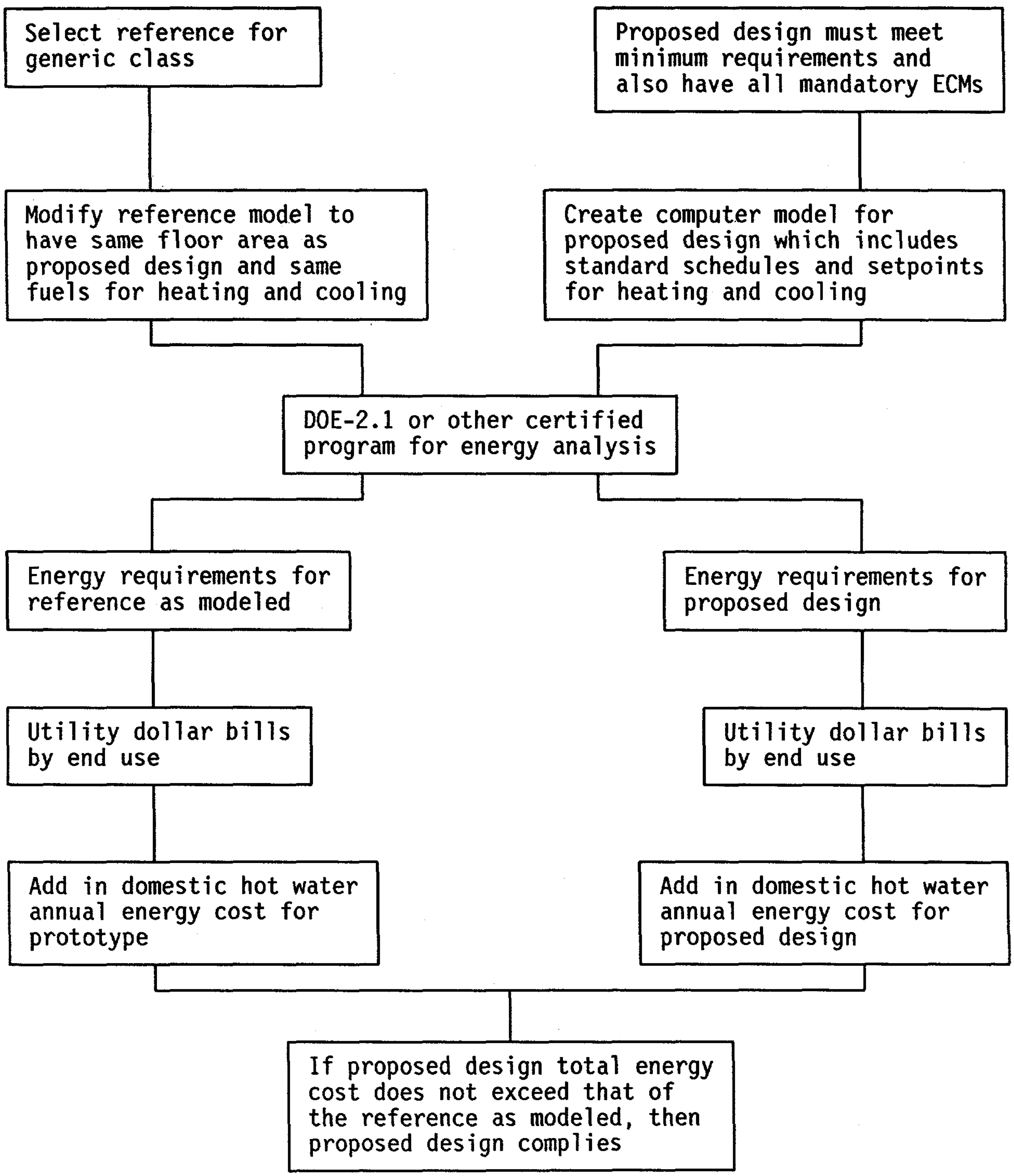
2. The reference would be modified to have the same floor area as the proposed design (the aspect ratio of the reference and percentage window area would remain constant) and use the same fuels for heating and cooling as the proposed design intends to use. For example, if the proposed design uses electricity for heating and for cooling, then the prototype would use electricity for heating and for cooling

in the form of the base system (same energy type and most similar to the design selected) selected for each fuel type. (For heating with electricity, the base system would be a heat pump with the minimum efficiency required under the standard.)

3. The model of the proposed design will be analyzed with the standard schedules matching those used in the reference design as well as the thermostat set points and schedule used with the reference. In addition, the design will also have to meet the minimum insulation and infiltration requirements and any mandatory requirements specified for the generic class of structure.

4. Compliance is demonstrated through a certified computer program energy analysis (see position paper #9-4 on Certification of Analysis Tools) of both the reference and the proposed designs. As long as the annual energy cost for the proposed design is less than that of the reference as modeled, then the design complies.

Flowchart of Compliance by Performance Path



ASHRAE SPECIAL PROJECT 53 POSITION PAPER #9-4

Title: CERTIFICATION OF ANALYSIS TOOLS

Statement of Issue: What are acceptable energy analysis tools or computer programs, and how do we specify the process to be used in certifying them?

Resolution: A suggested procedure is provided, but cannot be included in the standard because ASHRAE cannot certify computer programs.

Discussion:

Since DOE-2.1 is a public domain tool, it is possible to require that it be used for all analyses. However, though there is now a relatively inexpensive microcomputer version of DOE-2.1, the required use of DOE-2.1 may be restrictive enough to eliminate many of those who wish to use the performance path for compliance. As the intent of the performance path is to allow compliance of designs which do not fit under other paths, it is important that we not make any requirements which unduly restrict its use. To allow other programs, the method of certification must provide assurance that compliance is consistent throughout the programs (i.e. equality within energy analysis tools). SP-53 and ASHRAE cannot directly certify computer programs, but SP-53 does have the responsibility for identifying the requirements of such a certification process. It is suggested that we require the analysis tool to use calculation techniques as specified in the ASHRAE Handbook, Fundamentals Volume. The tool should also be capable of handling shading, thermal mass, and equipment modeling and should be appropriate to the building type and location to be analyzed. However, as comparisons are made between the reference design and a candidate design, it is important that the ECMs be handled in a consistent manner between the designs. This comparison makes it less important that the analysis tool be absolutely accurate. The question of certification and demonstration of compliance under a performance path is the major obstacle towards acceptance of a performance path. It is important to maintain flexibility and still be assured that complying designs are actually equivalent within the criteria specified by SP-53 in the process of developing the Standard.

ASHRAE SPECIAL PROJECT 53 POSITION PAPER #9-5

Title: SOLAR HOT WATER IN PERFORMANCE PATH

Statement of Issue: How is solar hot water to be handled in the performance path?

Resolution: It is suggested that solar hot water not be implicitly included in the performance path, but that for all paths, hot water and solar be handled in the last step of compliance.

Discussion:

Inclusion of solar hot water in the performance path presents a problem, as most computer programs used to analyze designs do not adequately handle solar hot water. Inclusion within the performance path would restrict the number of certified programs to a very few and significantly reduce the flexibility of this approach. Also, since Solar DHW is very dependent upon both location and design, it is difficult to predict performance without knowing both of these parameters. Two possibilities for handling this problem are available:

- Assign standard savings for Solar DHW which all designs are assumed to achieve. This could be done for each location based on solar availability.
- Create a standard design which would then be analyzed to provide the savings for all three approaches: packages, points, and performance.

Effectively, both possibilities reduce to the same set of 45 numbers (one for each standard location). The major problem with trying to incorporate a set of numbers into the performance approach is that the result of the performance path is not an energy dollar but a side by side comparison of the energy requirements by end use of the prototype and a proposed design. Unless there is a translation into dollars, there is no room in the path for trade-offs among ECMs which is sought by Solar DHW.

The suggested resolution to this problem is to treat the performance approach in a manner similar to the points approach. Use the computer model to calculate energy requirements and then enter these into a final compliance table. The final table would convert the heating and cooling energies into appropriate energy dollars, then add in the DHW energy costs. This table would be identical for both the points and performance paths. In this way it is possible to allow trade-offs between space conditioning measures and domestic hot water. This resolution applies to all demonstrations of compliance with the performance path including those with ordinary DHW systems.

There are still two issues which need to be resolved with regards to DHW. First, is the setting of a maximum savings allowable from solar or any other alternative DHW system. It is suggested that this number be set at 50% to provide a conservative estimate of savings which accurately reflects the majority of available systems. This value shall be used for all three paths. This will eliminate the problem of allowing too much envelope or equipment trade-off for a possible uncertain or shorter lifetime ECM. The second issue relates to fuel switching between the generic model and the proposed design. We have specified identical fuels for each end use. However, if solar DHW is proposed, then electric backup could be beneficial. This is a problem if the prototype uses gas DHW. It is suggested that the space heating fuel be used as the fuel type for both the generic model and the candidate design. This eliminates the problem of different fuel types and phantom savings which might result from such fuel switching.