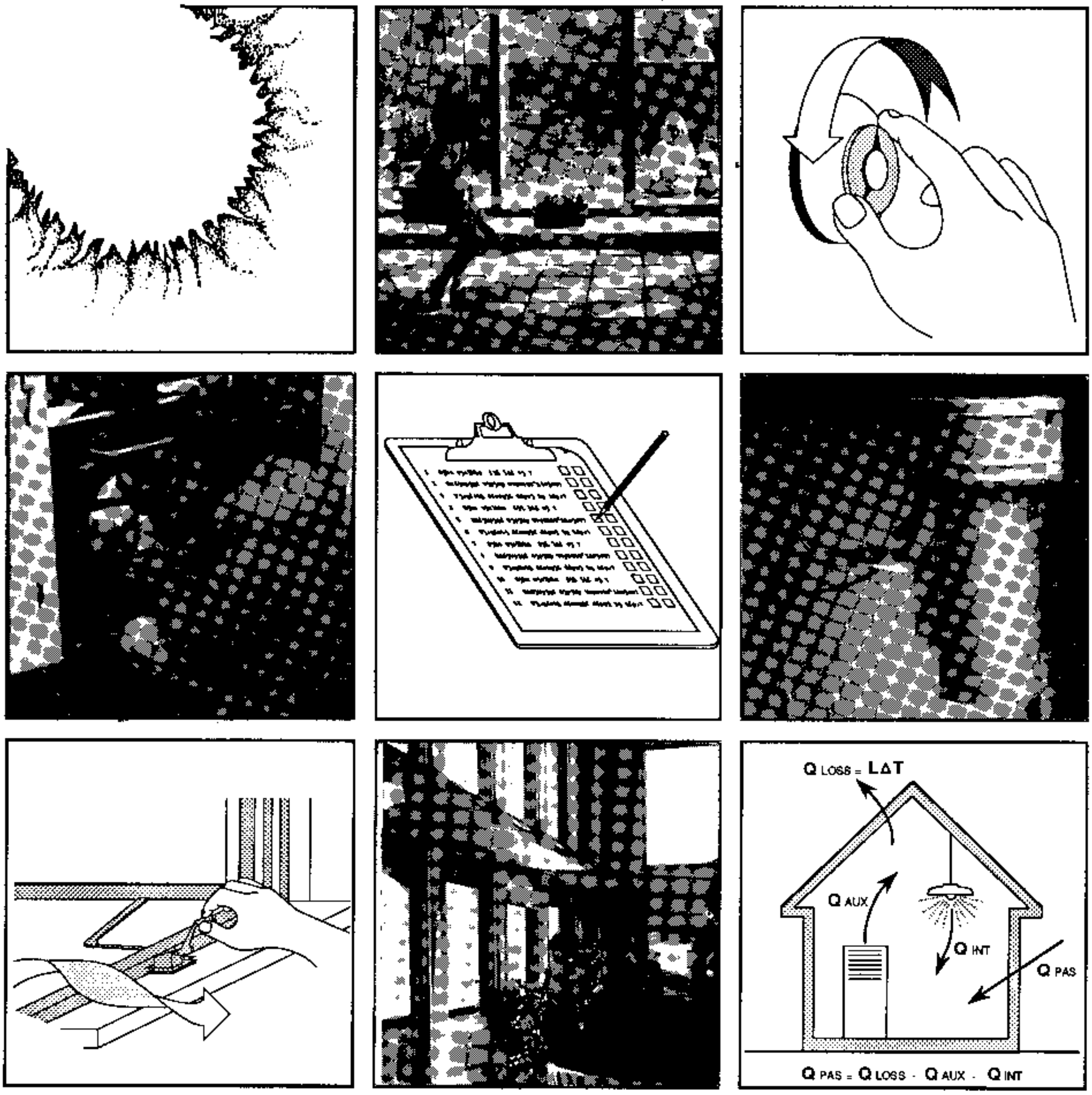
PASSIVE AND HYBRID SOLAR LOW ENERGY BUILDINGS

POST-CONSTRUCTION ACTIVITIES

8

DESIGN INFORMATION BOOKLET NUMBER EIGHT

AUGUST 1989



INTERNATIONAL ENERGY AGENCY: SOLAR HEATING AND COOLING PROGRAM

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AUGUST 1989

Sheila Blum
International Planning Associates, Inc.
Beltsville, Maryland

Michael J. Holtz and Ralph R.Tavino
Architectural Energy Corporation
Boulder, Colorado

INTERNATIONAL ENERGY AGENCY: SOLAR HEATING AND COOLING PROGRAM, TASK VIII

FOREWORD

The International Energy Agency (IEA), headquartered in Paris, France, was formed in November 1974 to establish cooperation among a number of industrialized countries in the vital area of energy policy. It is an autonomous body within the framework of the Organization for Economic Cooperation and Development. Twenty-one countries are presently members, with the Commission of the European Communities participating under a special arrangement.

One element of the IEA's program involves cooperation in the research and development of alternative energy resources in order to reduce excessive dependence on oil. A number of new and improved energy technologies that have the potential of making significant contributions to global energy needs were identified for collaborative efforts. Solar heating and cooling was one of the technologies selected for joint activities. Cooperative research is conducted under terms of a formal Implementing Agreement signed by the participating countries. One of the collaborative projects, Task VIII, concerns passive and hybrid solar, low energy buildings.

The goal of Task VIII is to accelerate the technical understanding and marketplace availability of energy efficient, passive solar homes. Fourteen countries have participated in the research - Austria, Belgium, Canada, Denmark, Federal Republic of Germany, Italy, Netherlands, New Zealand, Norway, Spain, Switzerland, Sweden, United Kingdom and United States.

The knowledge gained during this collaboration has been assembled in a series of eight booklets. The Design Information Booklets in the series are listed and described on the opposite page. Information on purchasing these booklets can be obtained by contacting the following organizations or by ordering directly from the U.S. Government Printing Office (GPO):

Austria
Osterreichisches
Forschungzentrum Seibersdorf
A - 2444 Seibersdorf

Belgium
Science Policy Office
Rue de la Science 8
B - 1040 Brussels

Canada
Solar Energy Development Program
Energy, Mines and Resources
460 O'Connor Street
Ottowa, Ontario K1A OE4

Denmark
Thermal Insulation Laboratory
Technical University of Denmark
Building 118
DK - 2800 Lyngby

Germany
Projektleitung Biologie, Ökologie und Energie
KFA Jülich
Postfach 1913
D - 5170 Jülich

Italy
Consiglio Nazionale Ricerche
Progetto Finalizzato Energetica
Via Nizza 128
I - 00198 Roma

Netherlands
Management Office for Energy Research (PEO)
P.O. Box 8242
NL - 3503 - RE Utrecht

New Zealand
School of Architecture
Victoria University of Wellington
Private Bag
Wellington 1

Norway
A/S Miljoplan
Kjorboveien 23
N - 1300 Sandvika

Spain
IER - CIEMAT
Avda Complutense 22
28040 Madrid

Sweden
Svensk Byggtjänst,
Litteratutjänst
Box 7853,
103 99 Stockholm

Switzerland
Federal Office of Energy
CH - 3003 Berne

United Kingdom
Renewable Energy Enquiries Bureau
Energy Technology Support Unit
Harwell Laboratory, Building 156
Oxfordshire OX 11 ORA

United States
Technical Inquiry Service
Solar Energy Research Institute
1617 Cole Boulevard
Golden, Colorado 80401

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The U.S. Department of Energy (DOE) is the Operating Agent of IEA Task VIII: Passive and Hybrid Solar Low Energy Buildings. Michael J. Holtz of Architectural Energy Corporation, Boulder, Colorado, serves as Task Chairman on DOE's behalf.

Booklet No. 1 Energy Design Principles in Buildings

This Booklet is essentially a primer of heat transfer in buildings. Fundamental heat transfer concepts and terminology are defined, followed by a discussion of heating and cooling strategies and principles for passive and hybrid solar buildings. It is written in non-technical language for the designer or builder not familiar with general heat transfer principles in buildings.

Booklet No. 2 Design Context

Booklet number 2 defines, in a checklist format, the issues that are unique to energy conserving, passive solar design that must be considered early in the design process. Issues discussed include site and climate analysis, building organization and design, building system options, space conditioning options, user influence and building codes and zoning ordinances.

Booklet No. 3 Design Guidelines: An International Summary

Passive solar and energy conservation design guidelines have been developed by each participating country. These guidelines are presented in national design guidelines booklets. Booklet number 3, Design Guidelines: An International Summary, summarizes the major findings and patterns of performance observed from the national passive solar and energy conservation guidelines.

Booklet No. 4 Design Tool Selection And Use

This Booklet addresses the characteristics desirable in a design tool and a means to select one or more for use. The selection process is organized around the design process; what design questions are being addressed, what information is available, what output or result from a design tool for which one is looking. A checklist is provided to assist in design tool selection. The use of benchmark test cases developed from detailed building energy analysis simulations is presented as a means to evaluate simplified design tools.

Booklet No. 5 Construction Issues

Construction problems unique to the use of passive and hybrid solar features are defined in this booklet as well as several proven solutions. Due to the unique construction technology in each country, representative construction details are provided. The intent is to define where construction detailing is crucial to the performance of low energy, passive solar homes and provide some ideas on how these detailing problems can be solved for a range of construction technology.

Booklet No. 6 Passive Solar Homes: Case Studies

This Booklet describes the passive and hybrid solar houses designed, constructed and monitored under the [lEA Task VIII project, as a means of showing the architectural impact of energy conservation and passive/ hybrid solar features. This booklet reinforces the idea that good energy design is also good architecture and is cost effective. Each of the passive solar houses is presented as a case study on the design, construction and performance results.

Booklet No. 7 Design Language

Booklet number 7 is aimed at designers, architects and educators. It defines an approach to generating whole building solutions based on climate analysis and design context analysis. It also addresses architectural typologies based on climatic/energy principles. This booklet forms a general, universal companion to Booklet Number 3, Design Guidelines.

Booklet No. 8 Post-Construction Activities

Post Construction Activities defines issues to be considered once the project is constructed and occupied. It addresses those elements of the passive solar building that are unique and may require special attention by the occupants. Performance evaluation of the home in terms of energy performance, comfort and occupant satisfaction is also addressed as a means of providing information back to the designer on how well the project is performing.

ACKNOWLEDGEMENTS

The preparation of this document has been a collaboration between Ms. Sheila Blum of International Planning Associates and Messrs. Michael Holtz and Ralph Tavino of Architectural Energy Corporation. A portion of this document is based on an earlier draft prepared by Ian Cooper of Eclipse Research Consultants and Ron Brewer of the U.K. Building Research Establishment. Their initial ideas and text are gratefully acknowledged. These individuals wish to acknowledge the helpful comments and suggestions provided by the Subtask C participants and the authors of other Booklets in the Design Information Booklet series including Ms. Anne Minne, Mr. Gunter Lohnert, Mr. Hans Kok, and Mr. Sergio Los. Also, the authors acknowledge the assistance of Chris Mack, Tracy Ashleigh, and Linda Ross of Architectural Energy Corporation in preparing the camera ready copy and in proofreading the final text.

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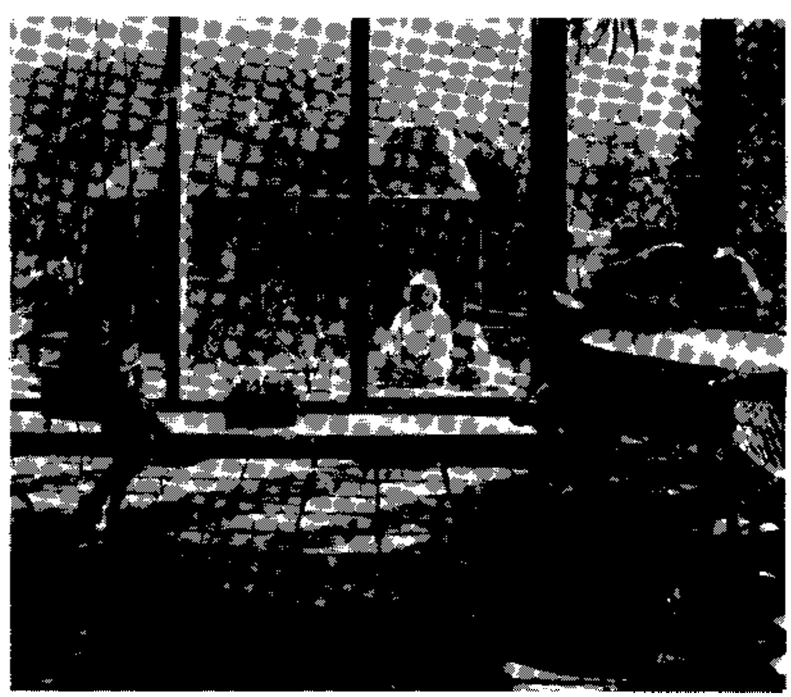


Post-Construction Activities discusses actions to be undertaken by home designers or builders following construction and occupancy of passive solar residences. These actions can help ensure that the home's energy systems perform as intended and can provide important information which can aid the designer in improving future designs.

The booklet focuses on the role and importance of building occupants in realizing the energy-saving potential of their passive solar home, including what information should be made available by the home designer or builder to the occupants, and how to evaluate occupant satisfaction. It also deals with thermal performance evaluation, a process which allows a designer to check design assumptions and expectations against actual performance and use after a passive solar house is occupied.

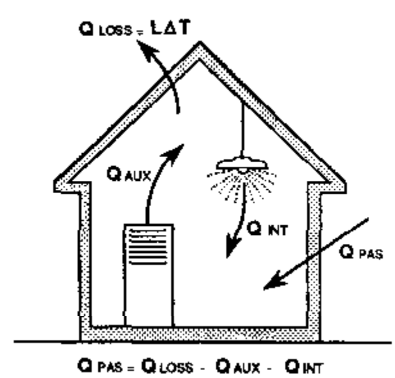
Specifically, the booklet recommends the following three post-construction activities:

INFORMATION FOR OCCUPANTS: Providing information to help occupants understand and properly use their passive solar home.

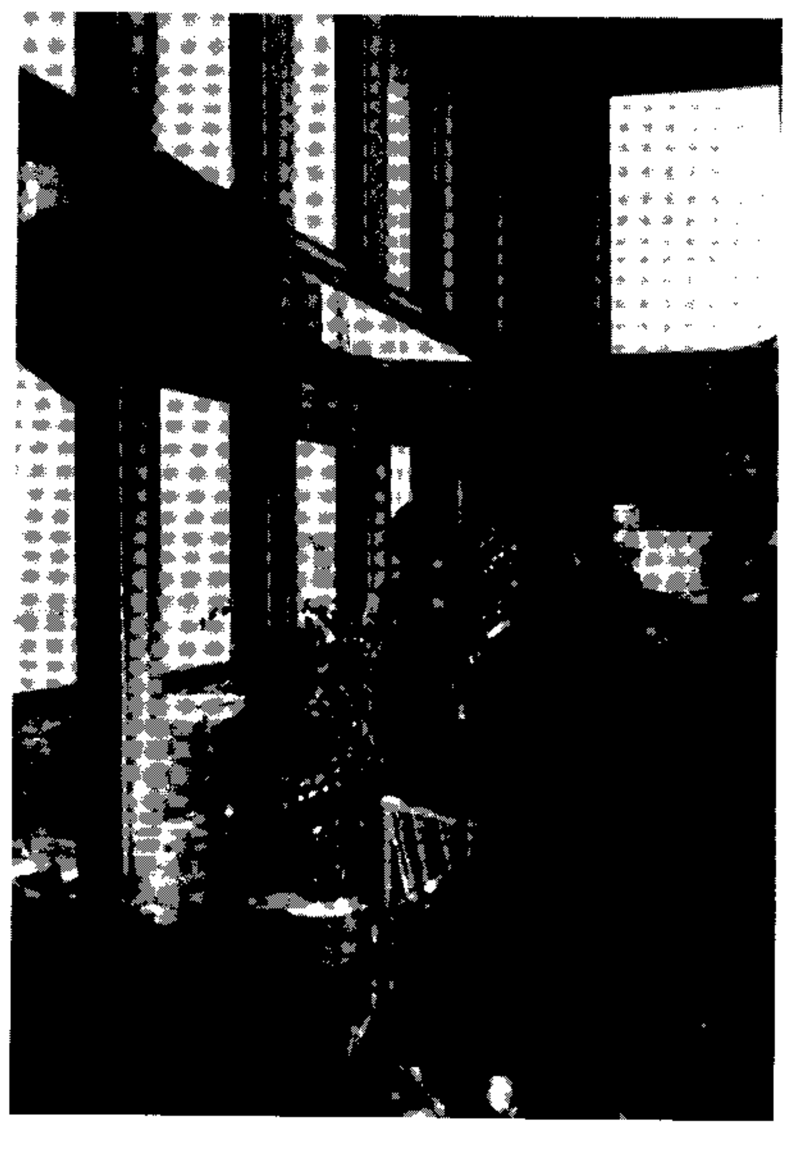
EVALUATION OF OCCUPANT SATISFACTION: Determining the satisfaction of the occupants with the energy performance and passive solar features of their home.

THERMAL PERFORMANCE EVALUATION: Evaluating the energy performance of passive solar houses using simple, low-cost monitoring procedures.

Providing the occupant with information on the house's passive solar features and how they are intended to work can reduce the possible negative impact of occupant behavior, thus improving the energy performance of the building and enhancing client satisfaction. Evaluations of occupant satisfaction and thermal performance provide valuable insights and ideas which can be applied to future designs.



It is recognized that designers may be inclined to consider the project finished when construction has been completed or when the occupant moves in. However, a modest investment of time, effort and money by the home designer or builder to perform these post-construction activities will be amply returned in the form of satisfied occupants and improved future project designs.



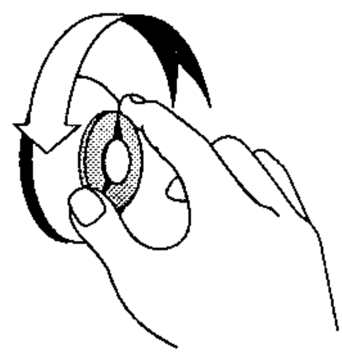
The strong but often subtle relationship between occupant behavior and how energy is used in a building has been well-documented. Virtually every major study conducted on occupant behavior, as well as the real-world experience of passive solar designers, indicate that the occupants' effect on the energy performance of the house cannot and should not be underestimated.

2.1 THE IMPORTANCE OF OCCUPANT BEHAVIOR

Studies show that identically designed and constructed houses adjacent to each other can have distinctly different patterns of energy use as a result of the requirements and preferences of the people who live in them.

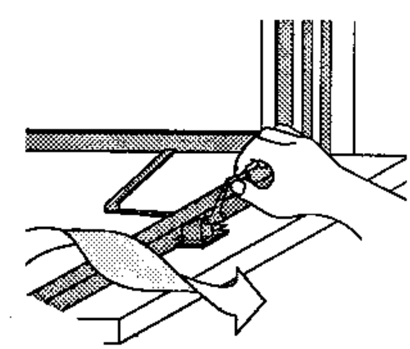
In one of the earliest studies (1978) conducted in the United States, researchers at Princeton University's Center for Environmental Studies monitored gas consumption in nine identical three-bedroom townhouses in suburban Twin Rivers, New Jersey (1). They found that one home consumed twice as much as another over a two-year period, due entirely to different occupant behavior. The connection was confirmed when a change of owner caused one townhouse to shift from the most energy-intensive to the least.

When scientists from Carnegie-Mellon University surveyed energy use patterns of low and moderate income households in Pittsburgh, Pennsylvania, USA, they found that occupant behavior had a greater impact on home energy consumption than greatly improved thermal integrity and sun-tempering, and that occupants with "energy-saving" behavior would use less energy even in a conventional house than occupants with "energy-wasting" behavior living in a house designed for maximum energy-efficiency (2).



The relation between the occupant and the energy performance of a passive solar house has always been a particularly close one. More attention has to be given to occupant effects in a passive solar house than in a "traditional" one because passive solar features, upon which the energy performance is based, can be subject to non-use, mis-use and abuse by the occupants.

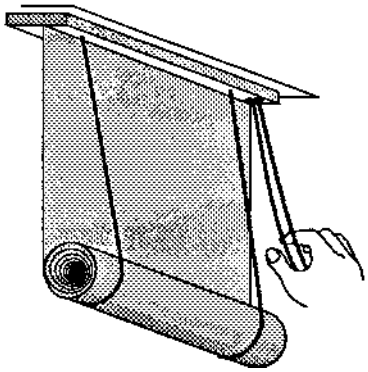
A report by the New Zealand Energy Research and Development Committee concluded that occupants can affect five operational factors of passive solar systems (3). Quoting directly from the report, these are:



Setting indoor temperatures (evident from data)

B. General ventilation levels (hypothesized from data)

C. Ventilation of the clothes dryer (hypothesized from data)



D. Positions of the north (sun facing) window curtains in the day time (hypothesized from data)

E. Positions of all the curtains in the night time (self-evident)

Nevertheless, the interaction of occupants and the passive system can be a very positive and effective one. Many of the early passive solar houses, built in the 1970's, were custom-designed for people who were sensitive to energy and environmental concerns. In many cases, the owner, designer, and builder were all the same person. For instance, the majority of passive solar homes surveyed in studies by the U.S. Department of Energy (DOE) (5, 6, 7), the U.S. Department of Housing and Urban Development (HUD) (8), the New Zealand Energy Research and Development Committee (3) and many other countries were custom-built, with many owners actively involved in design, construction and financing.

These designer-occupants typically had the motivation to pay careful attention to the operation of the energy-related features of their home, such as movable insulation. They were also willing to sacrifice a certain amount of comfort for energy-savings, by turning thermostats to very low set-points, for example, or by opening a window and wearing light clothing when the direct gain space overheated.

As passive solar houses began to move into the mass market, however, the profile of their occupants became similar to those of "traditional" homes, and features that were particularly cumbersome, costly or inconvenient were not marketable or accepted by the home owner or tenant. Also, speculative and production builders were especially cognizant of the fact that few houses are occupied by the same people throughout the building's life. The phrase "first-occupant syndrome" was coined to describe houses that were very efficient when their enthusiastic first occupants operated all the features conscientiously, but were inefficient and often uncomfortable when the house was sold to less-committed (or less informed) occupants.

In addition to these factors, field studies of thermal performance in passive solar homes were indicating that some energy-saving design features or devices were contributing little to energy performance because the occupants were not using them as intended. For example, occupants have been known to impede the proper performance of the passive solar system by covering thermal mass, misusing controls, blocking thermal mass with furniture, opening or closing curtains or shutters at the wrong time, failing to operate controls appropriately and so on. These kinds of actions will probably result in homes that do not fulfill the designers' intentions or the occupants' expectations in terms of energy consumption or comfort.

This is borne out by studies such as the U.S. DOE's Class B monitored projects (9, 10), in which researchers concluded with some surprise that the monitored houses equipped with movable window insulation used the same amount of purchased energy as houses without window insulation. The effectiveness of properly designed and used window insulation to reduce energy consumption in most climates is unquestioned; in fact, the houses with proper window insulation operation were among the best overall performers in the Class B program. What the study suggested, according to a National Association of Home Builders Research Foundation report (11), was that "actual operation of the movable window insulation in these houses is so irregular that it negates much of the insulation's potential performance benefit."

Not all inappropriate energy behavior is the fault of the occupant, however. In many cases, occupant behavior which impairs the energy performance of the house is linked to the design of the house. In the Carnegie-Mellon study, for instance, "wasteful" residents were found to be opening windows in the winter because the design did not provide adequate levels of ventilation, and drapes were being closed to provide for privacy, Which was more important to those occupants than solar gain.

In the Princeton study, improper location of the thermostat in the kitchen in one house caused very high energy consumption and discomfort. Heat from the furnace and heat from the kitchen appliances registered on the thermostat, cycling it off when the other rooms were still too cold, causing the occupant in turn to set the thermostat even higher.

2.2 IMPLICATIONS OF OCCUPANT STUDIES

The studies and experience with occupant behavior suggest three major reasons for wasteful or counterproductive energy behavior:

1. Lack of understanding on the part of the occupant as to how the passive system is supposed to operate.

2. Improper passive solar or building design.

3. Disinclination of the occupant to be actively involved in the building's passive solar system or energy performance.

Reason No. 1 can be addressed through effective occupant information, covered in Chapter 3 of this booklet. Reasons number 2 and 3 have important implications for the design process and the solutions lie in decisions made early in that process. These are discussed below.

AVOIDING PROBLEMS THROUGH PROPER DESIGN

The design of passive solar homes is not necessarily a simple matter. Because of the complexity of building energy dynamics and the interaction of the various elements of the energy system, achieving good energy performance and a comfortable environment requires an understanding of important, proven passive solar and energy conservation design principles.

For example, room layout must accomodate occupant lifestyle and living patterns as well as passive solar design requirements (3, 4). Sunlit rooms should be the ones in which activities occur that benefit from high daytime light levels.

Very useful guidance for the design process is provided in Booklets 1, 2, and 3 of this Design Information Booklet series. Knowledge and application of the information they contain can help a designer achieve excellent energy saving performance without undue reliance on occupant operation.

FAIL-SAFE DESIGN

As passive solar homes have increasingly moved from the custom home market to the mass market, designers normally do not know who the residents will be, their energy behavior, or their commitment to participation in the operation of their passive solar system.

It may therefore be wise to avoid the use of certain passive solar features which require specific and consistent involvement on the part of the occupant in order to work properly. This view is supported by the results of occupant studies which show that many occupants misunderstand the action required or do not perform them reliably and many simply prefer a design requiring no action on their part whatsoever.

An example of a passive solar feature requiring occupant involvement is movable window insulation which must be put in place on winter evenings to reduce window heat loss and removed on sunny winter mornings to allow the capture of solar heat. Using glazing systems with low-emissivity coatings instead may provide better energy conservation, particularly if the occupant would not have used the movable insulation properly.

Designers are increasingly utilizing a "fail-safe" approach to designing energy-efficient homes for the mass market, which employs simple, carefully-planned passive solar features requiring little or no extra operation, and a design which allows for modulated temperature swings and acceptable comfort levels year-round regardless of occupant behavior.

An exception to this approach can be made for custom-buill homes whose occupants are committed to effective participation in the operation of the passive system and to the home's overall energy performance.

In those cases, the designer is free to employ passive strategies, such as movable window insulation, movable exterior window shading devices, operable heat distribution vents and other design features which the designer believes would enhance the energy performance, with the confidence that they will be operated properly.

It has been found that the performance of passive solar houses in colder climates are more sensitive to occupant behavior and activities than those in warmer areas (3). Accordingly, fail-safe design features are more of a necessity in colder climates.

2.3 IMPACT OF PUBLIC OPINION

If passive solar designs are to have a significant impact on the energy consumption, the house-buying public must have certain positive opinions about houses with passive solar and energy conservation features. These are:

- houses with passive solar features use significantly less energy than comparable houses without these features;
- they save enough money to offset any additional cost; and
- they are comfortable, pleasant places to live that do not require any more effort to operate, maintain, or clean than comparable houses.

PASSIVE SOLAR MYTHS

In some cases, these opinions must replace a number of myths about passive solar houses. These myths include:

- living in passive solar houses requires at least minor lifestyle changes;
- they have cooler winter temperatures and greater temperature swings than comparable houses of "traditional" design;
- they require a great deal of time and effort to operate and maintain;
- they have glare problems and damage furnishings with excessive sunlight; and
- they cost more than comparable houses to operate and maintain.

DEVELOPING POSITIVE PUBLIC OPINION

There are a number of ways to overcome these myths, when they exist, and to impart the positive opinions discussed before. The easiest of these is to simply let public opinion change over time.

This "laissez-faire" method is probably the least effective, as passive solar houses have been available for over 50 years around the world without significant market penetration or a major shift in public opinion.

Another approach is to downplay the passive solar nature of the house with its potentially negative connotations, and to label the solar features as "greenhouses," "conservatories," or "sunspaces." Although this method does little to change public opinion concerning passive solar designs, it does bring these features into more common use.

However, the common use does not mean their proper and effective use. Because a house has passive solar features does not always mean it is a cost-effective, energy-saving house.

References to and referrals from satisfied customers (occupants) are traditional methods of overcoming resistance to non-traditional housing designs. Based on the generally positive response to occupant surveys presented in Section 4.1 of this booklet, reference and referral programs may be appropriate ways to overcome potential public distrust of passive solar houses.

Clearly, many other ways are available to present passive solar houses in a positive manner that results in acceptance by the prospective buyer. In summary, it is important to:

- recognize the possibility of negative feelings regarding passive solar designs based on past bad publicity or unfounded myths;
- avoid design features likely to add to passive solar's negative image and myths;
- choose design features likely to reinforce positive opinions, such as fail-safe designs, attractive exteriors, and convenient floor plans; and
- take advantage of every opportunity to make positive changes in public opinion, including marketing emphasis on such things as reduced fuel bills, improved comfort levels, and environmental benefits. Accentuate the positive and unique design features of passive solar house and the added amenities such as more sunlight, no drafts, and the added space afforded by a sunspace.

The owner-designer-builders of some of the early passive solar houses were highly motivated and enthusiastic about their homes, which consequently tended to have excellent energy performance. Today, the closest most designers of the typical passive solar house, unless it is a custom house for a solar enthusiast, can come to that situation is a well-informed and involved occupant who is fully-briefed on the design of his or her home.

The importance of providing information to the occupant is clearly demonstrated by the results of the occupant satisfaction studies which show that improper action on the part of the occupant can impede the performance of the best designed passive solar home.

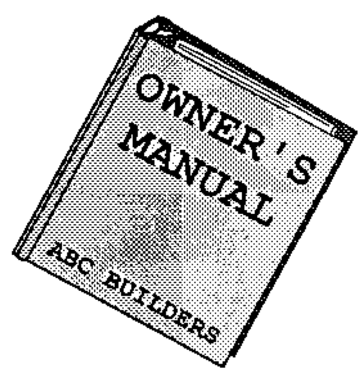
3.1 LESSONS LEARNED FROM OCCUPANT STUDIES

The designer who is interested in helping the occupant understand how the passive system works and how to maximize the energy performance of the building is well advised to prepare information for the occupant on the energy design of the house, the benefits of the design, and intended operation. This information can also be used as a marketing tool.

INFORM THE OCCUPANT ABOUT THE ENERGY DESIGN OF THE HOUSE.

Even if the passive system is simple and requires relatively little occupant involvement, descriptive materials such as fact-sheets or booklets, explaining how the house has been designed to save energy, will be useful to the occupants and encourage their participation. If possible, the materials can be discussed in a meeting with the occupant.

For example, occupants who are fully informed about the role their south (sun-facing) windows and adjoining tile floors are playing in saving them money will be less likely to pull the drapes on a sunny winter day, or cover the floor with wall-to-wall carpeting. Where the system is more complicated, occupant education becomes even more critical.



Some manual operations, such as opening or closing a door between a sunspace and a living room to control heat distribution, are considered inconvenient by occupants (5). Therefore, the importance of reasonably faithful operation should be emphasized. The information need not be lengthy; the essential information can probably be contained in just a few pages or a few appropriate sketches.

EMPHASIZE INCREASED COMFORT AND LIVEABILITY AS WELL AS INCREASED ENERGY PERFORMANCE.

Studies show that the reasons people buy passive solar homes, and the reasons they like them, have a great deal to do with factors other than energy savings.

For example, a sunspace provides a warm sunny place to grow plants, have your morning coffee, or read a book, as well as contributing useful solar heat to the house.

Information for occupants should reflect these concepts, by emphasizing that the passive solar features will also enhance their lifestyles and comfort. In other words, the designer should explain that leaving the drapes open on a sunny winter afternoon will not only save on fuel bills, but create a sunny, appealing space.

OCCUPANT INFORMATION SHOULD BE USED AS A POSITIVE TOOL FOR MARKETING AND FOR OCCUPANT SATISFACTION.

In most cases today, passive solar homes in the mass market are no longer perceived as radically different from "traditional" homes. This a positive development and occupant information should not suggest that they are somehow complicated and risky and can only be lived in with the aid of a large operating manual.

Instead, the information should take a more positive approach by emphasizing the clearly-documented benefits that can be realized in passive solar houses, such as energy savings, improved comfort, less outside noise, less dust, greater daylight and so on, and providing the occupants with the incentive to realize those benefits.

Such information can easily be included with the materials often given to new homeowners about warranties, instructions for appliances, and information about the neighborhood. It can also be incorporated into promotional brochures and pamphlets prepared by builders and housing developers.

3.2 SUGGESTED OCCUPANT INSTRUCTIONS AND INFORMATION

Some of the topics that might be covered in information for occupants of passive solar homes include:

The passive solar components of the house. Each component should be identified and described as to its' function as part of the overall passive solar design.

How each passive solar component operates, and any occupant-related intervention necessary to ensure intended component performance. This information is essential so that the occupants know how the components are supposed to function, and the ramifications of improper use.

Cleaning and maintenance requirements and operations. This information allows occupants to keep the system operating at the highest possible efficiency. Information on specific products and where to obtain them should be included.

How to determine if the system components are operating properly, and what to do if one is not. Since many occupants do not know when components have failed, or the system is not performing as well as it can, knowing how to "trouble-shoot" the system is a valuable occupant skill.

The anticipated energy performance of the house. This is based on either the design performance or the results of a thermal evaluation of the house "as-built." Information on how to analyze fuel bills should be included.

Detailed suggestions for occupant information are provided in Appendix A.

Previous surveys of the occupants of passive solar houses provide a great deal of valuable experiential information. The lessons learned include the popularity of design features, which manual operations are likely to be performed, and other practical information for the designer and builder.

The aspects of passive solar houses considered most beneficial by the occupants have been identified. This information can sharpen the focus of marketing programs.

In addition to using this historical information, designers and builders should perform their own post-construction survey of the new occupants of their houses. The same information can be derived for the specific designs being constructed.

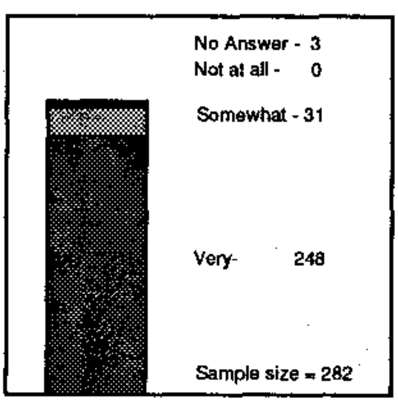
4.1 RESULTS OF OCCUPANT SATISFACTION STUDIES

One of the most striking results of occupant studies has been the overwhelmingly positive attitude of occupants toward their homes. For instance, 88% of the 282 owners interviewed in a U.S. Department of Energy (DOE) study were "very satisfied" with their passive solar homes (7) (See Figure 4.1), and all of the 52 owners surveyed in the U.S. Department of Housing and Urban Development study were satisfied with theirs (8).

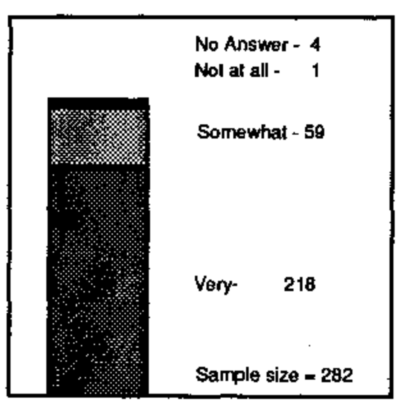
UNITED STATES OCCUPANT SATISFACTION STUDY

What is particularly interesting, however, is the reason for their satisfaction. Aesthetics and comfort level ranked with energy savings in most studies. In one section of the DOE study, passive solar homeowners in the midwest United States ranked interior design first, floor plan second, comfort level third, and **energy savings** the fourth most important factor in their satisfaction with their homes.

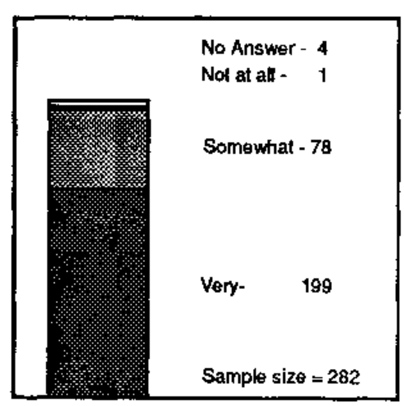
The DOE study also indicates that an attractive living environment - openness, light, and views - was one of the key factors motivating the purchase decision of passive solar homeowners. British market studies carried out by the London Business School bear this out, by concluding that amenities are as important as energy considerations to occupant satisfaction (12).



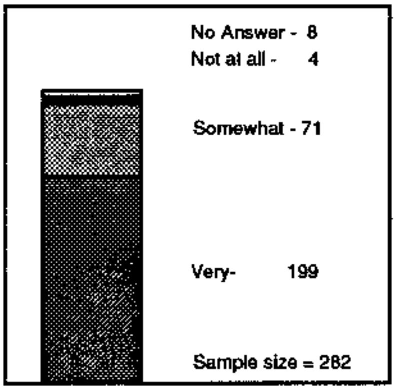
4.1: Overall Satisfaction (U.S.)



4.2: Satisfaction with Energy Savings (U.S.)



4.3: Satisfaction with Comfort (U.S.)



4.4: Satisfaction with Maintenance (U.S.)

When occupants were asked about problems in the DOE study, those mentioned most frequently were overheating, keeping windows clean, condensation on windows and glare, with owners of sunspaces reporting problems with overheating and keeping glass clean. However, they tended to characterize these as moderate problems. In addition, about half the respondents in homes with manually-operated components (movable insulation, fans, vents, shades) felt that these features were inconvenient while the other half did not.

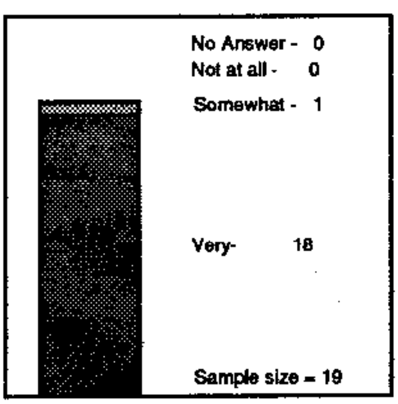
Despite problems encountered, 77% of the occupants reported they were "very satisfied" with the energy cost savings and 70% were "very satisfied" with the comfort level while less than 1% were "not at all satisfied" (See Figures 4.2 and 4.3). Of the occupants surveyed, 70% indicated they were "very satisfied" with the maintenance requirements of their houses, over 25% were "somewhat satisfied," and less than 2% were "not at all satisfied" (See Figure 4.4).

NEW ZEALAND OCCUPANT SATISFACTION STUDY

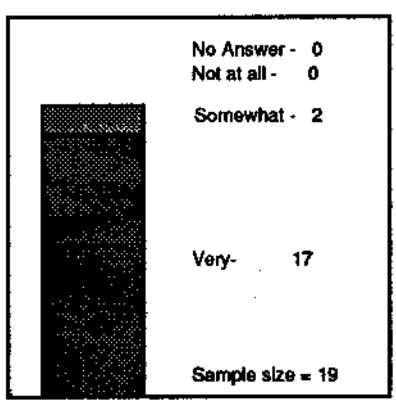
A study of 19 occupants of passive solar homes, performed by the New Zealand Energy Research and Development Committee, shows similar findings (3). Using a questionnaire nearly identical to the one used in the DOE program, surveyors found that 18 of the respondents were "very satisfied" with their passive solar houses. One was "somewhat satisfied" (See Figure 4.5).

In this study, 17 were "very satisfied" with the energy savings, and 16 were "very satisfied" with the comfort level (See Figures 4.6 and 4.7).

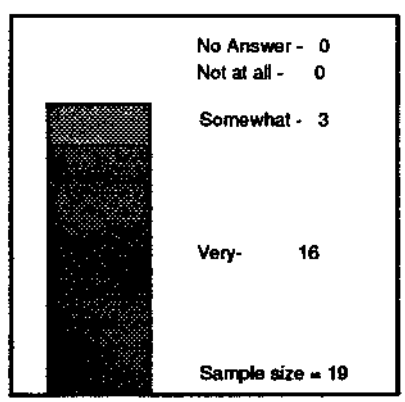
The findings regarding problems with passive solar houses are remarkably similar in the New Zealand study to those of the larger DOE study. Overheating and humidity control were the most common problems, but were characterized as "somewhat" serious, rather than "very" serious. Part of the reason for the similar findings may be the nearly identical survey forms used in the two studies.



4.5: Overall Satisfaction (New Zealand)



4.6: Satisfaction with Energy Savings (New Zealand)



4.7: Satisfaction with Comfort (New Zealand)

The high level of satisfaction expressed is very encouraging to the future and wider acceptance of passive solar homes. Moreover, a large number of the problems cited by respondents in the DOE study have since been ameliorated. This study was conducted during 1980-81 and much has been learned since then and incorporated into the newer passive houses. The improved features and performance are making passive solar homes even more attractive to the mainstream market in many countries.

4.2 APPROACH TO OCCUPANT EVALUATION

This section provides guidance on the evaluation of occupants' satisfaction regarding the features and energy performance of their passive solar home. A designer who makes the effort to obtain information on these factors is likely to be amply rewarded by the knowledge and foresight gained. The information resulting from the experience and perceptions of the occupants will allow the designer to improve future passive solar designs for greater occupant satisfaction and potentially fewer callbacks to correct problems.

DESIGNER VISITS

If possible, designers and builders should visit their "design" after it has been occupied, and talk to its occupants in person about how well the house works and how comfortable it is. A mail-in questionnaire or telephone interview can be utilized if it is inconvenient for the designer to interview the occupants in person.

Ideally, the evaluation should be conducted twice, in two different seasons, but at a minimum following the first heating season. An in-person or telephone interview will be more effective if the residents are given the questionnaire in advance so that they can think about their responses and gather needed information.

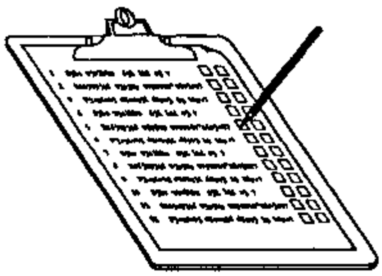
OCCUPANT EVALUATION TOPICS

Generally speaking, the following topics should be covered in the occupancy evaluation process:

- The house's energy performance during different seasons, and at different times of the day.
- The household's pattern of energy consumption.
- Review of fuel bills.
- Questions about general satisfaction, convenience and comfort.
- Inspection of the physical condition of the passive solar features.
- Inspection of the location of furniture, plants and other items to see if the system is being used to best advantage.

4.3 EVALUATION QUESTIONNAIRE

Whether the evaluation is conducted in person, by mail, or by telephone, a carefully prepared questionnaire is an essential tool. Standardized questionnaires have been developed in several countries, often as part of major studies of the effects of occupant behavior on performance. As such, many are designed for use by trained researchers, at a level of detail beyond what most designers or builders would need or want.



However, selected portions of the DOE and New Zealand occupant survey forms are included in Appendix B. Also, in Britain, the Department of Environment has developed a housing appraisal kit, including a computer program, which is a complete social survey package intended for use by those with little or no experience in survey work. Use of the kit is free, and passive solar designers in the U.K. may wish to adapt it to the special needs of a passive solar house.

OCCUPANT EVALUATION QUESTIONS

While level of detail can vary, the following are the general kinds of questions which should be asked regarding occupant satisfaction and perception of performance of the passive solar features of their house.

- How satisfied are you with your passive solar home?
- Indicate the existence and severity of any problems.
- How much of your total energy would you say is supplied by the passive solar features of your house?
- How much do you think you are saving on your energy bills as compared to a comparable house without passive solar features?
- How satisfied are you with the comfort level in your house?

  Are you satisfied that you understand how the energy-related features of your home work?

  Is there any part of the system that you do not use or do not often use because it is inconvenient?

  What would you change about your house if you had the chance?

Appendix B contains a more detailed list of potential questions for an occupant survey. Additions and deletions should be considered, to customize the questionnaire to the needs of the individual designer or builder. In many cases, additional marketing-oriented questions will be helpful. These include determining where and how the owner learned about passive solar houses and why a purchase decision was made.

Some type of thermal performance evaluation is another important post-construction activity. It provides "hard numbers" on the performance of the building, in contrast to the somewhat qualitative information provided by the occupants.

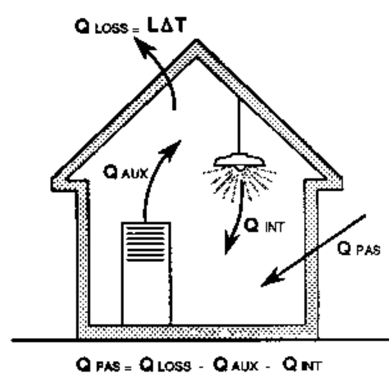
At the very least, electrical and fuel bills should be checked. They can be used for a cursory examination of the house's thermal performance. A comparison to anticipated energy consumption should be made. "Side-by-side" comparisons to other passive solar houses of similar design, and to nearby non-passive solar houses of equivalent size can also be made to determine the relative energy performance of the home.

Monitoring the thermal performance of a building in detail can be a difficult, costly, and time-consuming task (see Figure 5.1). It requires the use of specialized equipment operated by skilled and experienced personnel. Those who do not anticipate the need for detailed monitoring may wish to skip over this Chapter.

Detailed monitoring has typically been conducted over long time periods, ranging from an entire heating season to several years. Recently developed methods of performing short-term monitoring during the heating season, and extrapolating the performance over the entire heating season have reduced the time and cost required for monitoring. However, monitoring equipment costs and personnel requirements are still high. This Chapter will explain the various levels and methods of detailed performance monitoring.

5.1 EVALUATING BUILDING ENERGY PERFORMANCE

Proponents of passive solar buildings knew from the outset that before this energy saving concept could be widely accepted, its effectiveness had to be thoroughly demonstrated and documented. Therefore, since the late 1970's many governments, utilities, and private associations have mounted research and development programs which included major field studies to monitor the thermal performance of passive solar homes.



CLASS A PERFORMANCE EVALUATION

These programs have involved the collection and analysis of measurements of selected energy performance indicators, using complicated and expensive instrumentation.

One way to categorize the degree of depth and rigor of a monitoring program is the three categories developed by the United States Department of Energy (DOE), and utilized by other national and international passive solar research programs, including the European Community (13).

In the first of these, the Class A program, the energy balance of the building is determined exclusively by measurement. In a typical single family residential building this involves over 200 temperature, power, meteorological, and other sensors, zone-specific infiltration testing, well over a year of time, and costs well beyond the grasp of typical practitioners. In addition, the building is essentially uninhabitable during the test. However, this class of monitoring, which measures almost every variable condition and makes very few assumptions, is the most accurate of the three classes. It is typically used to characterize the components of passive system performance, to validate building analysis tools, and to develop simulation algorithms.

CLASS B PERFORMANCE EVALUATION

The Class B program is a less rigorous approach which requires approximately 20 sensors. In this approach, each building's heat loss coefficient is first determined. This coefficient, in KWh/C-day, describes the amount of energy required, per day, to maintain a particular inside temperature for a particular outside temperature. It can be estimated from physical measurements and assumptions about the thermal characteristics of building components.

For greater accuracy, the heat loss coefficient can be measured by "co-heating" the building in a one-time test. This process uses electric resistance heaters to heat the building on a cloudy, cold night. During the overnight test, the electrical energy required for heating is carefully measured, as are the inside and outside temperatures.

Now the building's heating load for any set of inside and outside temperatures can be calculated. After subsequent monitoring, measured auxiliary heating and internal heat gains are subtracted from the building's heating load to determine the passive heating contribution.

The measurement of auxiliary heating and internal heat gains is accomplished with the building's utility meters. For greater accuracy, submeters and/or elapsed time meters can be used. Elapsed time meters are only used on devices with fixed energy inputs and stable efficiencies, such as electric elements in water heaters.

This approach is well documented in an International Energy Agency Technical Report: Performance Evaluation Procedures, produced within Subtask A of Task VIII (14).

CLASS C PERFORMANCE EVALUATION

The third class of monitoring, Class C, estimates performance in a non-instrumented manner with a one-time audit of the thermal characteristics of the building. While a trained individual performs the audit, the building occupants fill out a comprehensive survey which determines their opinions of building performance.

In the majority of studies, the lessons learned about performance have been very positive. For example, both the U.S. DOE study which surveyed over 300 houses and Class B study which monitored 70 homes found, among other things:

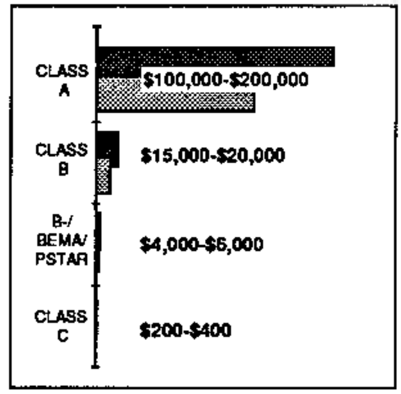
- Passive solar homes use less purchased energy (Class C: on the average about 30 percent less, although many save much more).
- Passive solar energy contributes a significant portion of a house's heating load (Class B: about 55 percent net heating load, on the average).
- The basic design types, direct gain, mass wall and sunspace, all perform equally well in different climates (Class B).

While the information and lessons gained from monitoring programs has been invaluable, an elaborate performance evaluation effort is beyond the resources of most designers, builders, owners, and, in recent years, even many national research programs.

Typically, performance monitoring will determine: useful solar contribution to the heated space, auxiliary energy used for space heating, system efficiency, average interior temperatures, and measured peak heating requirements. To obtain such information, numerous measurements must be taken, including, but certainly not limited to, hourly temperatures at various locations, solar radiation, fuel consumption, and ambient conditions.

Some monitoring programs are even more extensive. But the needs of researchers are not necessarily the same as those of designers or builders seeking an effective way to measure the performance of their "products."

Fortunately, innovative approaches to performance monitoring are being developed that make it possible for a designer to gather useful and sufficiently accurate information about the performance of a building without going through the usually prohibitive expense and trouble of setting up a major monitoring program. The focus of these innovative monitoring approaches is in two areas: (1) lower cost data acquisition equipment and (2) short-term tests that can be used to project long-term performance.



5.1: Cost, Per House, of Monitoring Program (1980 U.S. Dollars)

5.2 OVERVIEW OF SIMPLE PERFORMANCE EVALUATION PROCEDURES

A low-cost approach to obtaining measurements similar to the U.S. DOE Class B project has been developed in the U.S. (15). This method is an effective, economical performance monitoring procedure using low-cost data acquisition equipment which should be within the limits of the individual practitioner.

B- METHOD

The method, referred to as the B- (B minus) method, requires only manually-collected measurements and a minimum amount of paid labor.

In typical performance monitoring techniques, some of the most difficult and expensive performance measurements are those required to find out which part of energy savings is attributable to passive solar heating. In the B- method, separation of the passive solar contribution is not required, and only the most essential purchased energy measurements must be collected.

The B- method describes a minimum level of monitoring detail, but also includes optional alternatives for adding depth and rigor to a quantitative evaluation.

The total energy consumption of the building is estimated by measuring the average daily maximum and minimum indoor temperatures during the entire heating season, and during the month of July. These are measured either with two manually-read maximum-minimum thermometers (one inside and one outside), or a digital maximum-minimum thermometer with an indoor and an outdoor sensor. In either case, the equipment is read and reset daily by the occupant.

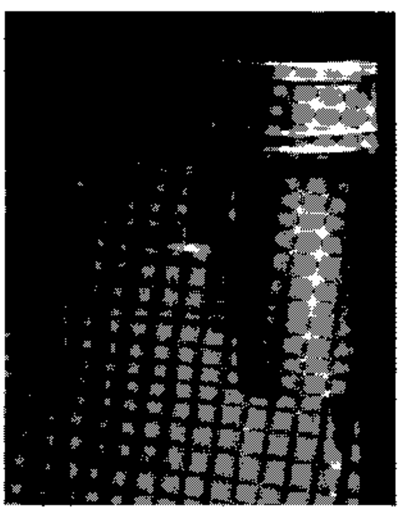
In addition, the total auxiliary space heating energy and internal gains energy are measured with the existing utility meter(s).

An option which simplifies the process of apportioning the total energy use is to install submeters for the duration of the project on space heating, DHW equipment, and other significant loads. An alternative to submetering is the use of elapsed time meters on equipment which uses energy at a constant rate (e.g., the electric elements of a water heater).

The most important measurable performance indicators to most users are comfort and energy savings. Comfort calculations can be complex and esoteric, but the B- method uses only simple indoor temperature measurements.

CALCULATING ENERGY SAVED

"Energy saved" is also a complex quantity, the immediate question being, "Compared to what?" A reference building with energy performance characteristics typical of conventional houses in that area must be specified for this purpose. Another difficulty with this measure is that comparison between two buildings is only meaningful if the same energy quantities are compared under the same operating conditions. Obviously, operating conditions can vary greatly, due to weather and particularly, as seen earlier, due to occupant behavior which affects temperatures to which the building is heated, internal heat gains, occupancy schedules, and many other factors.



Outdoor Humidity and Temperature Sensors Protected from Precipitation and Direct Sun by a Radiation Shield

These variations make it impossible to simply compare total metered energy consumption, or even submetered space heating energy. At a minimum, a consistent energy savings calculation must account for the effects of variations of weather, by accounting for outdoor temperature variations, and for occupancy factors by accounting for variations in indoor temperatures and internal heat gains. A minimum level of instrumentation for these factors is therefore required by the B- method.

Performance factors are the values which distill all the measured quantities down to a coherent result. The use of standard performance factors provides a common understanding of what is meant by various relative levels of performance. However, performance factors are useful only if they have been derived in a consistent way, without introducing bias into either the measurement or the analysis, so consistency was a major goal in the development of the B- method.

Because of the wide variation in buildings, climates, occupants, and audiences for evaluation data, the number of widely applicable performance factors is relatively small. The B- method recommends some factors as "required," and others as "optional."

B- PERFORMANCE FACTORS

The performance factors in the B- method (required except where indicated as optional) include:

Climate

Heating season total measured degree days (18°C base temperature)

Annual total solar radiation (optional)

Indoor Comfort

Heating season average daily maximum and minimum indoor temperatures

July average daily maximum and minimum indoor temperatures

Energy Consumption

Annual total electricity use

Annual total gas or oil use

Annual total space heating energy

Heating season total useful internal heat gains

Building Energy Balance

Heating season total heat loss (optional)

Heating season passive solar heating (optional)

In addition, the following information on relative energy performance can be determined. This information shows the performance of the passive solar building compared to buildings of comparable size without passive solar features which have insulation levels typical of the area.

Relative Energy Performance

Building performance index

Standardized heating energy use

Reference house standardized heating energy use

Standardized heating energy savings

BUILDING PERFORMANCE INDEX

The building performance index (BPI), in kJ/m^2-°C-day, is the performance factor which characterizes the overall heating energy efficiency of the building. It is normalized for the effects of climate, occupancy, and size by summing the internal heat gains and auxiliary heat used, then dividing by the actual number of degree days and the square footage of the house. The BPI is a building's "fuel efficiency factor," allowing comparisons between buildings of different size, or buildings in different locations.

STANDARDIZED ENERGY USE

Standardized heating energy use is the amount of energy the house will use in a "standard" heating season. If such a standard year is assumed to have 3600 degree days (18°C base), then multiplying the BPI times 3600 times the floor area of the house will result in the number of kilojoules of energy the house will require.

REFERENCE USE

The reference house standardized heating energy use is the amount of energy used by a building of comparable size which has insulation levels typical of the area, but without passive solar features. This quantity is determined by using a detailed simulation program for a standard heating season. Standard heating seasons are simulated using "typical meteorological year" (TMY) weather data.

STANDARDIZED ENERGY SAVINGS

The standardized heating energy savings is the difference between the (measured) standardized heating energy use of the passive solar house and the (simulated) energy use of the reference house.

The types of calculations necessary and the degree to which quantities must be estimated from qualitative observations depend on the degree of instrumentation used.

The performance factors listed above require some level of instrumentation to measure. However, a great deal of additional performance information can be determined from non-instrumented data, particularly from occupant responses such as those discussed in Chapter 4.0. Another important source of information are fuel bills. This information on purchased energy consumed is as important, and sometimes more important, than strictly defined "performance data" to builders and designers and other potential "evaluators" of a building.

BEMA METHOD

A method using the other approach, that of using short-term tests to project long-term performance, is the Building Energy Monitoring and Analysis (BEMA) method, developed by the National Association of Home Builders National Research Center (16). As an industry-based residential building thermal performance evaluation program, the primary goal was to transfer thermal performance monitoring and data analysis technology from the DOE Class B Program to the private sector.

In the BEMA system, the total energy load of the building is considered to be the sum of the energy delivered to the conditioned space by the space heating system plus the building's internal gains.

This total energy load is then normalized by dividing by the square footage of conditioned space floor area, dividing by the temperature difference between the inside of the house and the ambient temperature, and multiplying by 24. This results in the Building Load Coefficient (BLC), expressed in kJ/m2-°C-day. Notice that this is the same unit as the BPI previously described. In the English units the BEMA systems was developed with, the units are BTU/ft2-°F-day.

The BLC is measured by electrical coheating, generally on three to five nights to average the effects of wind, mass, temperature differential, humidity, and other factors.

A "cool down" test is also performed. This test measures the thermal capacity of the building by analysis of the inside and outside temperatures over a night during the test.

BEMA MEASUREMENTS

The conditions measured during the tests are:

- Outdoor temperature, usually with two or more sensors;
- Wind speed;
- Vertical solar radiation on a south-facing surface;
- Horizontal solar radiation;
- Indoor temperatures in all major zones;
- Buffer space temperatures;
- Movable insulation operating time;
- Vent operating time;
- Electrical power consumed for space and water heating; and
- Other fuel (e.g., oil or natural gas) consumed for space and water heating.

The on-site data acquisition system collects the sensor data, processes it, and stores it. An optional modem hookup can transfer the data over telephone lines to another computer for checking and analysis.

The BLC lumps the conduction and infiltration components of the load together into one term. The air infiltration component can be separated by doing a simple measurement using the Air Infiltration Measurement Service (AIMS) system (16).

The AIMS system uses a perfluorocarbon tracer gas and one or more sensors. The gas is emitted into the conditioned space. After three to five days, the sensors are removed and analyzed in a gas chromatograph. The amount of tracer gas the sensors collect (which has not left the building and been replaced by infiltrating air) is used to determine the infiltration rate.

The BLC and AIMS measurements describe the building performance during the monitoring period. The annual performance is projected using a calibrated computer model. BLC data is used as inputs to the model. The model is adjusted until the predicted performance for the monitoring period matches the actual measured performance.

The computer program with the calibrated model is then run for an entire year using TMY weather data.

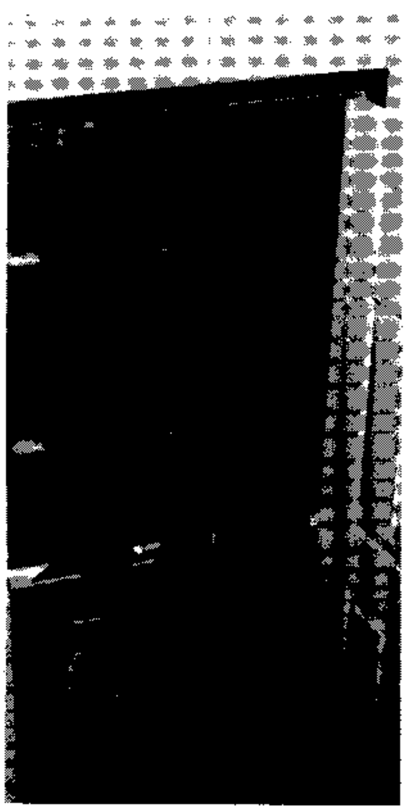
With the calibrated computer model, analyses can be made on the thermal and economic effects of changes in the building's thermal envelope, passive solar features, appliances, HVAC equipment, and other features.

This method gives relatively good data on the overall performance of the building. If additional information on component performance is required, a longer and more extensive monitoring program must be performed.

PSTAR METHOD

Another short-term method used to project long-term performance has been developed by the Solar Energy Research Institute. This method is called Primary and Secondary Terms Analysis and Renormalization (PSTAR) (17). The first step in PSTAR involves performing an audit of the building's physical characteristics. The dimensions of thermally significant components are recorded.

To determine the rate of infiltration, a blower door test is performed. In this test, all windows and doors are closed, fireplace and stove dampers are closed and their openings are sealed with plastic sheeting. An airtight door with a blower is fitted in the door jamb of an open entry door.



Technician Installing a Blower Door

When the blower runs, it discharges air to the outside, decompressing the inside of the house. Pressure differential measurements between the inside and outside of the house, combined with a determination of the air flow rate through the blower, allow the operator to calculate an effective leakage area. This area is combined with the house description and outdoor wind speed to determine the infiltration component of the total heating load.

A simple monitoring system, typically involving only about 20 input channels, is used to measure the building performance and weather conditions. The length of this test is usually three days to a week. Electrical coheating is used during this phase to determine the building's heat loss coefficient (BLC).

The same conditions measured during the BEMA BLC test are measured for PSTAR. In addition, the relative humidity of outside air is measured.

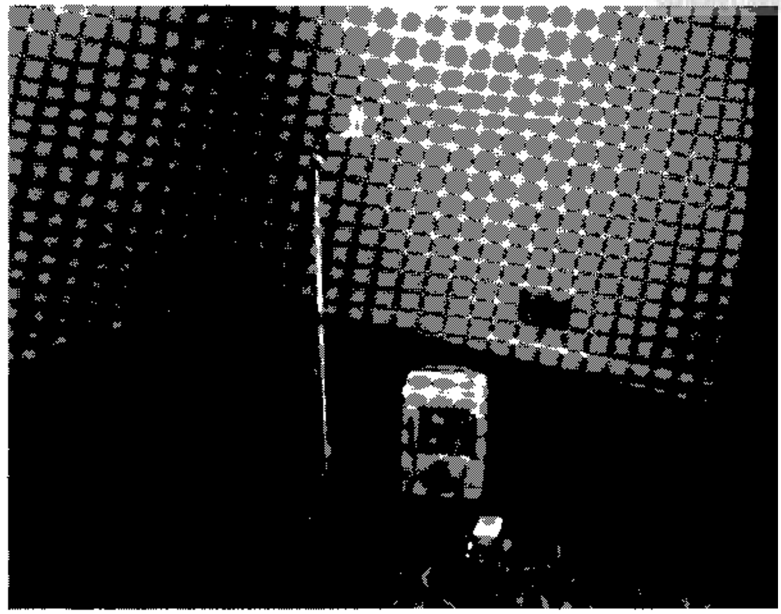
An on-site microcomputer operates the data acquisition equipment, and formats and records the data for later analysis.

The efficiency of central heating appliances can be calculated by this method. This information allows determination of the total energy consumption of the building, as well as the energy delivered to the conditioned space. To calculate furnace efficiency, the gas flow rate into the furnace must be determined, and the status of the gas valve monitored during at least one night of heating with the furnace.

The heat flows for the various building zones are calculated using SUNCODE-PC, a detailed building energy analysis program (18). The driving functions (e.g., outdoor temperatures, wind conditions, solar radiation, etc.) in the simulation are the same as those measured during the test of the actual building.

Because a particular building, as-built, will have positive and negative variations from the assumptions used to prepare the simulated building, the measured performance will vary from the calculated performance. The heart of PSTAR is the renormalization of the heat flow terms in the simulation to reflect the actual building's performance.

When the building energy analysis program is run for an entire year, using TMY weather data, the annual performance of the simulated building is presumably close to that of the actual, as-built, building.



Temperature Sensor, in Radiation Shield, Controlling Electric Coheating Equipment

Technician Installing Transducers to Measure Electrical Consumption

Although the general trend in passive solar design is toward houses that are conventional in appearance and operation, at least one fundamental difference should be emphasized: Passive solar houses are designed to be **better** than conventional houses - more energy efficient, more comfortable, and built to higher construction standards. The ideas in this booklet have been presented to help designers and builders maintain this important difference and to help occupants take maximum advantage of it.

Good performance in a passive solar house is the result of careful planning and attention to detail which should extend to educating the people who will live in the "design" after it has become a home. Encouraging the participation of the occupant is just as important as fine-tuning the design details of the passive solar system; in fact, occupants who have been, for all practical purposes, left out of the design process can undermine performance even in an otherwise excellent design.

Many designers consider their involvement in a building to be finished when construction is completed or even when the design is complete. But a designer can learn a great deal from the way the house actually works after it is occupied, particularly in the case of a passive solar home. By studying the way the house performs, day-to-day, season-to-season, the designer can gain invaluable insights and ideas that will apply to new designs. Such an analysis can be performed at many different levels, from a simple post-construction interview to a detailed questionnaire to extensive thermal performance monitoring.

Beyond the benefits to the designer and occupants of an individual house, the monitoring and analysis of passive solar houses is important on a much broader scale. One of the persistent barriers to the widespread adoption of passive solar building design techniques continues to be the lack of reliable, "real-world" performance and design information from large numbers of occupied buildings. Perhaps even more important, the thousands of passive solar buildings which now exist all over the world are an incomparable resource of knowledge and experience. The objective of this series of Design Information Booklets is to make this information available. The advances and refinements in passive solar design over the next decade will depend on how well the lessons from these buildings are learned.

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APPENDIX A: INFORMATION FOR OCCUPANTS

Information for the occupants should include four major sections:

1. What passive solar components their house has, and how they operate.
2. What operations they must perform, relative to their passive solar components.
3. Cleaning and maintenance requirements and operations.
4. Determining if the system is operating properly, and what to do if it is not.

Detailed information for each section follows.

1. What passive solar components their house has, and how they operate.

Include a description of all the elements of the passive solar design. This includes, but is not limited to:

Method of solar collection (e.g., direct gain windows, sunspace)

Thermal mass for storage (in floors, walls, or special containers)

Shading (fixed or seasonal)

Movable window insulation and/or high-performance windows

Ventilation (automatic or manual)

Controls (automatic or manual)

Auxiliary heating system (automatic or manual)

2. How the components operate, and what operations they must perform.

Add an explanation of how the system is intended to work, and what actions might impair the efficient operation of the system. Include the following information, as appropriate:

Direct gain windows need unobstructed sunlight during winter days.

Mass floors will store energy if they have clear access to the sun and are relatively dark in color.

Mass walls need only be in the rooms that receive sunlight and can be any color.

Buffer zones are intended to remain cooler in winter and thus protect more-used living areas.

Sunspaces are carefully arranged for the free movement of heated air into interior rooms and the return of cool air, provided no objects are put into their path to block the flow.

A thermal storage wall might decrease the need for the furnace during the night by releasing heat stored during the day.

The need for energy to heat the additional room in a sunspace can be reduced or eliminated by closing it off completely during the night.

Deciduous trees by a western window will reduce air conditioning costs by shading against intense summer sunlight.

How internal gains from lighting, appliances, or people affect the energy performance.

3. Cleaning and maintenance requirements and operations.

This section contains any needed information about cleaning or maintenance. Include the following information, as appropriate:

How to clean components such as thermal curtains, glazings, and other solar-specific components, with specific recommendations for cleaning materials and agents.

How to check, lubricate, adjust, and otherwise maintain manual and automatic system components.

A chart showing the intervals between specific maintenance operations.

A listing of solar-specific components used in the house with sources for replacement items and parts.

What colors and finishes can be used when repainting the house.

How to avoid damage to furnishings or fabric through exposure to direct sunlight.

4. Determining if the system is operating properly, and what to do if it is not.

Experience has shown that few owners of passive solar houses know if the building is performing as it was designed to do. Accordingly, include the following information, as appropriate:

How to tell if the design is working properly. This may require examples of anticipated temperatures and temperature swings, fuel bills (using units of measure rather than cost), auxiliary system run time, and other predictions of performance for specific examples of weather and occupancy patterns.

How to determine what the problem is, if the design does not seem to be working properly. Include suggestions such as changes in occupancy patterns, occupant behavior, thermostat setpoint, weather, and component operation.

How to solve the problem. If a component must be replaced, refer to the suppliers list in the previous section. Also describe where additional advice, information or services can be obtained.

Information on what to do in emergency and unusual situations. It is likely that information on leaking pipes, electrical problems and other difficulties common to all types of houses will be presented in other information provided to the occupants. In this document, discuss what to do to prevent damage to the passive solar components of the house.

APPENDIX B: OCCUPANT QUESTIONNAIRE

This information is provided as a starting point for a designer or builder interested in determining the degree of occupant satisfaction with a passive solar house. Questions can be added or removed to "customize" the questionnaire for a particular firm's needs.

Instructions: Please check the response which corresponds most closely to your opinion. If none of the responses are appropriate, check "Other" and explain in a brief written comment.

Your efforts in filling out this form are greatly appreciated. This information will help us design houses which are even more energy-efficient and comfortable for the occupants.

	Very	Somewhat	Not at all
1. Generally, how satisfied are you with your house?	☐	☐	☐
2. How satisfied are you with the comfort of your house in the:			
2a. Summer?	☐	☐	☐
2b. Winter?	☐	☐	☐
2c. Spring?	☐	☐	☐
2d. Fall?	☐	☐	☐
2e. Mornings?	☐	☐	☐
2f. Daytime?	☐	☐	☐
2g. Evenings?	☐	☐	☐
2h. Nighttime?	☐	☐	☐
3. How satisfied are you with:			
3a. The money saved by the passive solar features of your house?	☐	☐	☐
3b. The thermal performance of your house?	☐	☐	☐
3c. The humidity control of your house?	☐	☐	☐
3d. The exterior design of your house?	☐	☐	☐
3e. The floor plan of your house?	☐	☐	☐
3f. The interior design of your house?	☐	☐	☐
3g. The cleaning and maintenance requirements of your house?	☐	☐	☐
3h. The operation of the manual features (e.g., movable insulation,vents) of your house?	☐	☐	☐

		Very	Somewhat	Not at all
How satisfied are you with:				
3i.	The operation of the mechanical features (e.g., pumps, fans, controls) of your house?	☐	☐	☐
4.	How well do you feel you understand the operation of the manual features of your house?	☐	☐	☐
5.	Please estimate how faithfully you operate the manual features.	☐	☐	☐

6. What time of day does your family use the most energy?

7. What time of day does your family use the least energy?

8. If there are any times when little or no energy is used, what time ofday are they?

9. If you have experienced any of the following problems, please circle them, and indicate how severe they are.

		Very	Somewhat	Not at all
9a.	Overheating?	☐	☐	☐
9b.	Underheating?	☐	☐	☐
9c.	Drafts?	☐	☐	☐
9d.	Condensation?	☐	☐	☐
9e.	Uneven air distribution or ventilation problems?	☐	☐	☐
9f.	Difficulty in cleaning?	☐	☐	☐
9g.	Glare?	☐	☐	☐
9h.	Lack of privacy?	☐	☐	☐
9i.	Understanding the use or operation of control systems?	☐	☐	☐
9j.	Difficulty in using manual features?	☐	☐	☐
9k.	Failures of mechanical features?	☐	☐	☐
9l.	Fading of interior surfaces or furnishings?	☐	☐	☐

9m. Please briefly describe any other problems which are not listed, or give details on listed ones.

9n. If you consider overheating a problem, when does it occur? ___:__ AM/PM to ___:__ AM/PM (Circle AM or PM)

10. Please circle which of the following things you enjoy about your house, and indicate how important they are to you.

	Very	Somewhat	Not at all
10a. Saving money on heating and cooling?	☐	☐	☐
10b. Saving energy on heating and cooling?	☐	☐	☐
10c. Comfort?	☐	☐	☐
10d. Attractive exterior?	☐	☐	☐
10e. Attractive interior?	☐	☐	☐
10f. Convenient floor plan?	☐	☐	☐
10g. Bright interior with daylighting?	☐	☐	☐

10h. Please briefly describe any other features you like which are not listed, or give details on listed ones.

	Yes	Perhaps	No
11a. If you were to buy another house, would you buy one with passive solar features again?	☐	☐	☐

11b. Please briefly describe why or why not.

	Yes	Perhaps	No
12a. Are there parts of your house or its design you would change if you had the chance?	☐	☐	☐

12b. Please briefly describe changes you would make.

13a. Before moving into your house, how much did you expect to save on energy bills, per year, as compared to a comparable house without passive solar and energy conservation features?

13b. Please estimate what you feel you are now saving on energy bills per year.

13c. Please estimate what you expect to save next year on energy bills.

	Primary	Auxiliary
14. Do you consider the passive solar features of your house the primary heating system or an auxiliary system?	☐	☐

15. Please use the rest of this page for any additional comments you would like to make. Thank you again for your help with this survey.

APPENDIX C: PERFORMANCE EVALUATION

This information is provided as a starting point for a designer or builder interested in determining the energy performance of a passive solar house. Quantities can be added or removed to "customize" the evaluation for a particular firm's needs.

Project Name:____________________ Project Location:____________________

Prepared By:______________________________________ Date:____________

ONE TIME MEASUREMENTS AND CALCULATIONS

Quantity	Required for all buildings	Required as appropriate	Units	Included in Instrum. Plan Yes	No
Overall building conduction heat loss coefficient	X		W/°C	---	---
Wall and ceiling conduction heat loss coefficient		X	W/°C	---	---
Floor conduction heat loss coefficient		X	W/°C	---	---
Movable insulation heat loss correction factor		X	W/°C	---	---
Pascal building air change rate	X		ACH	---	---
Air infiltration	X		m^3/h	---	---
System efficiency of auxiliary heating system	X		-	---	---
Water heater jacket heat loss rate	X		W	---	---
Clothes dryer energy use rate		X	X	---	---
Solar operating energy use rate		X	W	---	---
Ventilation fan energy use rate		X	W	---	---
Ventilation flow rate	X		m^3/h	---	---

Quantity	Required for all buildings	Required as appropriate	Units	Included in Instrum. Plan Yes	No
Other internal heat gain adjustment		X	W	---	---
Heat gain rate from occupants	X		W	---	---
Apparent indoor set point temperature	X		°C	---	---
Heated floor area	X		m^2	---	---
Heated volume of house	X		m^3	---	---
Solar aperture area	X		m^2	---	---
Building effective thermal mass capacitance	X		MJ/°C	---	---

SYMBOL LEGEND	
Symbol	Description
W/°C	Watts per degree Celcius temperature difference between the building interior and exterior.
ACH	Air changes per hour
m^3/h	Cubic meters of air per hour
MJ/°C	Megajoules per degrees Celcius change in temperature

Project Name:____________________ Project Location:____________________

Prepared By:______________________________________ Date:__________

CONTINUOUS MEASUREMENTS

	Quantity	Designation	Required or optional	Typical sensor	Included in Instrum. Plan Yes	No
Outdoor Environment	Solar radiation	I_h	Required	pyranometer	---	---
	Wind velocity	W	Optional	anemometer	---	---
	Outdoor temperature	T_O	Required	temperature sensor	---	---
Indoor Environment	Primary zone temperature	T_I	Required	temperature sensor	---	---
	Secondary zone temperature	T_2	Required	temperature sensor	---	---
	Other indoor temperature(s)	$T_3, T_4, \ldots$	As necessary	temperature sensor	---	---
	Basement temperature sensor	T_b	Required	temperature	---	---
	Radiant temperature temperature	T_r	Optional	black globe sensor	---	---
	Relative humidity	RH	Optional	humidity sensor	---	---
Energy Use	Total electricity use	E_{elec}	Required	pulse-initiating kWh meter	---	---
	Purchased energy use	E_{auxh}	Required	pulse-initiating kWh meter	---	---

	Quantity	Designation	Required or optional	Typical sensor	Included in Instrum. Plan Yes	No
Energy Use	Purchased energy for auxiliary heating	E_{auxh}	Required	pulse-initiating gas or oil flow meter	---	---
	Purchased energy for lights & appliances	E_a	Required	pulse-initiating kWh meter	---	---
	Purchased energy for water heating	E_w	Required	see auxiliary heating	---	---
	Purchased energy for clothes dryer	E_d	As necessary	status relay	---	---
	Purchased energy for other uses	E_{other}	As necessary	kWh transducer	---	---
	Purchased energy for auxiliary cooling	E_{auxc}	As necessary	kWh transducer	---	---
	Operating energy	E_{op}	As necessary	status relay	---	---
System Operation	Movable insulation operating time	t_{mi}	As necessary	status switch	---	---
	Control element operating time	t_{s1}-t_{s8}	Optional	status relay or switch	---	---
	Primary storage temperature	T_{ps}	Optional	temperature sensor	---	---
	Secondary storage temperature	T_{ss}	Optional	temperature sensor	---	---