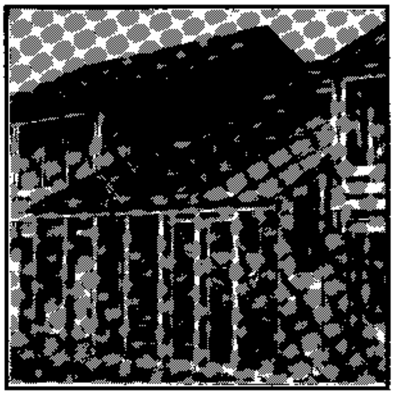
PASSIVE AND HYBRID SOLAR LOW ENERGY BUILDINGS

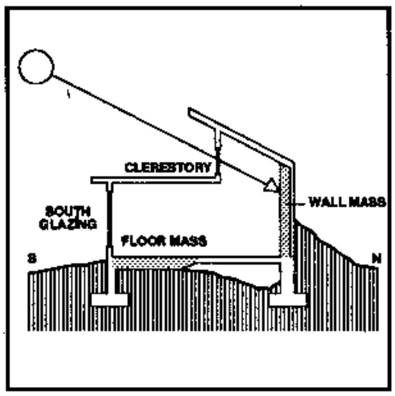
DESIGN GUIDELINES: AN INTERNATIONAL SUMMARY

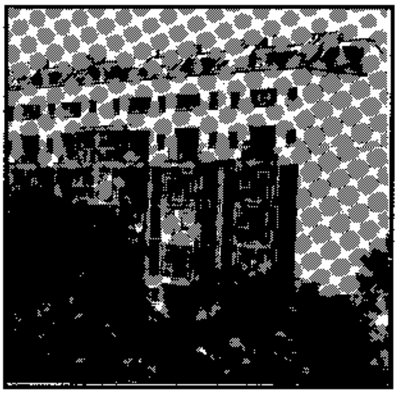
3

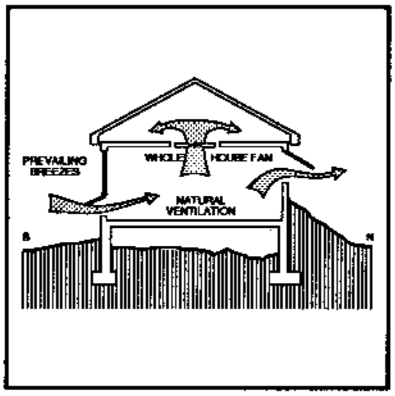
DESIGN INFORMATION BOOKLET NUMBER THREE

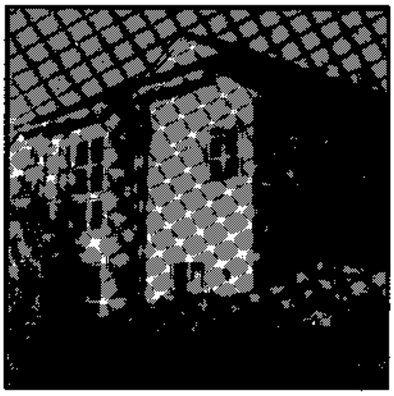
JULY 1990

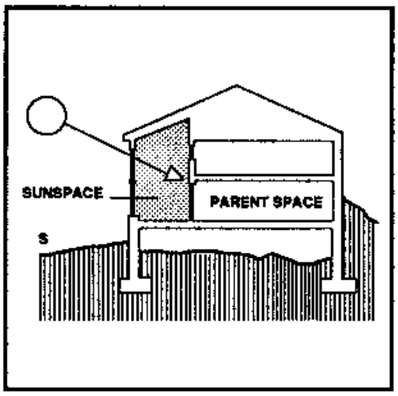


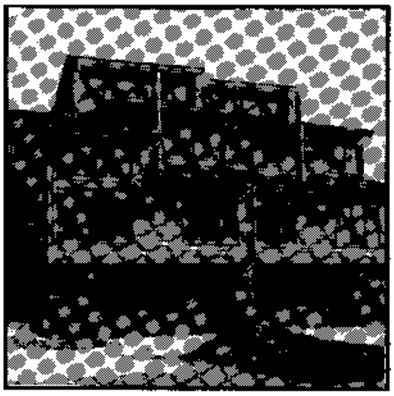


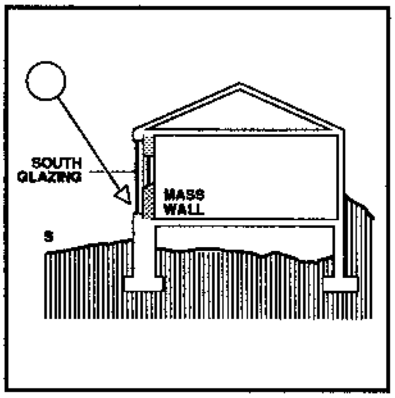












INTERNATIONAL ENERGY AGENCY: SOLAR HEATING AND COOLING PROGRAM

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PASSIVE AND HYBRID SOLAR LOW ENERGY BUILDINGS

DESIGN GUIDELINES: AN INTERNATIONAL SUMMARY

3

DESIGN INFORMATION BOOKLET NUMBER THREE

JULY 1990

Michael J. Holtz
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, the United Kingdom, and the 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:

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 0E4

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

Germany
Projektieitung Biologie, Okologie 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 Byggtjttnst,
LitteratutjAnst
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.

DESIGN INFORMATION BOOKLET SERIES

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 IEA 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

Mr. Michael Holtz of Architectural Energy Corporation is responsible for the preparation of this document. He was assisted by Mr. Ralph Tavino, Mr. Chris Mack, Ms. Susan Hollingsworth, and Ms. Tracy Ashleigh, all of Architectural Energy Corporation, in building energy analysis, graphic design, and camera-ready preparation. Their assistance is gratefully acknowledged. Mr. Holtz wishes 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, Mr. Sergio Los, and Ms. Sheila Blum. Also, the authors of the National Design Guidelines Booklets are acknowledged for their efforts to perform the building energy analyses of various energy conservation and passive solar design features that have led to the development of the national design guidelines.

The support of the U.S. Department of Energy Solar Building Program is gratefully acknowledged, especially that of Dr. Frederick Morse, Ms. Mary-Margaret Jenior, Mr. Robert Hughey, and Mr. Michael Lopez.

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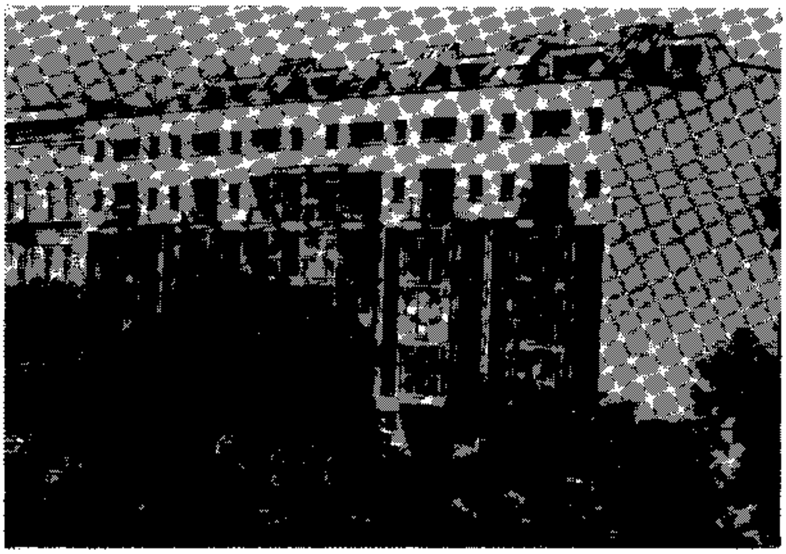
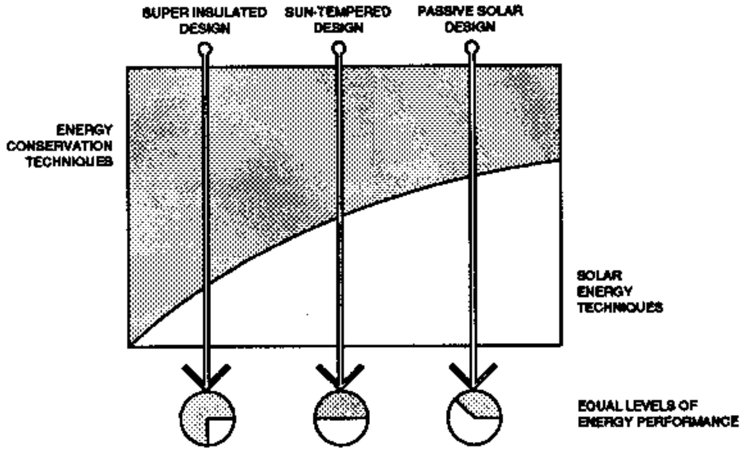


INTRODUCTION 1.0

Energy efficiency and comfort in residential buildings are best achieved through the intelligent blending of energy efficiency and solar energy design principles. It is possible to obtain equal levels of energy performance from different combinations of energy conservation and solar design features (Figure 1.1). Flexibility exists in the planning and design of an energy-efficient house or housing project. The choice of balance between energy conservation and solar design features becomes one of designer preference, site requirements, climatic conditions, marketing considerations, construction budget, and client needs, lifestyle and goals. Energy efficiency is always the first priority. However, passive solar and efficient mechanical system design are essential for achieving a truly integrated and effective residential energy design solution.



1.1: Residential Energy Design Alternatives

As part of collaborative research on passive and hybrid solar low energy home design, the 14 countries participating in the International Energy Agency project developed national guidelines for designing energy-efficient, passive solar homes. These guidelines, available from the organizations listed in the Foreword, provide a point of departure for passive solar home design in terms of recommended insulation levels, infiltration/ventilation rate, glazing type and area, thermal mass level, thermal zoning and other key energy design features. These guidelines consider the need for balanced heating and cooling season performance to obtain year-round comfort and low energy costs.

The national design guidelines were, in most cases, generated through an integrated process of climate analysis, energy analysis, and economic analysis. As a result, the guidelines represent cost-effective levels of energy conservation and passive/hybrid solar design. Obviously, assumptions have been made in the analysis. Consequently, careful review and perhaps further energy and economic analysis may be necessary to ensure optimal performance. The guidelines should be seen as a starting point for developing a new home design or as the basis of comparison for evaluating and modifying an existing home design.

The national design guidelines have been developed with the following criteria in mind:

FLEXIBILITY:	Enhance flexibility in siting and designing energy-efficient, passive solar homes.
AFFORDABILITY -ENERGY SAVINGS:	Significantly reduce energy consumption and costs while (1) lowering the home-owner's total annual mortgage and energy payments below that of a conventional home, and (2) minimizing the extra cost for the energy-saving features.
DURABILITY:	Improve overall durability and reliability of the home through appropriate solar and energy conservation construction detailing, especially moisture-related issues.
AIR QUALITY:	Maintain adequate levels of indoor air quality through appropriate material selection and ventilation strategies.
AMENITY AND COMFORT:	Provide a quiet and dust-free interior environment that is adequately daylit and comfortable year-round.
MARKETABILITY:	Improve marketability and resale value of the home due to solar and energy conservation features.

This Booklet summarizes the "patterns of performance" that have emerged from the national design guidelines. That is, the application of various energy conservation and passive solar design features has shown similar energy-saving effects in a variety of climates. The magnitude of these effects may vary by climate but the pattern of performance has remained constant. Therefore, it is possible to state some general rules or guidelines for the design of energy-efficient, passive solar homes. The purpose of this Booklet is to present these general energy-saving design rules and to refer the reader to the national guidelines booklets for specific design guidance.

Home designer and builder experience has shown that careful planning and design can significantly reduce problems during construction, marketing, and occupancy. This same principle applies to achieving energy savings. Carefully selecting, integrating, and detailing low cost, high performance energy-saving features during the design phase will reduce the number of more costly changes required during the construction phase and enhance occupant satisfaction and comfort. This international summary booklet, as well as the national design guidelines booklets, have been prepared to assist the home designer and builder during the design process.

WHY ENERGY-EFFICIENT, PASSIVE SOLAR HOME DESIGN?

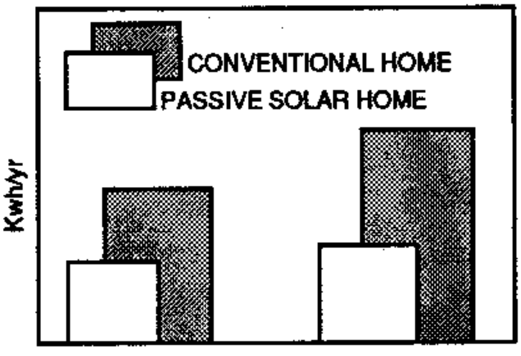
Three excellent reasons to design, build, or own an energy-efficient, passive solar home are:

1. It uses significantly less energy than a conventional home without the energy-saving design features; consequently, it costs less to operate. Reducing a building's heating and cooling needs means lower monthly utility bills. With the use of energy-efficient appliances, these monthly fuel costs will be even lower.

2. It is more comfortable than a conventional home. Tight construction, improved windows, a concern for interior air flow, passive solar gains, and proper shading create a draft-free indoor environment for year-round comfort.

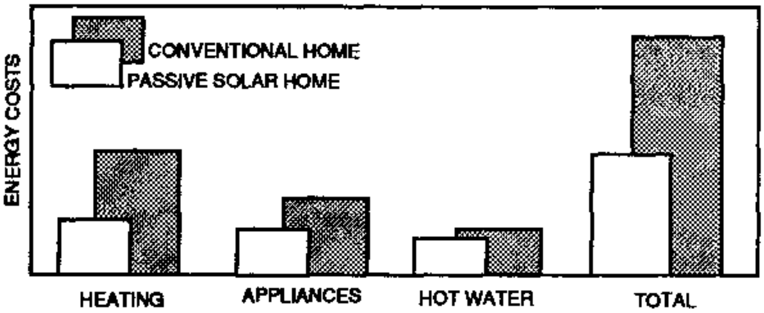
3. It is more marketable and will have a higher resale value. Energy performance remains one of the most important homebuyer considerations in many countries.

To illustrate the energy and cost-saving characteristics of an energy-efficient, passive solar home, a hypothetical comparison is made between a conventional single-family home built to current practice levels of insulation and an energy-efficient, passive solar home built according to the design guidelines suggested in this Booklet. As shown in Figure 2.1, the energy-efficient passive solar home uses substantially less energy than the conventional home.



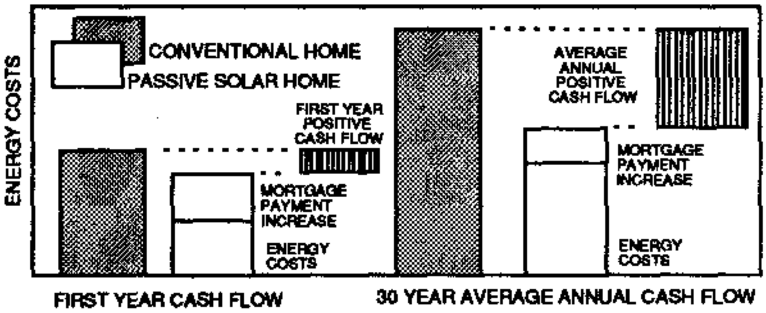
2.1: Energy Use Comparison

Consequently, the annual operating costs of the energy-efficient, passive solar home will be less than the conventional home, as shown in Figure 2.2, especially if energy-efficient appliances and a domestic water heater are also used.



2.2: Annual Total Energy Costs

With reduced energy costs, the first year cash flow for home ownership can be lower for an energy-efficient, passive solar home than for a conventional home, as illustrated in Figure 2.3.



2.3: Cash Flow Benefits

Although construction costs may increase for the energy-efficient, passive solar home, the annual energy costs drop considerably faster than the extra mortgage costs increase, leading to an immediate positive cash flow for the homeowner. Over the life of the mortgage, the average annual savings will increase due to the rising cost of energy. Consequently, if the home's energy performance is considered by the lending institution, the loan qualification potential of the homebuyer will be enhanced. This approach, known as the energy mortgage concept, is gaining acceptance in lending institutions throughout the International Energy Agency member countries.

Why buy or build an energy-efficient, passive solar home? An energy-efficient, passive solar home is not only affordable, durable, healthy, comfortable, and energy-efficient, it is also a good investment, provides security against the uncertainty of future energy prices, and is part of a larger solution to minimize global warming.

CLIMATIC CONSIDERATIONS 3.0

Sun, wind, temperature, humidity, and many other factors shape the climate of the earth. Basic to the design of energy-efficient, passive solar homes is understanding the relationship between climate and building energy performance.

3.1 DEFINITION OF CLIMATE

Climate (from Greek "Klima") is defined by the American Webster dictionary as "the average course or condition of the weather at a place over a period of years..." Since weather is the momentary state of the atmospheric environment (temperature, wind velocity, and precipitation at a particular location), climate could be defined as the sum total of all the weather that occurs at any place. Like the weather, climates are directed by the sun and are influenced by all the physical conditions of the earth - the nearness of an ocean, the presence of a mountain, prevailing winds, and so on. The climates of particular localities are comparatively constant, and despite pronounced and rapid changes, have an inherent character of weather patterns that repeat themselves time and again. Cold days occasionally occur in hot climates, and hot days are not unknown in cold climates; dry climates often have rainy periods, and wet ones, extended periods of drought. Even so, every place on the face of the earth over an extended period of time exhibits its peculiar combination of heat and cold, rain and sunshine.

3.2 CLIMATIC FACTORS

Global climatic factors such as solar radiation at the Earth's surface, tilt of the Earth's axis, air movement, and the influence of topography determine the climatic make-up of any area on Earth. These factors will determine the temperature, humidity, solar radiation, air movement, wind, and sky conditions for any specific location. Regional patterns of climate will emerge from a commonality among these climatic influences. Local climates are additionally influenced by site topography, ground surface, and three dimensional objects. The sum total of the above climatic factors will determine the need for and the design of energy-efficient, passive solar homes and sites. In essence, climate is the given condition within which energy-efficient, passive solar homes are designed.

3.3 CLIMATE-RESPONSIVE DESIGN

In response to these differing climatic conditions, housing styles in one area of the world have developed which are substantially different than those found in other areas. This same differentiation will be particularly true for houses that use energy from the sun and other local environmental sources for heating and cooling. A main purpose of this IEA project has been to understand the design and performance of buildings using active and passive solar and energy conservation technologies, the interactions of these technologies, and their effective combination in different climatic regions.

3.4 CLIMATE SIMILARITY INDEX

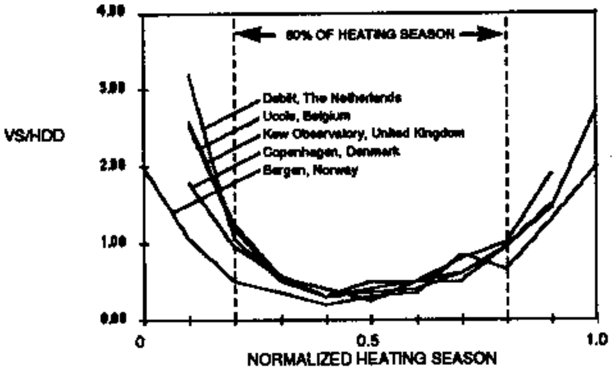
A climate similarity index, based on the work of Derickson and Holtz (1), was used to group various cities into climate regions for purposes of design guidelines development. The climate similarity index for heating (CSI_H) is a measure of similarity between climates based on the ratio of incident solar radiation on a sun-facing vertical surface (VS) to the total of heating degree days (HDD). The time period of interest is the number of days in whole months most nearly approximating 60% of the heating season for a given location. The heating season is defined as that portion of a year during which monthly heating degree day totals exceed 139°C-day (18.3°C Base). The VS/HDD ratio is calculated first on a monthly basis, then on a time-averaged basis.

Table 3.1 presents HDD and VS totals for 60% of the heating season, as well as the 60% seasonal CSI_H for 22 cities from various IEA countries. These cities are organized into 8 climate groups. The criterion for composition of these groups is a ± 5% range in CSI_H between cities at the extremes of a group and a mean value for the group.

City	HDD	VS	CSI_H	Climate Group
Milan	1382	457	0.34	1
Vienna	2096	758	0.37	1
Stockholm	3008	1114	0.37	1
Copenhagen	2535	1055	0.43	2
Debilt	1788	758	0.43	2
Uccle	2203	945	0.44	2
Bergen	2803	1205	0.44	2
Kew	1933	852	0.45	2
Salzburg	2721	1268	0.48	3
Zurich	2452	1143	0.48	3
Winnipeg	4556	2315	0.52	4
Ottowa	3722	1902	0.52	4
Venice	1266	660	0.52	4
Vancouver	2059	1092	0.54	4
Geneva	1802	941	0.54	4
Madison	3400	1852	0.55	4
Edmonton	4564	2636	0.63	5
Washington	1370	998	0.73	6
Rome	964	944	0.98	7
Madrid	1100	1081	0.99	7
Denver	1978	2045	1.04	7
Albuquerque	1389	1840	1.33	8

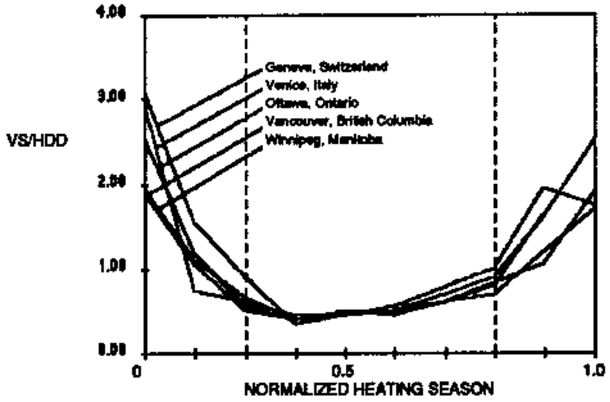
TABLE 3.1 Climate Similarity Table

Figures 3.1, 3.2 and 3.3 demonstrate the climate similarity concept for three climate groups. The VS/HDD ratio is plotted over a normalized heating season for selected cities in each climate group. The dashed vertical lines represent 60% of the heating season. The close agreement of the VS/HDD ratio among the cities in each climate group demonstrates the climate similarity of the cities during the heating season.



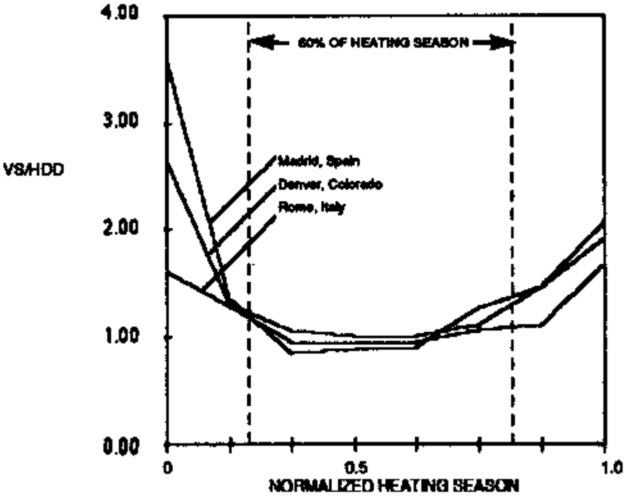
3.1: Climate Similarity Group

CLIMATE SIMILARITY GROUP 2



3.2: Climate Similarity Group

CLIMATE SIMILARITY GROUP 4



3.3: Climate Similarity Group

CLIMATE SIMILARITY GROUP 7

3.5 REPRESENTATIVE CITIES

For purposes of presenting the "patterns of performance" that emerged from the national design guidelines, three cities representative of diverse climate groups have been selected - Copenhagen, Denmark; Geneva, Switzerland; and Denver, Colorado (USA). Copenhagen is representative of a relatively cold, cloudy climate; Geneva is representative of a moderate continental climate; and Denver is representative of a cold, sunny climate. Climate data for these three cities are summarized in Table 3.2.

City	CSI_H	Avg Winter Temp °C	Avg Winter Global Irradiation GJ/m^2	Vertical Solar Radiation (January) GJ/m^2	Avg Summer Temp °C
Copenhagen	0.43	4.3	204	.101	15.5
Geneva	0.54	6.8	225	.145	18.1
Denver	1.04	2.2	403	.546	17.1

TABLE 3.2 : Representative Cities Climate Information

Copenhagen, Geneva and Denver will be used in Chapter 4.0 as cities representative of diverse climates to illustrate the energy saving effects of various energy conservation and passive solar design features. The previously described "patterns of performance" will be evident when reviewing the results.

This chapter presents the general design principles - patterns of performance - that have emerged from the analysis and testing of energy-efficient, passive solar homes in the 14 participating countries. Three locations - Copenhagen, Geneva, and Denver - are used as cities representative of diverse climate conditions. A single-family detached housing configuration is initially used to illustrate the energy design principles. However, single-family attached and multifamily housing configurations are considered in Chapter 5.0, Energy-Saving Combinations.

The intent of this chapter is to illustrate general residential energy principles, not to present location-specific design guidelines or recommendations. For this, the reader is referred to the National Design Guidelines Booklets, available from the organizations listed in the Foreword.

Energy considerations alone should not govern the design of homes. However, many of the design features that save energy, such as high performance glazing, thermal mass, or a sunspace, are also an amenity to the overall home design. For this reason, the choice of appropriate energy-saving strategies should be governed by their energy-saving potential as well as their amenity value.

Experience in designing, analyzing, constructing, and testing energy-efficient, passive solar homes throughout the world has shown that a high level of thermal performance can be achieved simply and without sacrificing design flexibility. The key elements of this integrated residential energy design approach are the following:

ELEMENTS OF INTEGRATED RESIDENTIAL ENERGY DESIGN

1. Proper Site Planning - Protecting solar apertures (windows or active collectors) from unwanted shadows of adjacent buildings or trees during the heating season and fostering natural air movement into and through the site during the cooling season are essential site planning considerations for the design of energy-efficient solar homes.

2. Improved Insulation Levels - Generally, an improvement in wall, ceiling, and floor insulation levels over current practice is required to improve the thermal integrity of the building envelope, thus reducing the heating and cooling loads.

3. Greater Air Tightness - Reducing air infiltration saves energy and improves comfort. This requires a continuous vapor and air barrier, high quality doors and windows, careful construction detailing and supervision, and mechanical ventilation with heat exchange for maintaining acceptable interior air quality.

4. Proper Glazing Selection - The choice of glazing type (double, triple, or double with a low emissivity coating) will determine the passive solar potential in each climate (positive window energy balance). Different glazing types may be used for each window orientation to optimize overall building performance.

5. Proper Window Sizing and Location/Orientation - Size for balanced heating and cooling season performance. Simple redistribution of windows from non-south to southern orientations (in northern latitudes) can result in large energy savings at no additional cost.

6. Add Thermal Mass (in lightweight buildings) - Thermal mass, properly sized and located in the building, may reduce seasonal heating and cooling loads and improve comfort. Greater solar aperture area generally requires greater thermal mass exposed to direct radiation. How the thermal mass is integrated into the building will generally determine its energy and economic performance. This can also be influenced by the mode of building operation; for example, intermittent heating can counter the effectiveness of added thermal mass in reducing heating demand in some climates.

7. Properly Shade All Windows - Eliminating or reducing unwanted solar gains during the summer months is essential for maintaining comfort and reducing mechanical cooling loads. Seasonal shading devices are more effective than fixed overhangs but require occupant intervention.

8. Proper Interior Thermal Zoning - Interior space planning should provide for the efficient distribution of passive solar gains in winter and the effective movement of air for ventilation in summer.

9. Proper Seasonal Ventilation - Eliminating excessive heat gain through appropriate ventilation strategies is essential to maintaining interior comfort during both the heating and cooling seasons. Natural or forced whole house ventilation can improve comfort during the overheated periods of the year. Additionally, paddle fans are an effective cooling strategy in many climates.

10. Efficient Auxiliary Heating and Cooling Systems and Controls - High performance heating, cooling, and hot water systems should be sized and designed for the low energy loads of energy-efficient passive solar homes. Additionally, proper controls must be chosen to operate mechanical equipment reliably and efficiently.

Following this simple and sensible design approach will result in balanced heating and cooling season performance, comfort, and low energy costs. Each of these ten integrated residential energy design principles is discussed in greater detail in the remainder of this Chapter.

BASE BUILDING DESCRIPTION

To illustrate the energy performance characteristics of the various residential energy design principles (guidelines), a comparison will be made between a single-family detached house that is designed with and without the particular energy-saving feature. Two reference or base houses will be used as the basis of comparison; a lightweight house typical of construction in the United States, Canada, Scandinavia, and New

Zealand; and a heavyweight house typical of construction in central and southern Europe. The characteristics of the two base buildings are summarized in Table 4.1 These building characteristics are not representative of any specific country. Rather, they are representative of average conditions for all 14 participating countries based on a survey of conventional building practice undertaken as part of this IEA project (2).

Base Building Characteristics	**Lightweight Building**	**Heavyweight Building**
Building Size (m^2)	108	108
Building Volume (m^3)	270	270
Insulation (m^2·k/w)		
Wall	1.93	1.93
Ceiling/Roof	3.30	3.30
Floor	1.93	1.93
Windows		
Total Area (m^2)	10.8	10.8
Glazing Type	Double	Double
Distribution	2.7m^2 all sides	2.7m^2 all sides
Summer Shading Factor	1.0	1.0
Thermal Capacitance	5,013KJ/°C	18,876 KJ/°C
Infiltration Rate	0.5 ACH	0.5 ACH
Internal Gains (kWh/day)	0.5	0.5
Thermostat Setpoint (°C)	20°	20°
Venting Setpoint (°C)		
Heating Season	25.64°	25.64°
Cooling Season	21.10°	21.10°

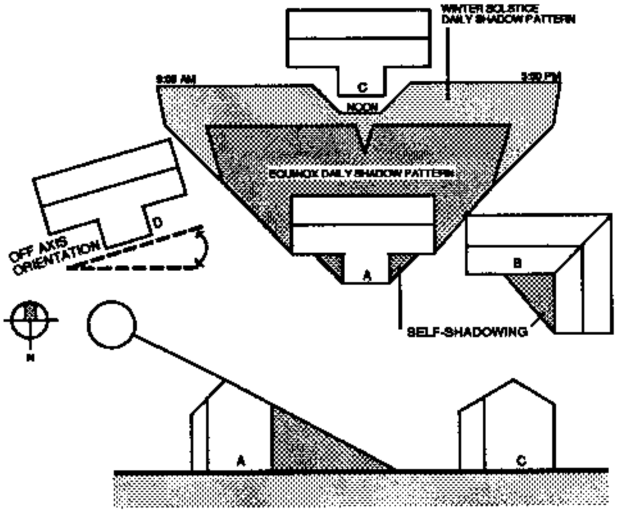
TABLE 4.1: Base Building Characteristics

The base buildings are analyzed, using typical meteorological year data for Copenhagen, Geneva, and Denver with the SUNCODE-PC program, a detailed hourly building energy analysis simulation (3). SUNCODE-PC has been thoroughly evaluated and verified as part of IEA project activities (4, 5), and was used as the common analytical tool by many of the participating countries.

4.1 SITE PLANNING FOR ENERGY EFFICIENCY

A concern for energy-efficient, passive solar housing must begin at the site planning scale. Establishing an effective land use plan is as important an energy consideration as proper building design. See Booklet No. 2 - Design Context for further information on site planning considerations.

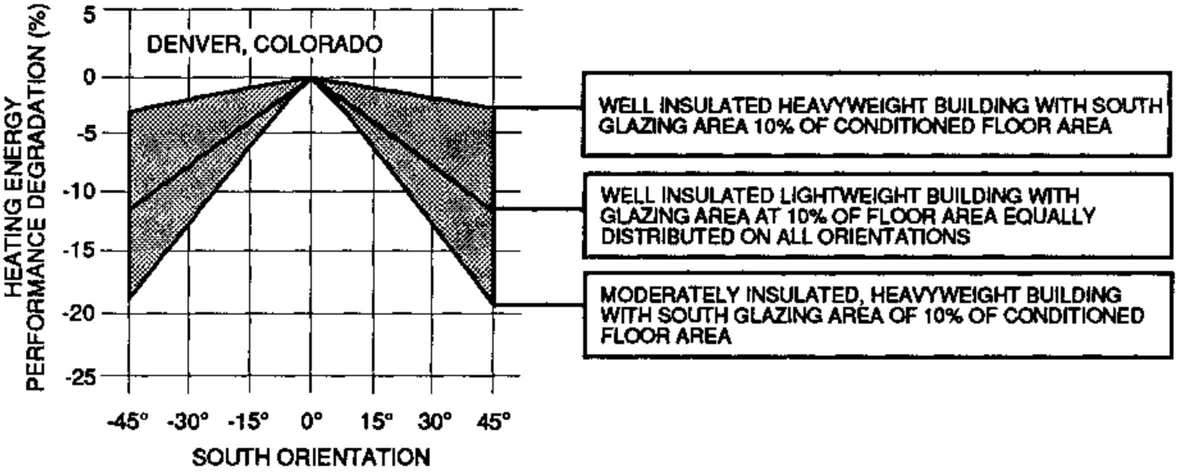
During the heating season, protecting solar apertures (windows or active collectors) from unwanted shadows of adjacent buildings or trees is a primary site planning concern. Figure 4.1 illustrates several of the major site planning considerations. Buildings should be situated so that full solar access is achieved on the solar collection apertures between 10:00 am and 2:00 pm. Also, the building itself should be designed to minimize unwanted self-shadowing from wingwalls and other building appendages (as in buildings A and B). L-shapes and other building shapes are possible so long as one is careful about window placement and shading from steep roofs. Some communities have adopted solar access ordinances. These ordinances will define the specific requirements that must be followed to protect solar access of your building site or an adjacent building site.



4.1: Site Planning Considerations

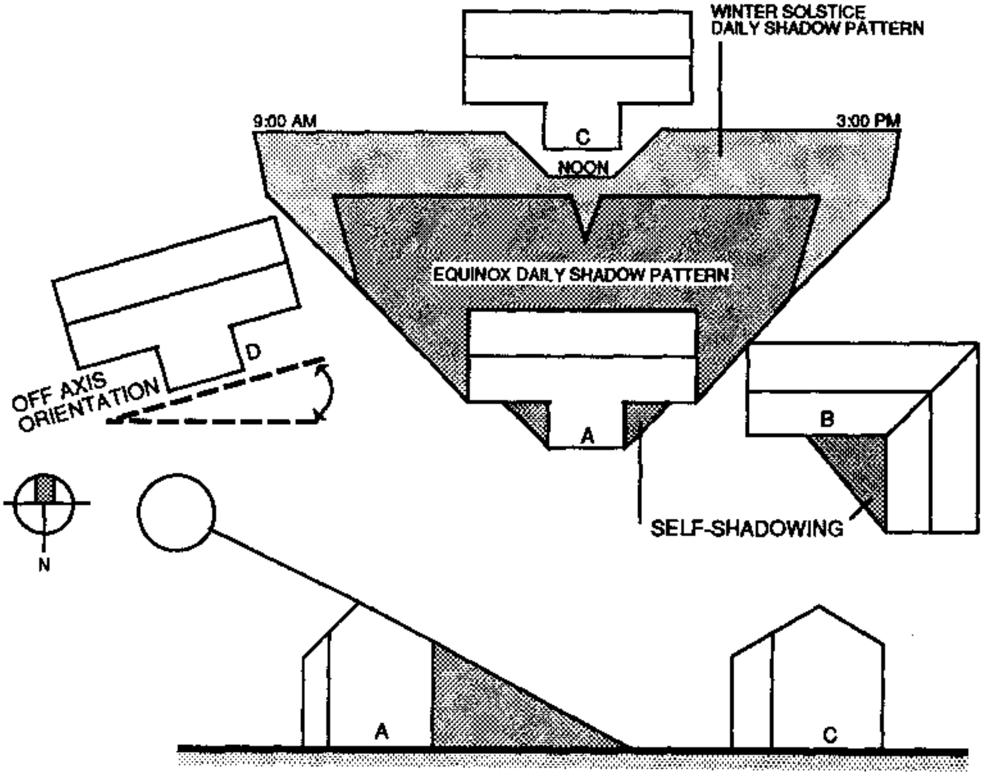
Orientation of the primary solar collection aperture within 10° of true south (in northern latitudes) is preferable in most locations. As Figure 4.2 shows, initial deviation from true south results in only a minor degradation in building energy performance. However, beyond 15°, building energy performance drops off rapidly. Micro-climatic conditions will influence the appropriate orientation of solar collection apertures. Building sites with regular morning fog during the heating season should orient windows 10° to the west. Building sites with afternoon clouds or mountain shadowing should shift window orientation 10° to the east.

Off-south orientation of the primary solar apertures. usually results in greater summer overheating. Consequently, more attention to solar control (shading) strategies will be necessary to ensure summertime comfort.



4.2: Heating Energy Performance Degradation for Off-South Orientations

Natural air movement through the site may be an important consideration for locations with extended overheated periods during the summer months. Topography, vegetation, and man-made objects (fences, walls) can be used to channel the wind into and through the house, thus providing natural ventilative cooling.



4.3: Site Planning for Overheated Periods in Northern Latitude

4.2 IMPROVED INSULATION LEVELS

Adding insulation over current levels to the building envelope (walls, floor, ceiling, and foundation) is typically one of the most cost-effective energy design strategies. Table 4.2 lists insulation values for three levels of thermal integrity. Figure 4.3 shows the impact of each of these levels of thermal integrity for the lightweight and heavyweight buildings in the three representative climates for a range of south glazing area.

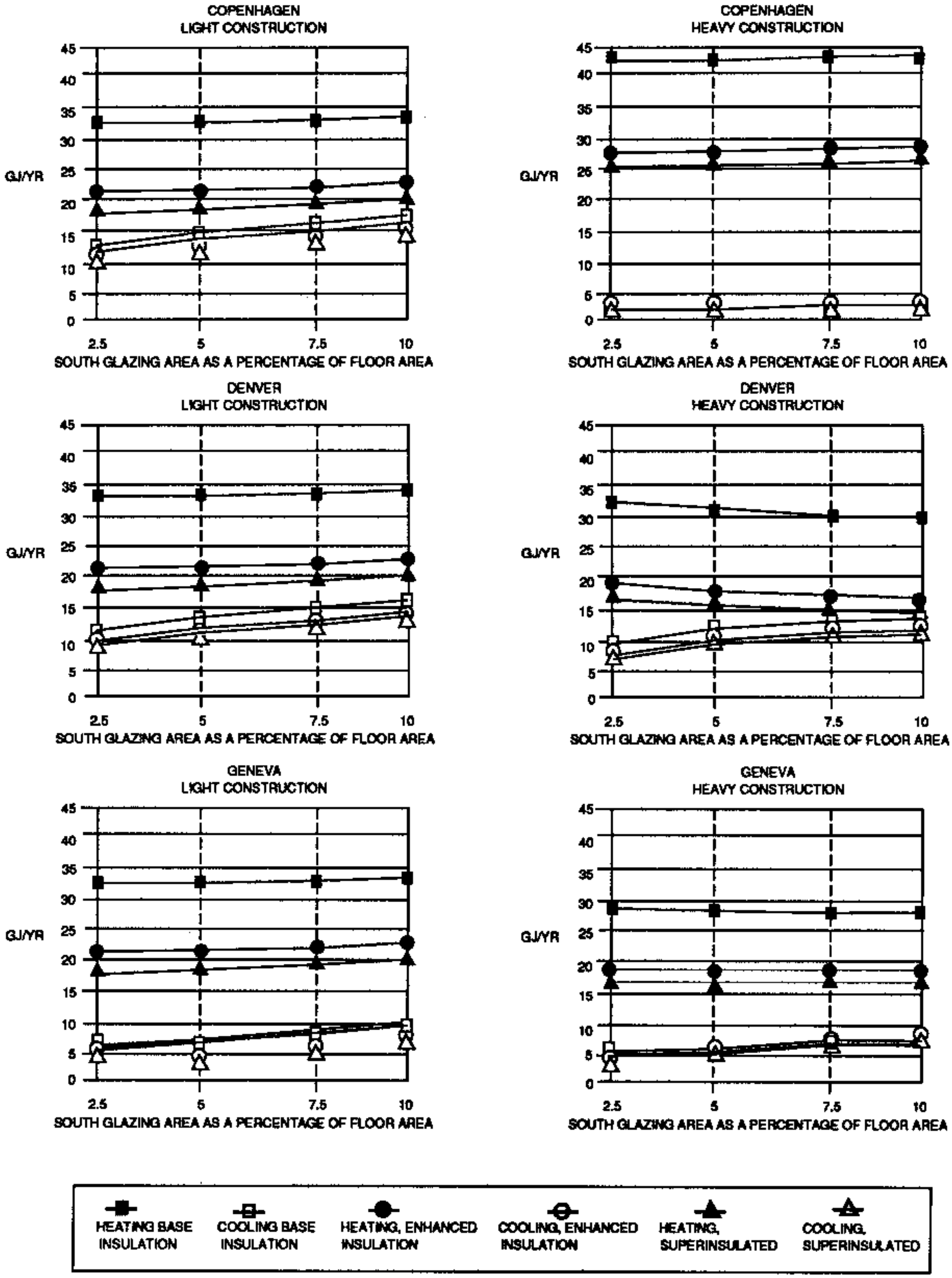
The first increment of improvement in building envelope insulation has the greatest impact on the heating and cooling loads in all three climates. For lightweight construction, the heating and cooling loads increase as south-facing window area increases. However, for heavyweight construction, the heating load decreases as south-facing window area increases. This decrease is small in more cloudy climates such as Copenhagen, and is larger in sunnier climates such as Denver.

The cooling load increases with larger south window area in all climates regardless of insulation level or construction type. This demonstrates the relationship of cooling load to window solar gains. No summertime shading is applied to the windows in the analysis.

Because energy conservation is always the first priority in integrated residential energy design, thermal integrity level 2 insulation values will be used in the base buildings in future design guideline discussions.

Building Description	**Wall Insulation ($m^2 \cdot k/w$)**	**Floor Insulation ($m^2 \cdot k/w$)**	**Ceiling Insulation ($m^2 \cdot k/w$)**
1. Base Building	1.93	1.93	3.30
2. Enhanced Building	3.30	3.30	6.65
3. Superinsulated Building	4.21	3.30	8.60

TABLE 4.2: Insulation RSI-Values for Three Levels of Thermal Integrity



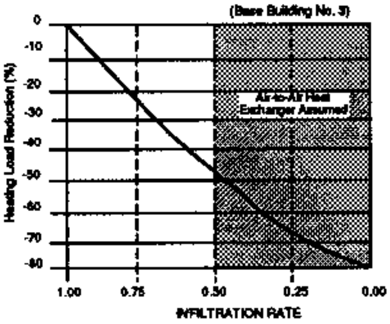
4.3: Impact of Insulation Levels on Heating and Cooling Season Performance

4.3 GREATER AIR TIGHTNESS

Reducing air infiltration will reduce energy consumption in both the heating and cooling season, improve comfort, and minimize moisture damage due to water vapor in wall and ceiling cavities. Figure 4.4 shows the reduction in annual heating load for different air infiltration rates specified in Air Changes per Hour (ACH).

The key to effectively reducing infiltration is the continuous air barrier. To be effective, air barriers must be: (1) continuous, (2) impermeable to air, (3) able to withstand air pressure differences due to mechanical ventilation, stack and wind loads and (4) durable. A continuous air barrier can be achieved in heavyweight buildings through proper material/product selection and construction detailing, and in lightweight buildings through the use of a polyethylene wrap and proper construction detailing.

Table 4.3 identifies various design and construction practices used to reduce air infiltration. Typically, a combination of techniques is required to achieve a low infiltration rate. Quality workmanship is mandatory and frequent construction inspection is necessary to insure that the infiltration reduction measures are carefully and correctly installed.



4.4: Sensitivity of Heating Load to Infiltration Rate

Only through actual measurement is it possible to determine the level of infiltration in a building. Building pressurization and infrared photography techniques can be used to locate sources of infiltration so that they can be plugged. Also, a tracer gas technique can be used to determine the average infiltration rate during the heating and cooling season. One or more of these measurement techniques should be used to assess construction quality control.

If an infiltration rate below 0.5 ACH is anticipated, mechanical ventilation, usually with an air-to-air heat exchanger, is recommended to maintain acceptable levels of indoor air quality. Even at higher infiltration rates, indoor air quality may be adversely impacted by the choice of building materials and products. Care should be taken to select those materials and products that do not "outgas" harmful pollutants. Additionally, in locations with significant levels of radiation in the soil, mitigative techniques should be employed to prevent radon gas from the ground entering the building through the basement floor or walls, or other openings in the foundation system.

	ACH	Design and Construction Guidelines
Current Practice	0.6-0.8	Standard design and construction practice All doors and windows caulked and weatherstripped
Energy-Efficient Homes (A)	0.3-0.5	Current practice measures plus: • Low infiltration windows • All ceiling wall and floor penetrations sealed • Continuous air/vapor barrier on walls, floor, and ceiling • Outside air to combustion-type heating system • Rough opening seals • Storm doors or airlock entry
Super Tight Construction (A,B)	<0.3	• Minimum ceiling, wall, and floor penetrations • Continuous air barrier (permeable to water vapor) on exterior wall sheathing Note A: Any number of combination of air infiltration reduction measures can be used to achieve this air infiltration rate. B: Mechanical ventilation recommended to maintain indoor air quality.

TABLE 4.3: Infiltration Reduction Alternatives

4.4 PROPER GLAZING SELECTION

Choice of glazing type - double, triple, double with a low emissivity coating (low E), or gas filled - will determine the passive solar potential for a specific location. Passive solar potential means that the solar heat gain through one square meter of glazing during the heating season is greater than the corresponding heat loss. Thus, the passive solar heat gain is contributing to reducing the auxiliary heating energy requirement. The passive solar potential will obviously vary by glazing type and orientation, envelope insulation levels and building thermal mass level.

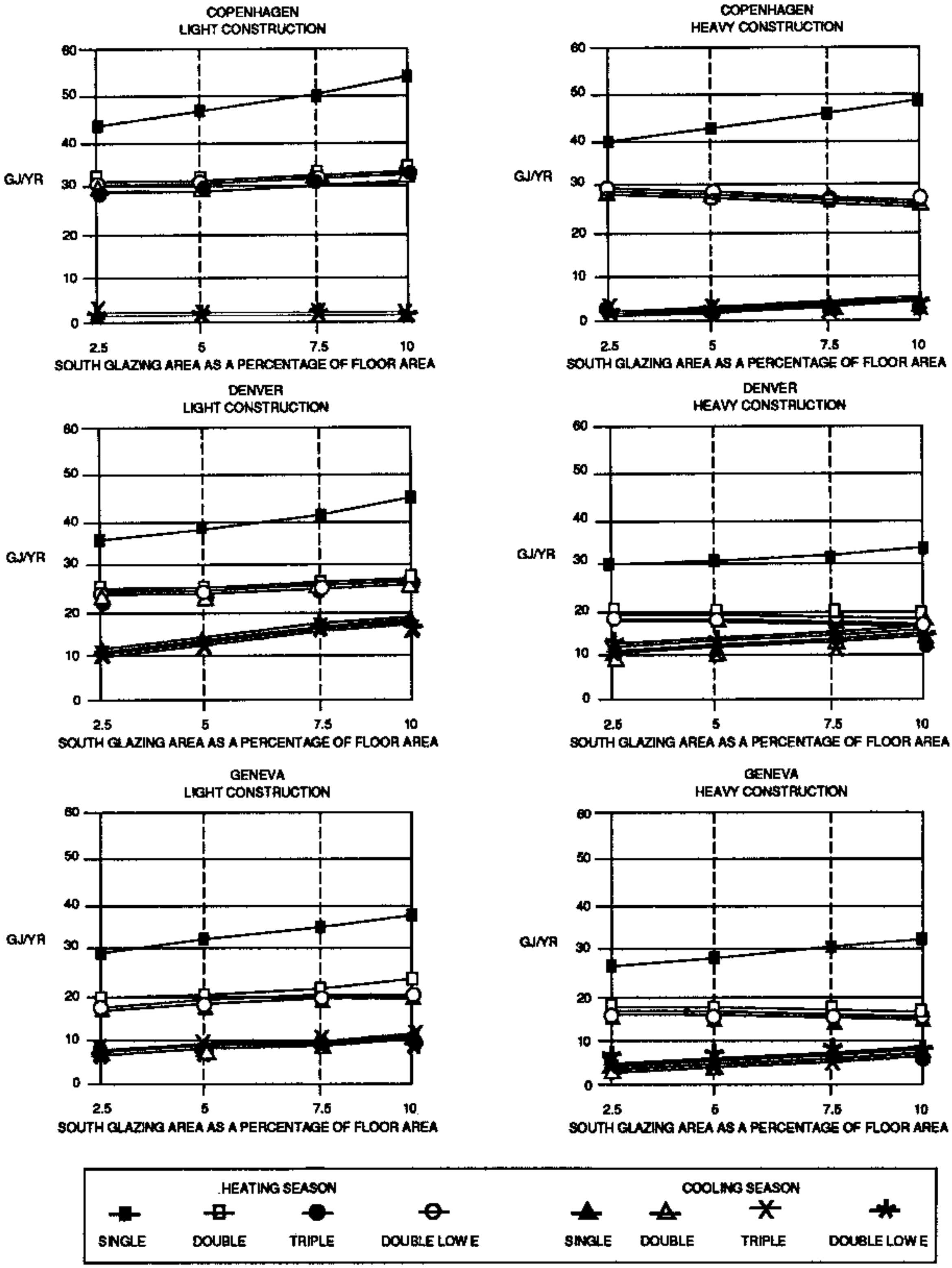
Figure 4.5 shows the performance of four glazing types for different south window areas in the two base buildings in the three representative climates. The glazing on the east, west, and north orientations remains constant while the south glazing increases from 2.5% to 10% of the conditioned floor area.

The figures illustrate the dramatic improvement in heating season performance achieved by double, triple, and double low E glazing over single glazing. However, the performance variation between double, triple, and double low E glazings is not large, on the order of 10%. Thus, the choice of glazing type will most likely be governed by cost and comfort considerations.

For lightweight construction, the heating load increases for all glazing types, except double low E, in all climates as the south glazing area increases. This demonstrates that for this particular combination of building loss coefficient, thermal capacitance and glazing area, the passive solar potential is negative for all glazing types except for double low E glazing at approximately 5% of floor area.

For heavyweight construction, the heating load increases for single glazing in all climates as the south glazing area increases. However, the heating load decreases for the remaining types, except for double in Copenhagen and Geneva, over the full range of south glazing area. Thus, the passive solar potential is positive for double, triple, and double low E for this particular combination of building loss coefficient, thermal capacitance and glazing area. This is due to the storage of solar gain in the thermal mass of the heavyweight construction.

Regardless of glazing type, the cooling load increases in all climates as the south window area increases. No summertime shading is assumed in the analysis. The importance of window shading, thermal mass, and ventilation in reducing the cooling load will be discussed in sections 4.6, 4.7, and 4.9.

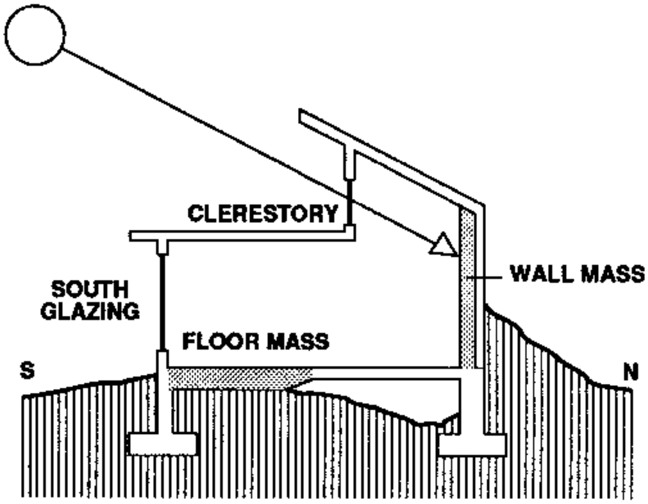


4.5: Impact of Glazing Type on Heating and Cooling Season Performance

4.5 PROPER WINDOW SIZING AND LOCATION/ ORIENTATION

Windows are the primary solar apertures in a passive solar heating system; therefore, their size, location, and orientation are crucial to the overall energy performance of the home. Three passive solar apertures are common in residential energy design - direct-gain windows, thermal storage walls, and sunspaces - and each has its own unique requirement for window size and location.

Any home with windows facing within 15-20° of south (in northern latitudes) is utilizing direct-gain passive solar energy. Direct-gain windows should be located relative to interior zoning and thermal mass placement (Figure 4.6). To reduce auxiliary heating requirements, passive solar gains must be absorbed by massive materials in the walls and floor. Mass floors must be exposed to direct sunlight and be relatively dark in color to be adequately charged. Massive walls can be any color, but must be located in rooms that receive appreciable sunlight.



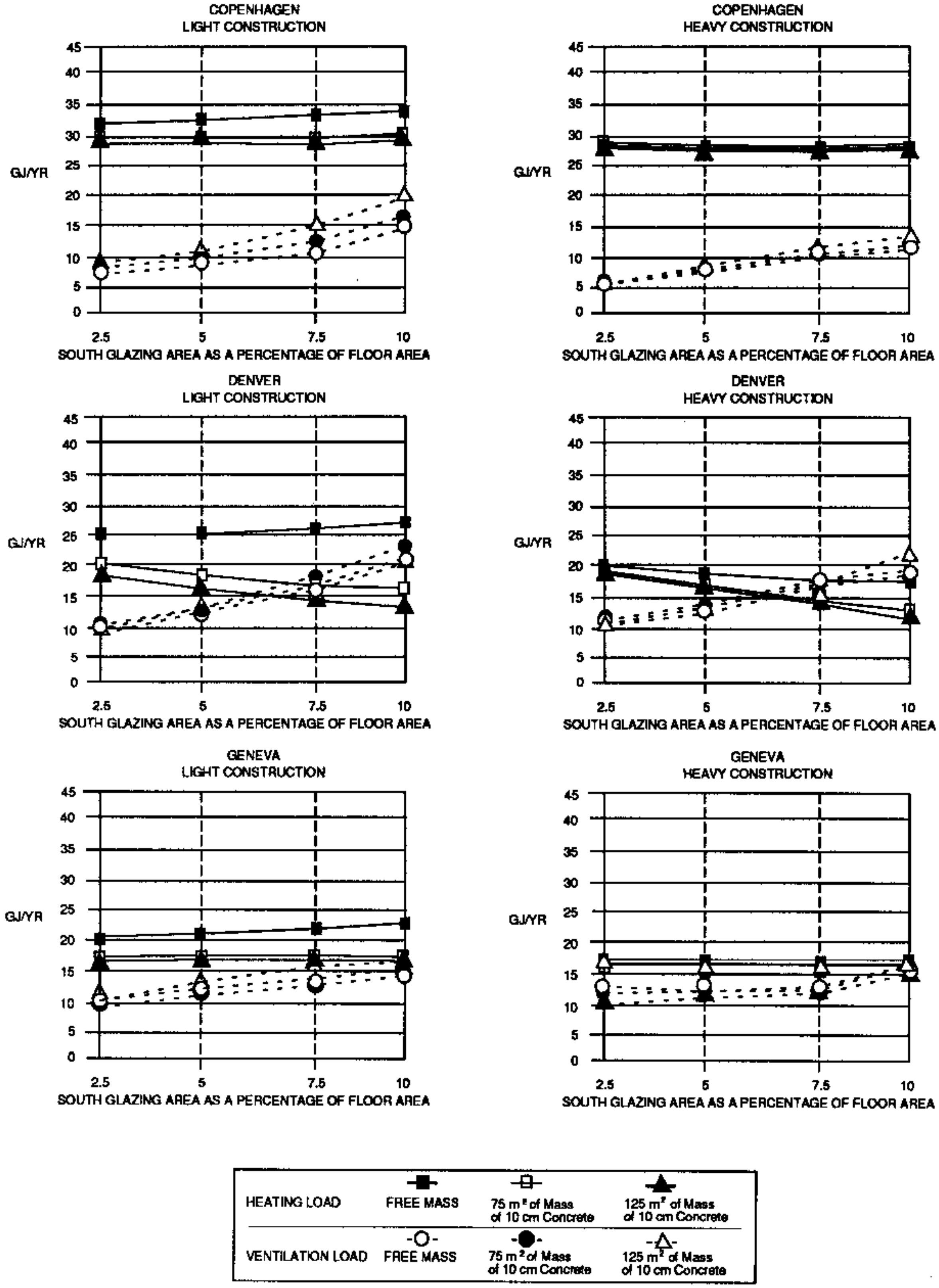
4.6: Direct-Gain Systems

DIRECT GAIN WINDOWS

Direct-gain window area is determined by the amount of thermal mass in the home. For heavyweight buildings, the amount of inherent mass in the structure is generally sufficient for reasonably large window area, so long as the mass is adequately exposed. For lightweight buildings, additional mass is typically required for south window area that exceeds 5-7% of the floor area.

Year-round comfort is a major criterion for direct-gain window sizing. Overheating can occur during both the heating and cooling season, due to oversized direct-gain windows, inadequate or improperly designed thermal mass, lack of summer window shading, or ineffective ventilation. The overall residential energy design should be based on balanced heating and cooling season performance, year-round comfort, and low energy costs.

Figure 4.7 illustrates the relationship between south window area and thermal mass on the heating and ventilation loads. The envelope insulation level of the base building corresponds to



4.7: Impact of Mass Levels on Heating Season Performance thermal integrity level 2, as defined in Section 4.2, page 14. The mass increment levels are as follows:

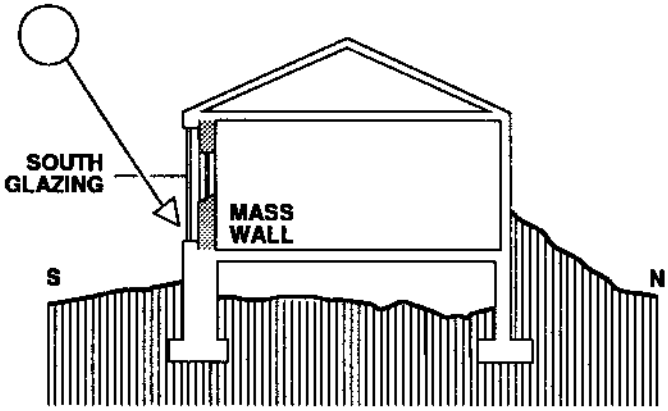
Level 1: Free Mass - thermal mass inherent in the building's structural and enclosure system, interior walls, fixtures, and occupant's furniture and other belongings.

Level 2: Partial Mass - additional mass equivalent to 75 m^2 of 10 cm. thick concrete. This added mass could take the form of contained water, phase change storage material, or solid concrete or brick materials.

Level 3: Full Mass - maximum amount of thermal mass that could be reasonably and realistically added to the base building considering architectural geometric constraints (125 m^2 of 10 cm thick concrete or equivalent).

THERMAL STORAGE WALL

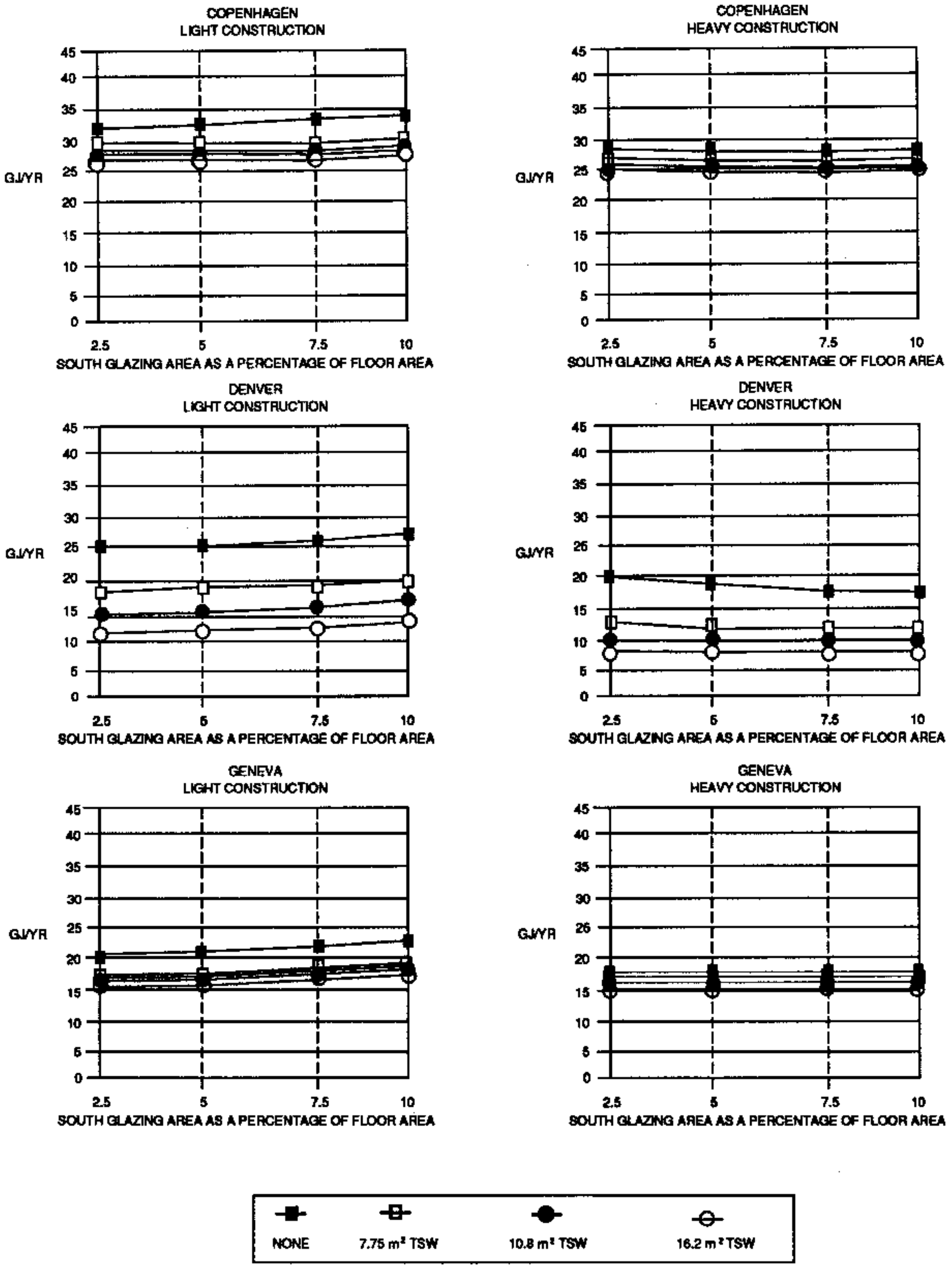
A thermal storage wall (TSW), as shown in Figure 4.8, is a south-facing (in northern latitudes) glazed wall constructed of materials with a high heat storage capacity that absorbs solar heat, transfers this heat through the wall, and distributes heat to the building interior by radiation and convection. A thermal storage wall is typically constructed of solid concrete or masonry, contained water, or phase change materials. The primary advantage of using water or phase change materials is the higher heat storage capacity per unit volume and weight compared to a concrete or masonry wall.



4.8: Thermal Storage Wall System

Although the design of a thermal storage wall must be done in relation to the specific location and architectural constraints, the following general principles should be followed:

- Size the thermal storage wall area between 5-15% of total heated floor area. Orientation of the TSW should always be within 5-10° of true south (in northern latitudes).
- Always use the thermal storage wall in combination with direct-gain windows. Figure 4.10 shows heating load reduction for different combinations of TSW and direct-gain windows.



4.10: Impact of a Thermal Storage Wall on Heating and Cooling Season Performance

- Provide full solar access for the total thermal storage wall area during the heating season.
- Use a selective surface - absorptivity of > 0.90, emissivity of < 0.15, as the absorber surface on the storage wall.
- Use single-pane low-iron glazing to cover the storage wall.
- Shade the entire thermal storage wall during the cooling season.
- For concrete or masonry TSW, use an unvented configuration (no supply or return vents between the storage wall and the building interior).
- A concrete or masonry TSW should be solid (no air gaps) and between 25-30 cm in total thickness.
- All materials used for glazing framing, structural supports, shading, and so on, must be durable and resistant to solar radiation and moisture degradation, and create an air and weather tight seal between the TSW and the outside. See Booklet No. 5 - Construction Issues for information on thermal storage wall construction related issues and details.

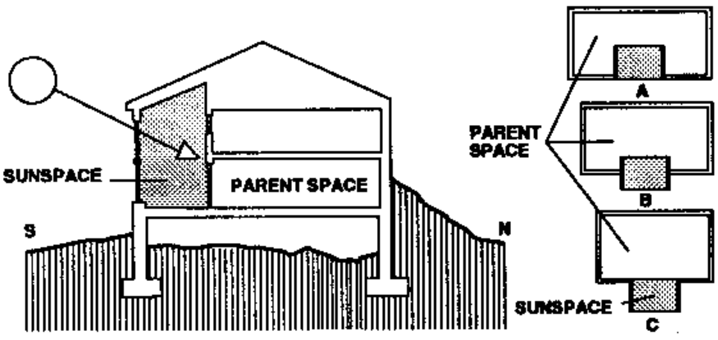
SUNSPACE

A sunspace, also known as a conservatory, winter garden, or greenhouse, is a south-facing (in northern latitudes) glazed room adjacent to the living area of a house that can be closed off from the house, and where greater temperature fluctuations are acceptable. A sunspace should be designed for year-round livability and energy savings. If not properly designed and operated, a home with a sunspace may use considerably more energy than a home without a sunspace. Consequently, the goal of sunspace design is to satisfy the occupants' sunspace design objectives - semi-conditioned living space, growing plants and vegetables, or maximize energy supply to primary living space - without incurring an energy liability.

A sunspace may be designed in an enclosed (A), semi-attached (B) or attached (C) configuration, as shown in Figure 4.11. As in the case of a thermal storage wall, the design of a sunspace must be done in relation to the specific location, design objectives and architectural constraints. Consult the appropriate National Guideline Booklet for location-specific recommendations for sunspace design.

A number of factors are involved in the design of a sunspace, including, but not limited to, the following:

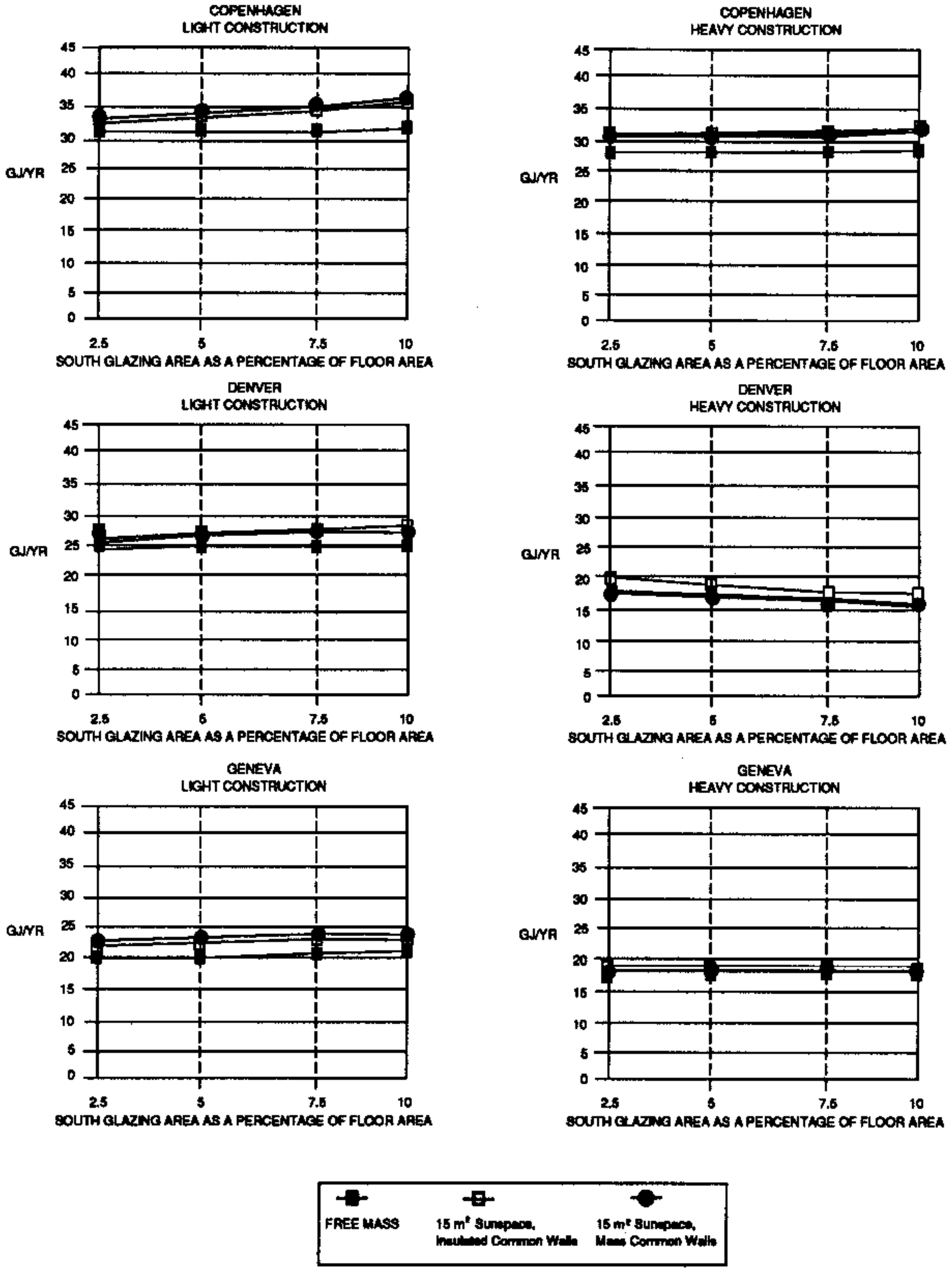
- size of sunspace in relation to size of parent space.



4.11: Sunspace System

- choice and orientation of glazing.
- area of sunspace glazing.
- amount and location of thermal mass to store passive solar heat gains and to moderate temperature savings.
- insulation levels of sunspace opaque walls, roof, and foundation.
- means of thermally coupling sunspace with parent space, whether through an open door or window, fan or a massive common wall.
- shading of sunspace glazing in summer.
- need for auxiliary heating system to maintain a minimum sunspace temperature.
- means to ventilate sunspace during both heating and cooling season.

Because of the complex and interdependent relationship between these issues, use of a residential energy analysis tool is generally required to properly design a sunspace. With such a tool, the performance impact of different design variations can be assessed. For example, Figure 4.12 on page 26 shows heating energy consumption as a function of parent space direct-gain window area with and without a massive common wall. In this instance, except for the heavyweight building in Denver, the designs are rather insensitive to the amount of south window area or whether the common is of massive material.


COPENHAGEN LIGHT CONSTRUCTION

COPENHAGEN HEAVY CONSTRUCTION

DENVER LIGHT CONSTRUCTION

DENVER HEAVY CONSTRUCTION

GENEVA LIGHT CONSTRUCTION

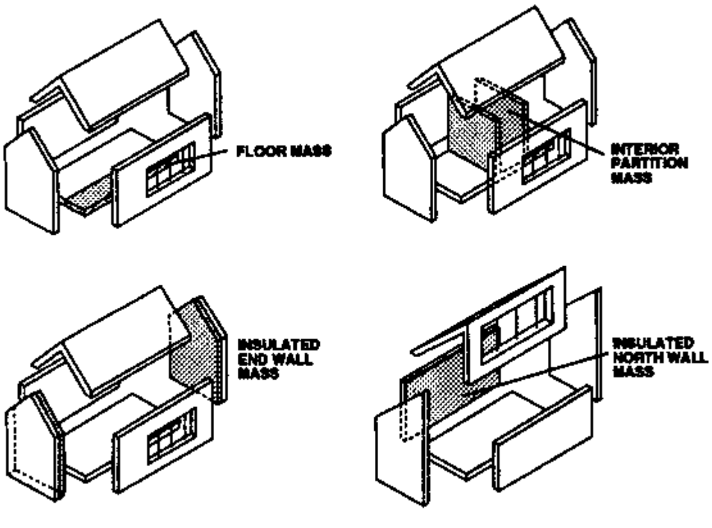
GENEVA HEAVY CONSTRUCTION

4.12: Impact of a Sunspace on Heating Season Performance

4.6 ADDED THERMAL MASS

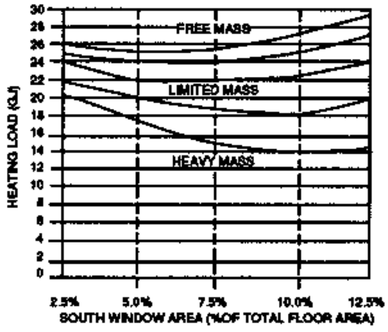
Thermal mass refers to the heat storing capacity of materials within the insulated envelope of a building that, if effectively coupled to the environment, can reduce auxiliary energy requirements for heating and cooling. The materials can be conventional materials typically used in residential construction, such as gypsum board, brick, slab concrete or concrete masonry products, or materials and products specifically designed to store thermal energy such as contained water, waxes, or phase change materials. The standard method of residential construction in a country or region will determine the inherent or "free" mass of a building. Free mass refers to the thermal mass typically found inside the insulated envelope of a building such as interior or exterior clay block and plaster walls; concrete structural elements; tile floors; gypsum board or interior partition walls; and ceilings, furniture and fixtures, and all occupant belongings.

"Added" mass is thermal mass specifically incorporated into the house, such as contained water or phase change storage materials, to increase its thermal capacitance so that greater amounts of passive solar heat can be stored, thus reducing the auxiliary heating or cooling requirement. Figure 4.13 shows the most common locations for incorporating "added" thermal mass in lightweight residential construction.

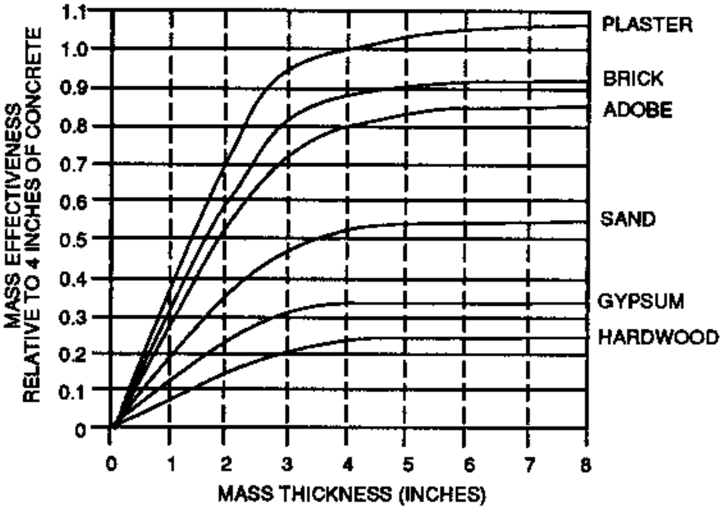


4.13: Added Thermal Mass Locations for Lightweight Construction

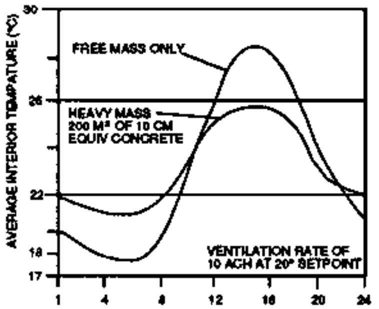
Figure 4.14 illustrates the heat storage effectiveness of some common construction materials relative to 10 cm of concrete.



4.15: Thermal Mass- South Glazing Sensitivity



4.14: Heat Storage Effectiveness of Various Materials

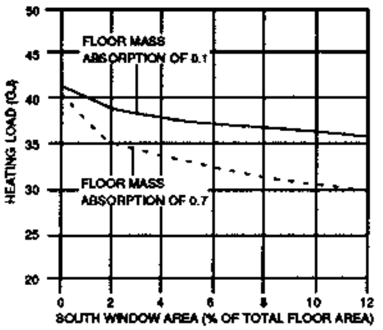


4.16: Effect of Thermal Mass on Summer Interior Temperatures

During the heating season, thermal mass can save energy by replacing auxiliary heating with solar heat "stored" in the thermal mass (Figure 4.15). However, sufficient winter sunlight must be available to charge the thermal mass. Also, where intermittent heating of the home is common and passive solar gains are small, thermal mass may actually increase auxiliary heating because the "cool" mass must be heated when bringing the room air up to the setpoint.

During the cooling season, thermal mass, when combined with nighttime whole house ventilation, can also help maintain comfortable indoor daytime temperatures by absorbing heat into the "cooled" thermal mass (Figure 4.16). However, this strategy works best in climates with a large diurnal temperature swing and low humidity. To achieve these energy-saving and comfort benefits, thermal mass must be designed in accordance with the guidelines that follow.

The effectiveness of thermal mass to reduce the heating and cooling loads is climate dependent and building operation dependent. Therefore, the reader is encouraged to obtain and carefully read the national design guidelines booklet for specific recommendations in the appropriate use of thermal mass.



4.17: Floor Mass Absorption Sensitivity

MASS FLOORS - HEATING SEASON

- Mass floors must be exposed to direct sunlight to be adequately charged. No more than 10-15% of the sunlit floor area should be covered by carpet or area rugs. Any insulating surface cover with an RSI-value above 0.017(m^2-k/w) significantly decreases thermal mass effectiveness.

- The mass floor surface must be relatively dark in color, with a solar absorption of greater than 0.65. See Figure 4.17 for sensitivity of heating load to solar absorption coefficient of mass floor.

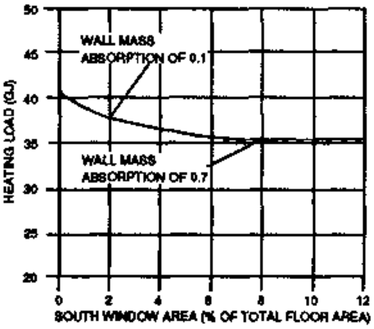
- A mass floor should be approximately 10 cm thick. However, a 5 cm thick mass floor achieves two-thirds the performance as the 10 cm mass floor (Figure 4.14). A 15 cm thick mass floor is only 8% better than the 10 cm thick mass floor.

- Choose a flooring material with the highest heat storage effectiveness that is appropriate for the application. Painted, colored, or vinyl covered concrete is extremely effective. Brick, quarry tile, or other non-structural surface treatments have less heat storage effectiveness but are more attractive. Figure 4.14 shows the heat storage effectiveness of some common flooring materials.

MASSIVE INTERIOR WALLS - HEATING SEASON

- Massive interior walls must be in zones that receive appreciable sunlight but do not require sunlight directly on them. Scattered sunlight and solar-heated air can effectively charge the massive walls.

- Color is not important to the energy performance of massive interior walls. See Figure 4.18 for sensitivity of heating load to solar absorption coefficient of massive walls. However, light colored walls are more effective in distributing sunlight throughout the space, thus improving the daylighting in the home.



4.18: Wall Mass Absorption Sensitivity

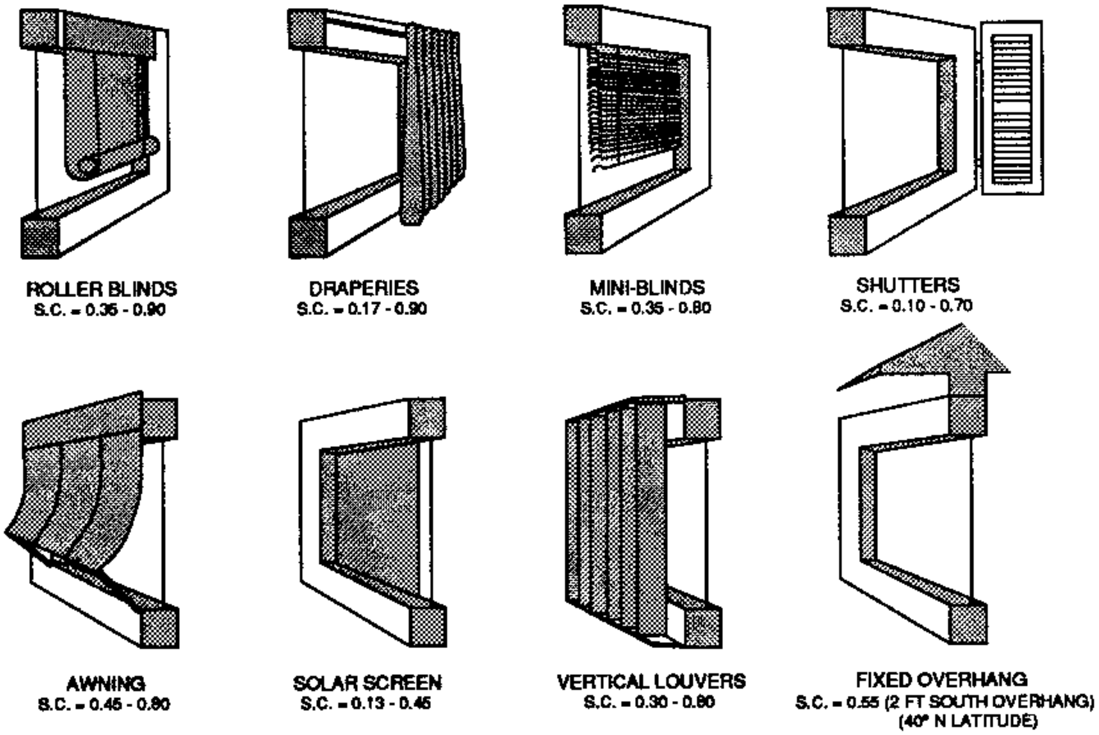
MASS WALLS AND FLOORS - COOLING SEASON

- All interior walls and floors should be completely shaded from passive solar gains during the cooling season.

- The effective cooling surface area of mass walls and floors includes all exposed surfaces within the insulated shell of the building, so long as adequate nighttime whole house ventilation is provided.

4.7 PROPER SEASONAL SHADING

For many temperate climates and for most hot climates, window shading is essential for maintaining comfort during the summer months. Without effective window shading, overheating will occur due to solar gains. Figure 4.19 illustrates a number of interior and exterior shading devices together with their approximate shading coefficients. Exterior shading devices typically have a lower shading coefficient than interior shading devices, because they block the solar gain before it reaches the glazing surface.



4.19: Representative Shading Devices and Coefficients

Typically, in northern latitudes, south, east, and west windows should have a lower shading coefficient, on the order of 0.3-0.5, than north windows. This is recommended to reduce early morning solar gains that can lead to mid-day overheating or large mechanical cooling loads. Late afternoon solar gains are especially detrimental because they add heat to a typically already overheated situation.

In all but the most tropic climates, large fixed overhangs are not recommended since they block useful solar gains on sun-facing windows during the heating season. Also, fixed overhangs are ineffective in shading east and west windows due to the low morning and afternoon sun angles. An advantage of a fixed overhang is that it requires no occupant intervention for use. However, because the heating and cooling seasons are not generally symmetrical about the winter and summer solstice, fixed overhangs must be carefully designed so as to maximize their summer shading benefit while minimizing their negative heating season impact. When used in combination with other interior or exterior shading devices, fixed overhangs are an effective strategy for reducing window solar heat gains in the summer months.

The preferred approach to controlling summer solar heat gains is with seasonally adjusted exterior shading devices. Such devices provide variable window shading during the heating and cooling season, thus maximizing solar gain when needed and minimizing solar gain when it is not. However, occupant participation is required to obtain optimal use.

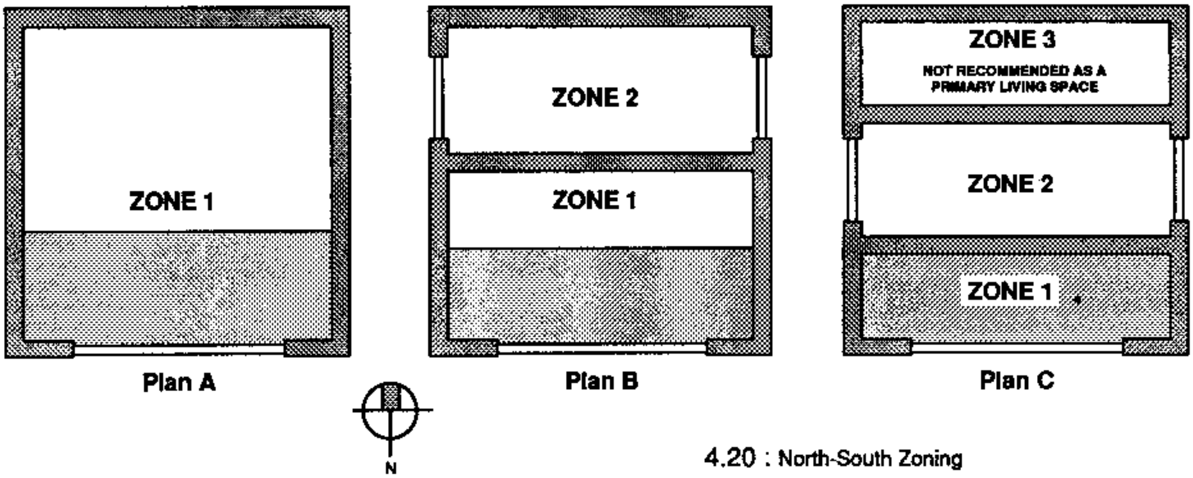
Many effective configurations for exterior shading devices are available. Solar screens are tightly woven mesh products resembling insect screens, which can be mounted in frames or in Roman shade mechanisms. They block 30-80% of the solar radiation that strikes them. These screens allow ventilation, some daylighting, and easy removal during winter months. Canvas awnings block a large portion of direct solar radiation while providing convenient seasonal flexibility and attractive exterior building features. Like movable insulation, movable shading devices must be fully and carefully evaluated in terms of durability, reliability, maintenance requirements, cost effectiveness, and occupant involvement to insure the proper selection and operation.

Interior shading devices, while not as thermally effective as exterior mounted devices, are generally easier to operate and maintain. Common interior shading devices include roller shades, blinds, drapes and movable panels. These same devices, if so designed, can also act as movable insulation during the heating season; however, daylighting is lost when in place.

4.8 PROPER INTERIOR THERMAL ZONING

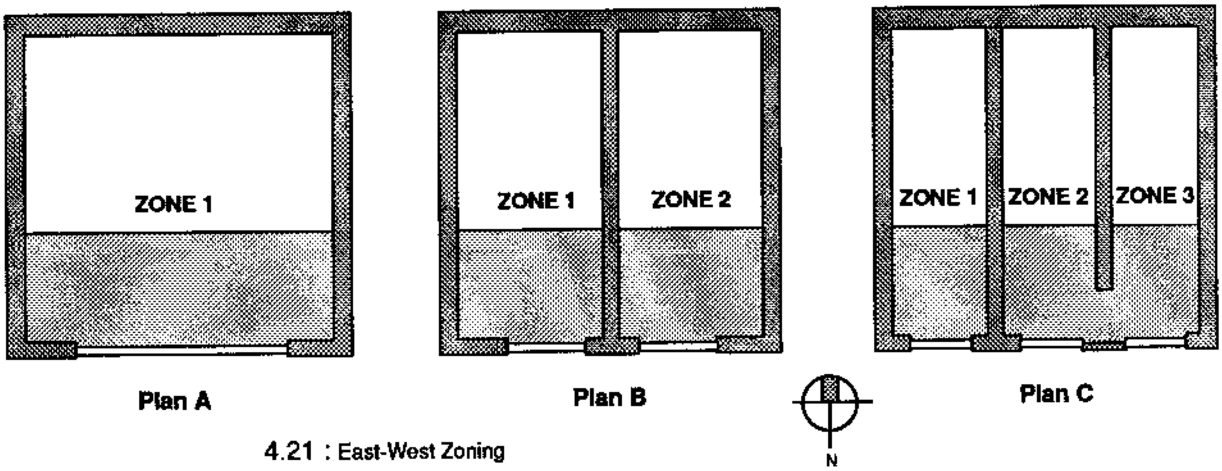
Interior thermal zones are spaces within a building that are unequally heated due to solar gains or mechanical equipment design and control. They are often created by partition walls separating one space from another and by individual thermostat controls for room heating. Interior thermal zones can be planned such as locating closets, storage spaces, or vestibules on exterior walls to serve as thermal buffers to the primary living space. However, many times they are not planned, and as a result comfort and energy savings are compromised.

Figure 4.20 illustrates the typical interior zoning that occurs when rooms are organized in a north-south fashion. Floor plan B is the most common condition. The partition wall and door openings generally provide adequate coupling for moving passive solar heat from the south zone to the north zone. Unless lighted by a south facing clerestory, Zone 3 in floor plan C should not be used for the primary living spaces. Properly sized east and west windows in the north zones are important to the energy performance and comfort of these zones. Solar access to these east and west windows is essential. This can present difficult site planning problems for high-density housing. However, south-facing clerestory windows in north zones can enhance or replace east and west windows.



4.20 : North-South Zoning

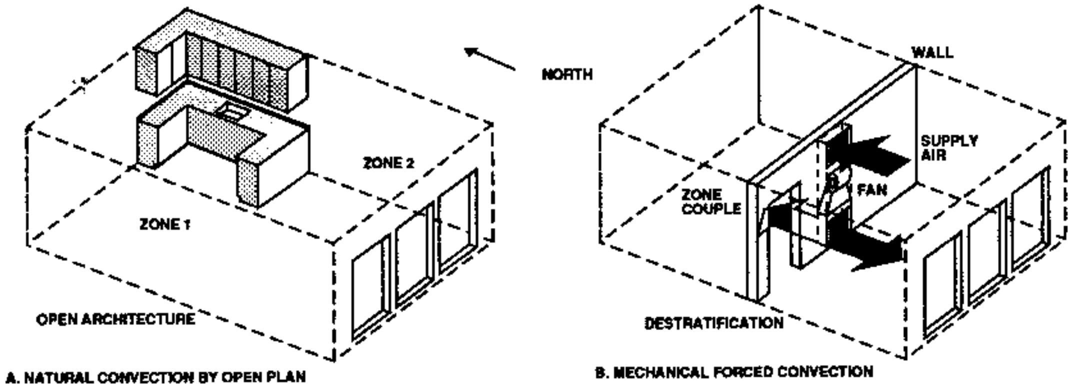
Figure 4.21 illustrates typical east-west interior zoning. The partition wall between zones, if of massive material, can become the primary thermal storage element in the design. This approach is effective for many building types such as row house designs.



Plan A Plan B Plan C

4.21 : East-West Zoning

For most designs, you will have both north-south and east-west zoning conditions. The issue then becomes one of thermally coupling these zones. Figure 4.22 illustrates two design strategies. In plan arrangement A, open architecture is used to thermally couple a south zone with a north zone through natural convection. In plan arrangement B, a fan is used. Natural convection through doorways can be an effective means to thermally couple interior zones; however, the openings must be larger, on the order of 20% of the wall area. Conduction through lightweight partition walls is not effective.



A. NATURAL CONVECTION BY OPEN PLAN

B. MECHANICAL FORCED CONVECTION

4.22: Zone Thermal Coupling

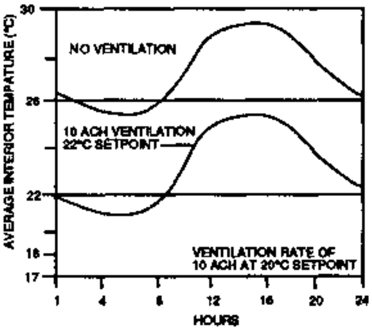
4.9 PROPER SEASONAL VENTILATION

During both the summer and winter months, the interior temperature may exceed limits of comfort due to solar and internal heat gains and may be warmer than the ambient temperature. When this condition occurs, natural or forced air circulation can be used to remove warm air from the building and replace it with cooler air from the outside.

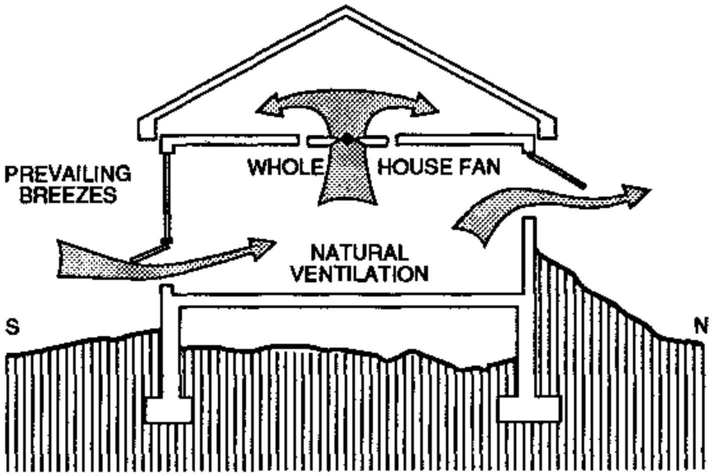
For properly sized passive solar aperture and thermal mass, this situation usually occurs in the swing seasons - spring and fall - when the ambient temperature and solar gain are relatively high and the heating load is small. Consequently, unless movable window shading devices are used, excess passive solar gains enter the windows and must be vented to avoid overheating. Slightly opening a few windows is generally adequate to remove the excess heat.

Ventilation during the summer months is an attempt to improve indoor comfort by circulating cooler air over the occupants or over the interior thermal mass. The first strategy is generally employed when the ambient air temperature is cooler than the interior air temperature. The natural ventilation process is driven by temperature differences or by the wind. For this strategy to work effectively, the inlets and outlets for the air must be properly sized and located to ensure an adequate flow rate. Booklet No. 1 - Energy Design Principles in Buildings discusses each of these natural ventilation processes in greater detail.

The second ventilation strategy is generally employed in climates that have a large diurnal temperature swing and low humidity levels during the summer months. Circulating cool night air through the house cools the free mass, and any added mass of the building (Figure 4.23). With closed windows and effective window shading, comfort will likely be maintained through the heat of the day. Figure 4.24 shows the effect of summer ventilation on interior temperature in a passive building with heavy mass.



4.24: Effect of Summer Ventilation on Interior Temperature



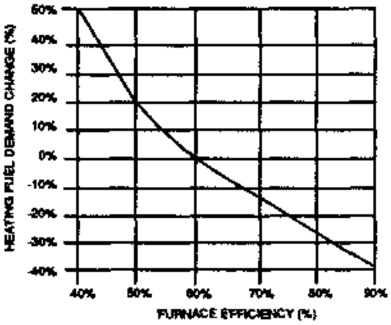
4.23: Ventilation Strategies

A whole house fan is recommended, sized to exhaust interior air at a rate of 10-15 air changes per hour. The fan should be centrally located to minimize the air path from any room in the house (Figure 4.23). Use of ceiling paddle fans to augment the whole house fan is an effective strategy, since they directly cool the occupants.

4.10 EFFICIENT AUXILIARY HEATING AND COOLING SYSTEMS AND CONTROLS

The proper selection and design integration of mechanical heating and cooling equipment and controls has a major impact on the energy consumption of the home. The residence can be designed with the lowest possible heating and cooling loads, but if an oversized or poorly designed mechanical system is installed, energy consumption could be very high. The same care that goes into the design of the building should also go into the selection and design of the mechanical heating and cooling systems and controls.

Figure 4.25 shows the influence of furnace efficiency on heating energy consumption. A gas-fired, central warm air furnace with an Annual Fuel Utilization Efficiency of 60% is assumed as the baseline design condition.



4.25: Furnace Efficiency Sensitivity

Numerous factors must be considered when selecting an auxiliary heating and/or cooling system for an energy-efficient, passive solar home, including:

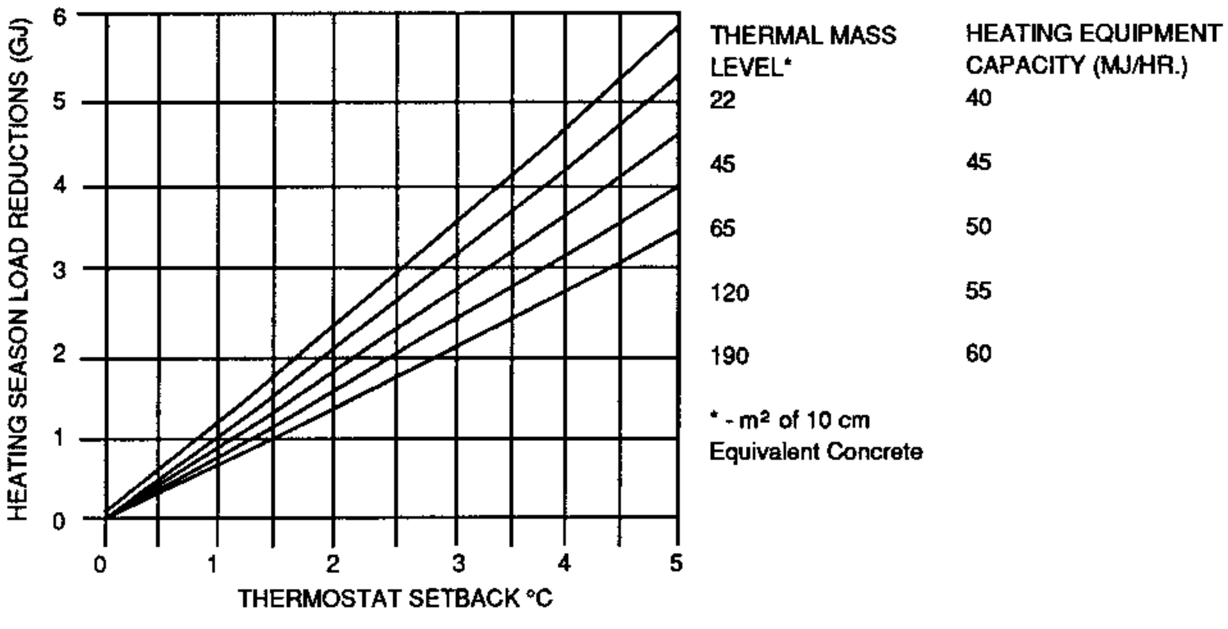
- Available fuel choices (natural gas, electricity, oil, wood) and issues of long-term availability and environmental impact.
- Cost of fuel - current prices and likely price escalation, existence of time of day or demand charges for electricity.
- Comfort requirements - whether the entire house is to be conditioned to comfort level, or only a few rooms.
- Continuous versus intermittent conditioning - will the house be occupied during the day, thus requiring continuous conditioning, or will the house be unoccupied during most of the day, thus allowing intermittent heating and/or cooling?
- Coupling of heating system to room air and thermal capacitance of the house - must the auxiliary systems provide a quick response to heating and cooling loads?
- Equipment/system efficiency - the entire auxiliary system should be as efficient as possible so that the energy consumed goes to meeting the heating and cooling loads of the house.
- Architectural integration - duct and pipe runs should be as short as possible and through conditioned space.

Booklet No. 2 - Design Context, discusses these and other auxiliary space conditioning system selection factors in greater detail.

AUXILIARY SYSTEM CONTROL

The thermostat is the key device for controlling the amount of heating or cooling supplied by the mechanical equipment to the home. It is controlled by the occupant. Lowering the thermostat temperature setting during the night can result in moderate energy savings. This can be done through a manual setback or an automated clock thermostat.

As shown in Figure 4.26, energy savings from lowering the nighttime thermostat temperature setting during the heating season depends on the amount of thermal mass in the building and the setback chosen. Greatest savings are achieved in lightweight buildings with a large setback because very little heat is stored in the thermal mass and carried over to the nighttime hours. Massive buildings, however, store considerable daytime solar gains and carry this heat into the nighttime hours; therefore, setback is less effective. Additionally, temperature setback in massive buildings may actually result in greater energy use due to the need to oversize heating equipment to provide a fast early morning "pick-up." Properly sized equipment would require a longer time to reach the setpoint level because of the heat absorption by the "night-cooled" mass. As an example, the change in heating equipment capacity required to handle the peak heating load is shown in Figure 4.26 for Denver, Colorado. It is clear that the energy savings from temperature setback in massive buildings will be reduced due to the need to oversize the heating equipment to meet the peak heating load.



4.26: Temperature Setback Sensitivity

In Chapter 4.0, ten principles or guidelines were presented for the design of energy-efficient, passive solar homes. While the use of any single energy design principle may result in significant energy-savings, the effective combination and integration of a number of these principles can lead to even greater energy-savings. In this chapter, the energy performance of "combinations" of the design guidelines are compared to the base building energy performance in Copenhagen, Geneva, and Denver for lightweight and heavyweight single family detached, attached, and multifamily housing configurations.

Energy conservation is a prerequisite for effective passive solar heating and cooling. Reducing the homes' heating and cooling load enables passive energy to offset a larger percentage of the purchased heating and cooling energy. Consequently, the initial set of energy-saving combinations for each location and building type address energy conservation features, such as the following:

- higher levels of wall, floor, and ceiling insulation
- lower infiltration rates
- triple or double glazing with a low emissivity coating
- night thermostat setback

The remaining set of combinations addresses various passive solar design strategies, including:

- larger south-facing (sun) glazing area
- added thermal mass
- movable insulation
- thermal storage wall
- sunspace

The results are presented as energy-savings, expressed as a percentage change when compared to the base building.

The listed energy conservation and passive solar combinations are not intended to cover all possibilities. However, they do point out important trends and potential directions for good residential energy design.

5.1 SINGLE-FAMILY DETACHED HOUSING CONFIGURATION

Two sets of combinations are presented. The first set of combinations, shown in Figures 5.1 to 5.3, addresses the energy conservation features of a single-family detached housing configuration. The second set of combinations, shown in Figures 5.4 to 5.6, address passive solar design strategies. It is through the effective combination and integration of passive solar and energy conservation design features that balanced heating and cooling season performance, comfort, and low energy costs will be achieved in residential buildings.

CONSERVATION COMBINATIONS FOR SINGLE-FAMILY DETACHED HOUSING

Figures 5.1 to 5.3 present the performance results for 14 combinations of energy conservation measures integrated into a lightweight and heavyweight single family detached housing unit in Copenhagen, Geneva, and Denver. The performance improvement of all combinations is relative to Current Practice and is not additive. The impact of the energy conservation measures on summertime performance is also assessed. A ⊕ symbol means the measure will reduce cooling loads or improve comfort. A ⊖ symbol means the measure will increase the cooling load or degrade comfort. A ○ symbol implies no summertime impact. Again, the summertime impact assessment is relative to Current Practice and not to any of the other combinations.

Combinations 1 and 2 assess the influence of glazing type on energy-savings. Combination 1 replaces the standard double glazing in the north, east and west windows with triple glazing. Combination 2 replaces the standard double glazing in these three sides with double glazing with a low emissivity coating. The energy-savings for both these combinations are about the same, 5 and 3%, respectively. Each glazing modification has a positive summertime impact because of a lower shading coefficient.

Combinations 3, 4, and 5 investigate the energy-savings of higher insulation levels in the walls, floors, and ceiling, respectively. The significant energy-savings realized for each component indicates that the base building insulation levels are too low. Combination 6 shows a modest increase in energy-savings when reducing the air infiltration rate from 0.5 air changes an hour (ACH) to 0.4 ACH. However, to insure acceptable levels of indoor air quality, an air-to-air heat exchanger or heat recovery by a heat pump to domestic hot water is recommended for infiltration rates below 0.5 ACH.

Combination 7 incorporates all the previous energy conservation improvements, except for a different glazing type, to create a new base building. The new base building has a heating load that is almost 40% lower than the original base building. Combinations 8 and 9 assess the energy-savings potential of triple and double, low emissivity glazing, respectively, on the north, east, and, west windows.

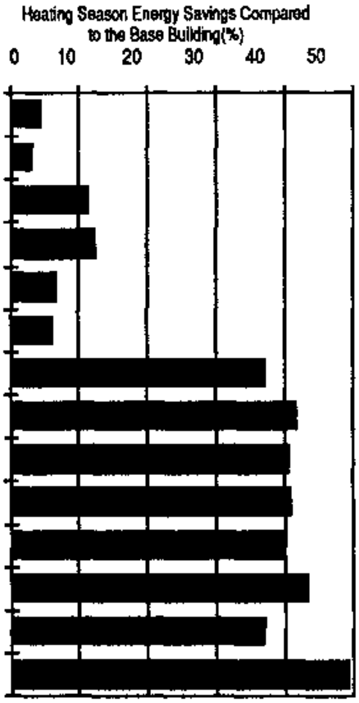
Combinations 10 through 12 assess the energy-savings potential of increased levels of insulation and a lower infiltration rate. Compared to the new base building (combination 7), higher levels of envelope insulation result in a small reduction in heating load. Reducing the infiltration rate to 0.3 ACH lowers the heating load another 6% (compared to the new base building). Again, air quality concerns dictate that some form of forced ventilation with heat recovery be used.

Combination 13 employs a 5°C thermostat setback from 10:00 pm to 6:00 am during the heating season. This strategy achieves an energy-savings of 16 to 20% for the lightweight building, and 10 to 15% for the heavyweight building (both compared to the new base building). Caution is advised in using a night

Base Building: Single-Family Detached

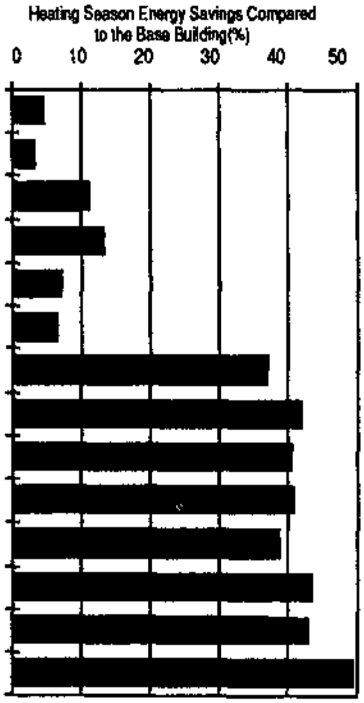
Insulation Levels:	RSI - 1.93 walls, 1.93 floor, 3.3 ceiling	Infiltration Rate:	0.5 ACH
Window Type:	Double glazing	Window Area:	10% of floor area, equal distribution on N, S, and W walls
Solar Access:	Restricted, 50% exposure all windows	Shading Coefficient:	0.6

Lightweight Construction



Combination Number and Description		Summer Impact
1)	Change N, E, and W windows to triple glazing	○
2)	Change N, E, and W windows to double, low E glazing	○
3)	Increase walls to RSI-3.3	○
4)	Increase floor to RSI-3.3	⊖
5)	Increase ceiling to RSI-5.25	⊕
6)	Reduce infiltration to 0.4 ACH, (assumes air-to-air heat exchanger)	○
7)	Energy-conserving house: RSI-3.3 walls and floor, RSI-5.25 ceiling, 0.4 ACH infiltration level, shading factor on all windows of 0.6, double glazing	○
8)	Change N, E, and W windows to triple glazing	○
9)	Change N, E, and W windows to double, low E glazing	○
10)	Increase walls to RSI-4.21	○
11)	Increase ceiling to RSI-6.65	○
12)	Reduce infiltration level to 0.3 ACH, (assumes air-to-air heat exchanger)	○
13)	5° C thermostat setback from 10:00 pm to 6:00 am	○
14)	Increase walls and floors to RSI-3.3, increase ceiling to RSI-5.25, and reduce infiltration to 0.4 ACH,	○

Heavyweight Construction



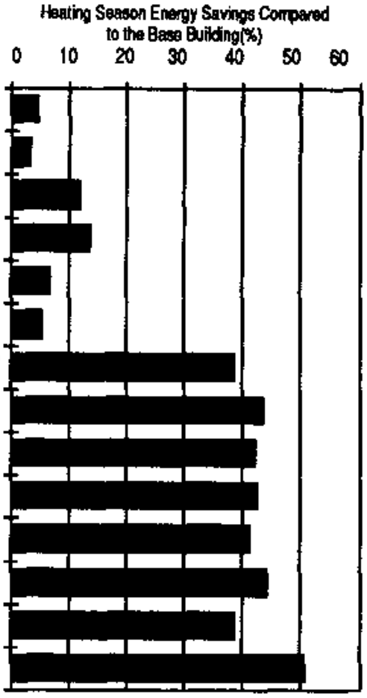
Combination Number and Description		Summer Impact
1)	Change N, E, and W windows to triple glazing	○
2)	Change N, E, and W windows to double, low E glazing	○
3)	Increase walls to RSI-3.3	○
4)	Increase floor to RSI-3.3	⊖
5)	Increase ceiling to RSI-5.25	⊕
6)	Reduce infiltration to 0.4 ACH, (assumes air-to-air heat exchanger)	○
7)	Energy-conserving house: RSI-3.3 walls and floor, RSI-5.25 ceiling, 0.4 ACH infiltration level, shading factor on all windows of 0.6, double glazing	⊕
8)	Change N, E, and W windows to triple glazing	⊕
9)	Change N, E, and W windows to double, low E glazing	⊕
10)	Increase walls to RSI-4.21	⊕
11)	Increase ceiling to RSI-6.65	⊕
12)	Reduce infiltration level to 0.3 ACH, (assumes air-to-air heat exchanger)	⊕
13)	5° C thermostat setback from 10:00 pm to 6:00 am	○
14)	Increase walls and floors to RSI-3.3, increase ceiling to RSI-5.25, and reduce infiltration to 0.4 ACH,	⊕

5.1: Copenhagen Energy-Saving Conservation Combinations

Base Building: Single-Family Detached

Insulation Levels:	RSI - 1.93 walls, 1.93 floor, 3.3 ceiling	Infiltration Rate:	0.5 ACH
Window Type:	Double glazing	Window Area:	10% of floor area, equal distribution on N, S, and W walls
Solar Access:	Restricted, 50% exposure all windows	Shading Coefficient:	0.6

Lightweight Construction



Combination Number and Description		Summer Impact
1)	Change N, E, and W windows to triple glazing	○
2)	Change N, E, and W windows to double, low E glazing	○
3)	Increase walls to RSI-3.3	○
4)	Increase floor to RSI-3.3	○
5)	Increase ceiling to RSI-5.25	⊕
6)	Reduce infiltration to 0.4 ACH, (assumes air-to-air heat exchanger)	○
7)	Energy-conserving house: RSI-3.3 walls and floor, RSI-5.25 ceiling, 0.4 ACH infiltration level, shading factor on all windows of 0.6, double glazing	⊕
8)	Change N, E, and W windows to triple glazing	⊕
9)	Change N, E, and W windows to double, low E glazing	⊕
10)	Increase walls to RSI-4.21	⊕
11)	Increase ceiling to RSI-6.65	⊕
12)	Reduce infiltration level to 0.3 ACH, (assumes air-to-air heat exchanger)	⊕
13)	5° C thermostat setback from 10:00 pm to 6:00 am	⊕
14)	Increase walls and floors to RSI-3.3, increase ceiling to RSI-5.25, and reduce infiltration to 0.4 ACH,	⊕

Heavyweight Construction

Combination Number and Description		Summer Impact
1)	Change N, E, and W windows to triple glazing	○
2)	Change N, E, and W windows to double, low E glazing	○
3)	Increase walls to RSI-3.3	○
4)	Increase floor to RSI-3.3	○
5)	Increase ceiling to RSI-5.25	⊕
6)	Reduce infiltration to 0.4 ACH, (assumes air-to-air heat exchanger)	⊕
7)	Energy-conserving house: RSI-3.3 walls and floor, RSI-5.25 ceiling, 0.4 ACH infiltration level, shading factor on all windows of 0.6, double glazing	⊕
8)	Change N, E, and W windows to triple glazing	⊕
9)	Change N, E, and W windows to double, low E glazing	⊕
10)	Increase walls to RSI-4.21	⊕
11)	Increase ceiling to RSI-6.65	⊕
12)	Reduce infiltration level to 0.3 ACH, (assumes air-to-air heat exchanger)	⊕
13)	5° C thermostat setback from 10:00 pm to 6:00 am	⊕
14)	Increase walls and floors to RSI-3.3, increase ceiling to RSI-5.25, and reduce infiltration to 0.4 ACH,	⊕

5.2: Denver Energy-Saving Conservation Combinations

Base Building: Single-Family Detached

Insulation Levels:	RSI - 1.93 walls, 1.93 floor, 3.3 ceiling	Infiltration Rate:	0.5 ACH
Window Type:	Double glazing	Window Area:	10% of floor area, equal distribution on N, S, and W walls
Solar Access:	Restricted, 50% exposure all windows	Shading Coefficient:	0.6

Lightweight Construction

Combination Number and Description		Summer Impact
1)	Change N, E, and W windows to triple glazing	○
2)	Change N, E, and W windows to double, low E glazing	○
3)	Increase walls to RSI-3.3	○
4)	Increase floor to RSI-3.3	○
5)	Increase ceiling to RSI-5.25	⊕
6)	Reduce infiltration to 0.4 ACH, (assumes air-to-air heat exchanger)	○
7)	Energy-conserving house: RSI-3.3 walls and floor, RSI-5.25 ceiling, 0.4 ACH infiltration level, shading factor on all windows of 0.6, double glazing	⊕
8)	Change N, E, and W windows to triple glazing	⊕
9)	Change N, E, and W windows to double, low E glazing	⊕
10)	Increase walls to RSI-4.21	⊕
11)	Increase ceiling to RSI-6.65	⊕
12)	Reduce infiltration level to 0.3 ACH, (assumes air-to-air heat exchanger)	⊕
13)	5° C thermostat setback from 10:00 pm to 6:00 am	⊕
14)	Increase walls and floors to RSI-3.3, increase ceiling to RSI-5.25, and reduce infiltration to 0.4 ACH,	⊕

Heavyweight Construction

Combination Number and Description		Summer Impact
1)	Change N, E, and W windows to triple glazing	○
2)	Change N, E, and W windows to double, low E glazing	○
3)	Increase walls to RSI-3.3	○
4)	Increase floor to RSI-3.3	○
5)	Increase ceiling to RSI-5.25	⊕
6)	Reduce infiltration to 0.4 ACH, (assumes air-to-air heat exchanger)	○
7)	Energy-conserving house: RSI-3.3 walls and floor, RSI-5.25 ceiling, 0.4 ACH infiltration level, shading factor on all windows of 0.6, double glazing	⊕
8)	Change N, E, and W windows to triple glazing	⊕
9)	Change N, E, and W windows to double, low E glazing	⊕
10)	Increase walls to RSI-4.21	⊕
11)	Increase ceiling to RSI-6.65	⊕
12)	Reduce infiltration level to 0.3 ACH, (assumes air-to-air heat exchanger)	⊕
13)	5° C thermostat setback from 10:00 pm to 6:00 am	⊕
14)	Increase walls and floors to RSI-3.3, increase ceiling to RSI-5.25, and reduce infiltration to 0.4 ACH,	⊕

5.3: Geneva Energy-Saving Conservation Combinations thermostat setback in heavyweight buildings due to the added equipment capacity required to bring up the building temperature quickly in the morning.

Combination 14 represents a second new base building made up of the conservation features of combinations 10 and 12. While this building results in energy-savings of approximately 50% compared to the original base building, it saves only around 20% compared to the first new base building (combination 7). Consequently, the conservation levels embodied in combination 7 most likely represent economically justified levels of insulation and infiltration reduction. Because energy conservation is a prerequisite to the effective utilization of passive solar design strategies, combination 7 will become the base building for investigating passive solar design features in Figures 5.4 to 5.6.

PASSIVE SOLAR COMBINATIONS FOR SINGLE-FAMILY DETACHED HOUSING

Figures 5.4 to 5.6 present the performance results for 12 combinations of passive solar measures integrated into a lightweight and heavyweight single-family detached housing unit in Copenhagen, Geneva, and Denver.

Combination 1 deviates from the baseline only in terms of solar access, and shows that site planning for solar access can result in significant energy savings and enhanced daylighting at little or no cost.

Combinations 2 and 3 involve two window treatment options-double low emissivity glazing and movable insulation. Replacing the double glazing on the north, east, and west walls with double low emissivity glazing results in a minor improvement (5-7%) in energy-savings. Use of R-0.875 movable insulation for eight hours at night during the heating season obtains a 15-18% savings over the base building, depending on location.

Combinations 4 through 6 involve the redistribution of glazing area from non-south to a south (sun-facing) orientation, and gradual increase in thermal mass. It is clear that as south glazing area and thermal mass area increase, energy-savings also significantly increase. A performance improvement of over 50% is possible compared to the well-insulated base building.

The magnitude of energy-savings varies with the climate of the building's location. Savings are 9-20% in Copenhagen (a relatively cold, cloudy climate), 9-26% in Geneva (a temperate, cloudy climate), and 8-52% in Denver (a cold, sunny climate).

The design issue for lightweight buildings is how to integrate, in a cost-effective manner, the large amounts of thermal mass needed to absorb the solar gains from the larger south-facing windows. With whole house ventilation and proper summertime window shading coefficients, these three combinations can have a positive impact on summertime performance.

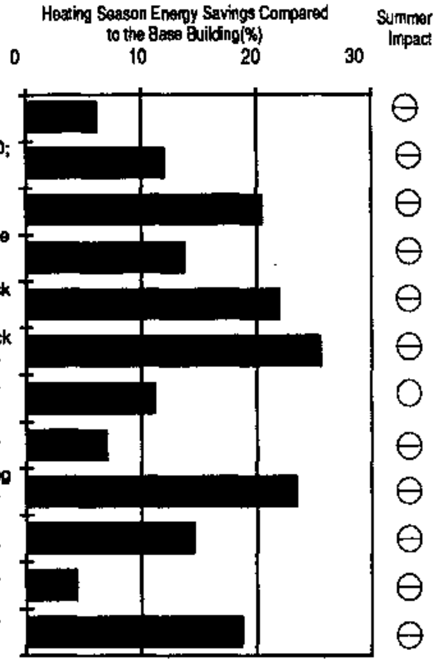
Base Building: Single-Family Detached

Insulation Levels:	RSI - 3.3 walls, 3.3 floor, 5.25 ceiling	Infiltration Rate:	0.5 ACH
Window Type:	Double glazing	Window Area:	2.5% of floor area, equal distribution on all four sides
Solar Access:	Full access	Shading Coefficient:	0.6

Lightweight Construction

Combination Number and Description

1) Provide full solar access for all windows
2) Change N, E, and W windows to double, low E glazing; heating season shading factor = 1.0; cooling season shading = 0.3 (These shading factors used on all other buildings)
3) RSI-0.9 movable insulation on all windows from 8:00 pm to 6:00 am during winter
4) Increase S glazing to 6% of floor area; N - 2%, E and W - 1.5%; no additional mass (free mass only)
5) Increase S glazing to 9% of floor area; N - 2%, E and W - 1.5%; add 70 m² of 0.10 cm thick concrete (65% of floor area)
6) Increase S glazing to 12% of floor area, N - 2%, E and W - 1.5%; add 140 m² of 0.10 cm thick concrete (130% of floor area)
7) Increase S and N glazing to 6% of floor area, E and W - 0%
8) Increase S glazing to 6% of floor area, N - 0%, E and W - 6%
9) Add a 25 cm thick concrete thermal storage wall sized at 10% of floor area; increase S glazing to 6% of floor area, N - 2%, E and W - 1.5%
10) Sunspace * with uninsulated common walls. (See description of sunspace below)
11) Same as combination 10*, except common walls are 0.10 cm thick concrete mass walls
12) Same as combination 10*, except common walls insulated to RSI-1.93



Heavyweight Construction

Combination Number and Description

1) Provide full solar access for all windows
2) Change N, E, and W windows to double, low E glazing; heating season shading factor = 1.0; cooling season shading = 0.3 (These shading factors used on all other buildings)
3) RSI-0.9 movable insulation on all windows from 8:00 pm to 6:00 am during winter
4) Increase S glazing to 6% of floor area; N - 2%, E and W - 1.5%; no additional mass (free mass only)
5) Increase S glazing to 9% of floor area; N - 2%, E and W - 1.5%; add 70 m² of 0.10 cm thick concrete (65% of floor area)
6) Increase S glazing to 12% of floor area, N - 2%, E and W - 1.5%; add 140 m² of 0.10 cm thick concrete (130% of floor area)
7) Increase S and N glazing to 6% of floor area, E and W - 0%
8) Increase S glazing to 6% of floor area, N - 0%, E and W - 6%
9) Add a 25 cm thick concrete thermal storage wall sized at 10% of floor area; increase S glazing to 6% of floor area, N - 2%, E and W - 1.5%
10) Sunspace * with uninsulated common walls. (See description of sunspace below)
11) Same as combination 10*, except common walls are 0.10 cm thick concrete mass walls
12) Same as combination 10*, except common walls insulated to RSI-1.93

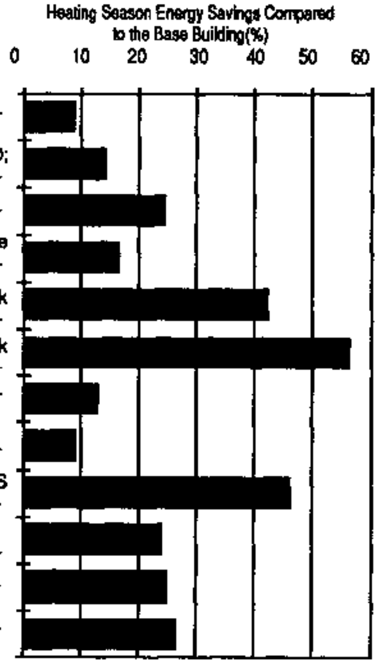
* Description of sunspace: 12% parent space converted to a sunspace with 13 cm thick concrete slab floor; common walls as per Combinations 10,11, and 12; with 9 m² window to parent space; sunspace glazing double and -7% of total flow area; parent space glazing (all double low E); S-2% of total floor area, N-2%, and E and W (where applicable)-1.5%.

5.4: Copenhagen Solar Energy-Saving Combinations

Base Building: Single-Family Detached

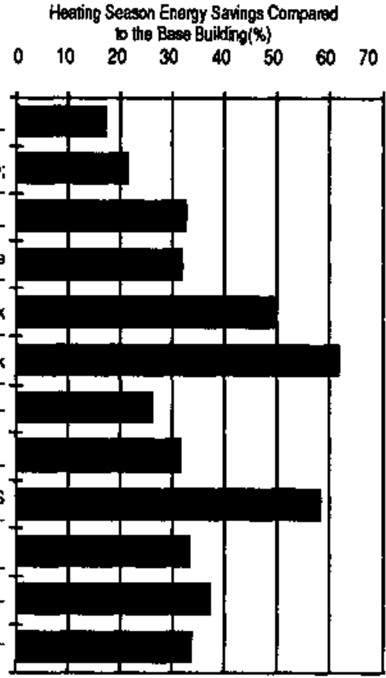
Insulation Levels:	RSI - 3.3 walls, 3.3 floor, 5.25 ceiling	Infiltration Rate:	0.5 ACH
Window Type:	Double glazing	Window Area:	2.5% of floor area, equal distribution on all four sides
Solar Access:	Full access	Shading Coefficient:	0.6

Lightweight Construction



Combination Number and Description		Summer Impact
1)	Provide full solar access for all windows	⊖
2)	Change N, E, and W windows to double, low E glazing; heating season shading factor = 1.0; cooling season shading = 0.3 (These shading factors used on all other buildings)	⊕
3)	RSI-0.9 movable insulation on all windows from 8:00 pm to 6:00 am during winter	⊕
4)	Increase S glazing to 6% of floor area; N - 2%, E and W - 1.5%; no additional mass (free mass only)	⊕
5)	Increase S glazing to 9% of floor area; N - 2%, E and W - 1.5%; add 70 m² of 0.10 cm thick concrete (65% of floor area)	⊕
6)	Increase S glazing to 12% of floor area, N - 2%, E and W - 1.5%; add 140 m² of 0.10 cm thick concrete (130% of floor area)	⊕
7)	Increase S and N glazing to 6% of floor area, E and W - 0%	⊕
8)	Increase S glazing to 6% of floor area, N - 0%, E and W - 6%	○
9)	Add a 25 cm thick concrete thermal storage wall sized at 10% of floor area; increase S glazing to 6% of floor area, N - 2%, E and W - 1.5%	○
10)	Sunspace * with uninsulated common walls. (See description of sunspace below)	⊕
11)	Same as combination 10*, except common walls are 0.10 cm thick concrete mass walls	⊕
12)	Same as combination 10*, except common walls insulated to RSI-1.93	⊕

Heavyweight Construction



Combination Number and Description		Summer Impact
1)	Provide full solar access for all windows	⊖
2)	Change N, E, and W windows to double, low E glazing; heating season shading factor = 1.0; cooling season shading = 0.3 (These shading factors used on all other buildings)	⊕
3)	RSI-0.9 movable insulation on all windows from 8:00 pm to 6:00 am during winter	⊕
4)	Increase S glazing to 6% of floor area; N - 2%, E and W - 1.5%; no additional mass (free mass only)	⊖
5)	Increase S glazing to 9% of floor area; N - 2%, E and W - 1.5%; add 70 m² of 0.10 cm thick concrete (65% of floor area)	⊖
6)	Increase S glazing to 12% of floor area, N - 2%, E and W - 1.5%; add 140 m² of 0.10 cm thick concrete (130% of floor area)	⊖
7)	Increase S and N glazing to 6% of floor area, E and W - 0%	○
8)	Increase S glazing to 6% of floor area, N - 0%, E and W - 6%	⊖
9)	Add a 25 cm thick concrete thermal storage wall sized at 10% of floor area; increase S glazing to 6% of floor area, N - 2%, E and W - 1.5%	⊖
10)	Sunspace * with uninsulated common walls. (See description of sunspace below)	⊕
11)	Same as combination 10*, except common walls are 0.10 cm thick concrete mass walls	⊕
12)	Same as combination 10*, except common walls insulated to RSI-1.93	⊕

* Description of sunspace: 12% parent space converted to a sunspace with 13 cm thick concrete slab floor; common walls as per Combinations 10,11, and 12; with 9 m² window to parent space; sunspace glazing double and -7% of total flow area; parent space glazing (all double low E); S-2% of total floor area, N-2%, and E and W (where applicable)-1.5%.

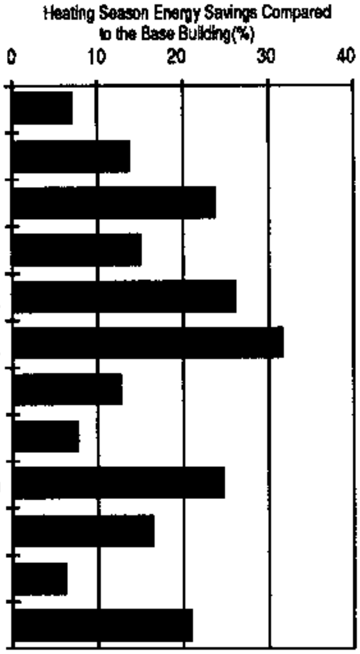
5.5: Denver Solar Energy-Saving Combinations

Base Building: Single-Family Detached

Insulation Levels:	RSI - 3.3 walls, 3.3 floor, 5.25 ceiling	Infiltration Rate:	0.5 ACH
Window Type:	Double glazing	Window Area:	2.5% of floor area, equal distribution on all four sides
Solar Access:	Full access	Shading Coefficient:	0.6

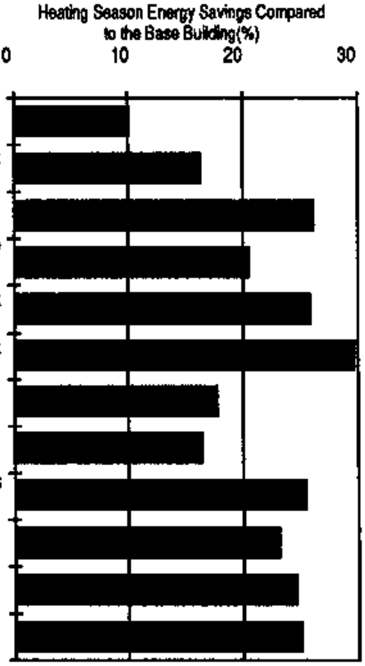
Lightweight Construction

Combination Number and Description		Summer Impact
1)	Provide full solar access for all windows	⊖
2)	Change N, E, and W windows to double, low E glazing; heating season shading factor = 1.0; cooling season shading = 0.3 (These shading factors used on all other buildings)	⊕
3)	RSI-0.9 movable insulation on all windows from 8:00 pm to 6:00 am during winter	⊕
4)	Increase S glazing to 6% of floor area; N - 2%, E and W - 1.5%; no additional mass (free mass only)	⊕
5)	Increase S glazing to 9% of floor area; N - 2%, E and W - 1.5%; add 70 m^2 of 0.10 cm thick concrete (65% of floor area)	⊕
6)	Increase S glazing to 12% of floor area, N - 2%, E and W - 1.5%; add 140 m^2 of 0.10 cm thick concrete (130% of floor area)	⊕
7)	Increase S and N glazing to 6% of floor area, E and W - 0%	⊕
8)	Increase S glazing to 6% of floor area, N - 0%, E and W - 6%	⊖
9)	Add a 25 cm thick concrete thermal storage wall sized at 10% of floor area; increase S glazing to 6% of floor area, N - 2%, E and W - 1.5%	○
10)	Sunspace * with uninsulated common walls. (See description of sunspace below)	⊕
11)	Same as combination 10*, except common walls are 0.10 cm thick concrete mass walls	⊕
12)	Same as combination 10*, except common walls insulated to RSI-1.93	⊕



Heavyweight Construction

Combination Number and Description		Summer Impact
1)	Provide full solar access for all windows	⊖
2)	Change N, E, and W windows to double, low E glazing; heating season shading factor = 1.0; cooling season shading = 0.3 (These shading factors used on all other buildings)	⊕
3)	RSI-0.9 movable insulation on all windows from 8:00 pm to 6:00 am during winter	○
4)	Increase S glazing to 6% of floor area; N - 2%, E and W - 1.5%; no additional mass (free mass only)	○
5)	Increase S glazing to 9% of floor area; N - 2%, E and W - 1.5%; add 70 m^2 of 0.10 cm thick concrete (65% of floor area)	○
6)	Increase S glazing to 12% of floor area, N - 2%, E and W - 1.5%; add 140 m^2 of 0.10 cm thick concrete (130% of floor area)	⊖
7)	Increase S and N glazing to 6% of floor area, E and W - 0%	○
8)	Increase S glazing to 6% of floor area, N - 0%, E and W - 6%	⊖
9)	Add a 25 cm thick concrete thermal storage wall sized at 10% of floor area; increase S glazing to 6% of floor area, N - 2%, E and W - 1.5%	⊖
10)	Sunspace * with uninsulated common walls. (See description of sunspace below)	⊕
11)	Same as combination 10*, except common walls are 0.10 cm thick concrete mass walls	⊕
12)	Same as combination 10*, except common walls insulated to RSI-1.93	⊕



* Description of sunspace: 12% parent space converted to a sunspace with 13 cm thick concrete slab floor; common walls as per Combinations 10,11, and 12; with 9 m^2 window to parent space; sunspace glazing double and -7% of total flow area; parent space glazing (all double low E); S-2% of total floor area, N-2%, and E and W (where applicable)-1.5%.

5.6: Geneva Solar Energy-Saving Combinations

Combination 7 represents a case where a zero lot line or minimal sideyards may eliminate the possibility of east and west windows. With greater south and north window areas, energy-savings range from 5-10% compared to the base building. Energy consumption increases in lightweight buildings as east and west glazing is increased in combination 8, with a corresponding negative summertime impact on cooling loads and comfort.

Combination 9 shows that a thermal storage wall, when combined with south windows for daytime solar gains, is an effective strategy in all locations/climates. This is especially true in Denver, due to the high levels of winter sunshine and cold temperatures. If properly shaded, the storage wall should have a positive summertime impact.

Combinations 10, 11, and 12 are sunspace designs with an uninsulated, massive, and insulated common wall, respectively. All other design conditions are the same. The energy-savings for both the lightweight and heavyweight buildings are nearly the same, except for the lightweight buildings located in the cloudier climates of Copenhagen and Geneva. The key performance difference among the three sunspace combinations is the sunspace temperature. Where the conductive coupling between the sunspace is higher (Combination 10) or the amount of sunspace mass is greater (Combination 11), the temperature fluctuations in the sunspace are smaller. Thus, the sunspace will have better year-round comfort than a sunspace which is isolated from the parent space, as in combination 12.

The three sunspace combinations consider only common wall design variations. A sunspace is a complex passive solar strategy involving many design parameters. Careful analysis of a specific set of design parameters is required to ensure that the sunspace provides energy-savings while maintaining acceptable levels of year-round comfort.

5.2 SINGLE-FAMILY ATTACHED HOUSING CONFIGURATION

Figures 5.7 to 5.12 address the passive solar features of a single-family row house in end unit and middle unit configurations. The performance improvement is expressed as a percentage energy savings compared to the base building, and is

Bear in mind that because the heating and cooling loads of these units are relatively small, modest reductions in annual loads will yield fairly large percentage improvements. (A reduction of 2 GJ/VR can result in an energy savings percentage of as much as 20%)

PASSIVE SOLAR COMBINATIONS FOR ROW HOUSE UNITS

Combinations 1 through 12 address the energy-savings of passive solar measures integrated into a row house end unit. Combinations 13 through 20 assess many of the same passive solar measures integrated into a middle unit.

Combination 1 provides full solar access to all windows and results in savings of 8-15%, with the exception of the lightweight unit in Denver's sunny climate, which saves nearly 25%. Replacing all non-south windows with double, low emissivity glazing in combination 2 shows a reasonable improvement over the double-glazed base building. The heavyweight units benefit from this change more than the lightweight ones. Adding RSI-0.9 movable insulation to the windows results in a even greater energy-savings. These two window treatments are successful because windows comprise a larger percentage of the envelope exposed to ambient conditions compared to the detached family housing.

Combinations 4 through 6 involve the redistribution of glazing area from non-south to a south (sun-facing) orientation and a gradual increase in thermal mass. The energy-savings with higher south glazing and thermal mass levels is substantial. In cloudy climates it approaches that of movable insulation. In the sunny climate of Denver, this approach can provide the highest savings we have seen thus far, with lower maintenance costs and less uncertainty of occupant behavior than movable insulation. However, construction cost increases for the added glazing and mass must be considered.

Combination 7 represents a case where a zero lot line or minimal sideyards may eliminate the possibility of west windows. With greater south and north window areas, energy-savings range from 15-35% compared to the base building. Energy consumption increases in lightweight buildings in Copenhagen and Geneva as west glazing is increased in combination 8, with a corresponding negative summertime impact on cooling loads and comfort.

Combination 9 shows that a thermal storage wall is a viable passive solar strategy so long as construction costs are not excessive.

Combinations 10, 11, and 12 are sunspace designs with an uninsulated, massive, and insulated common wall, respectively. All other design conditions are the same.

The energy-savings for all the sunspace designs are nearly the same in each location/climate for the heavyweight units. However, the results vary considerably between designs in the lightweight units, particularly in the sunny climate of Denver. As with the detached housing units, a key performance difference among the three sunspace combinations is the sunspace temperature. Where the conductive coupling between the sunspace is higher (Combination 10) or the amount of sunspace mass is greater (Combination 11), the temperature fluctuations in the sunspace are smaller. Thus, the sunspace will have better year-round comfort than a sunspace which is isolated from the parent space, as in combination 12.

As before, these three sunspace combinations consider only common wall design variations. The same careful analysis of a specific set of design parameters is required to ensure that the sunspace provides energy-savings while maintaining acceptable levels of year-round comfort.

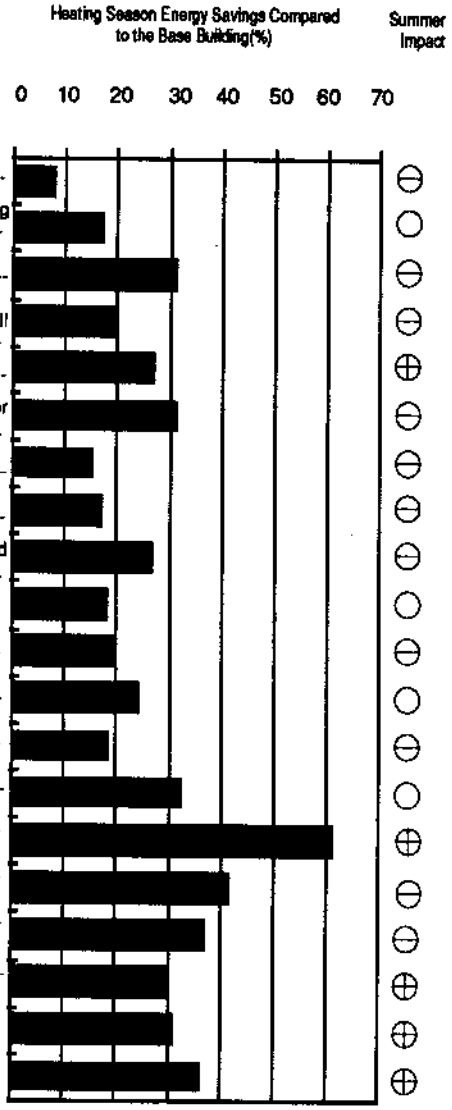
Base Building: Single-Family Attached Row House

Insulation Levels:	RSI - 3.3 walls, 1.93 floor, 3.3 ceiling	Infiltration Rate:	0.4 ACH
Window Type:	Double glazing	Window Area:	10% of floor area, equal distribution on N, S, and W walls
Solar Access:	Restricted, 60% exposure all windows	Shading Coefficient:	1.0 Winter, 1.0 Summer

Lightweight Construction

Combination Number and Description

1) Provide full solar access for all windows
2) Add double low E glazing on all windows; heating season shading factor = 1.0, cooling season shading factor = 0.3; (These shading factors used on all other buildings)
3) Add RSI-0.9 movable insulation on all windows from 6:00 pm to 6:00 am; during winter
4) Increase S glazing to 6% of floor area, N and W - 2%; free mass; double low E glazing on all windows (double low E on all other buildings as well)
5) Increase S glazing to 9%, N and W - 2%; 62.4 m² of 10 cm thick concrete (65% of floor area)
6) Increase S glazing to 12%, N and W - 2%; 124.8 m² of 10 cm thick concrete (130% of floor area)
7) Increase S glazing to 6%, W - 0%; no additional mass (free mass only)
8) Increase S glazing to 6%, N - 0%, W - 6%; no additional mass (free mass only)
9) Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N and W-2%
10) Sunspace * with uninsulated common walls. (See description of sunspace below)
11) Same as combination 10*, except common walls are 10 cm thick solid concrete
12) Same as combination 10*, except common walls insulated to RSI-1.93
13) Eliminate W wall to convert from end to mid unit; 5% of floor area in N glass, 5% in S glass.
14) Increase S glazing to 6% of floor area, N is 2%; free mass
15) Increase S glazing to 9%, N - 2%; 62.4 m² of 10 cm thick concrete (65% of floor area)
16) Increase S glazing to 12%, N - 2%; 124.8 m² of 10 cm thick concrete (130% of floor area)
17) Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N - 2%
18) Sunspace* with uninsulated common walls. (See description of sunspace below)
19) Same as combination 18*, except common walls are 10 cm thick solid concrete
20) Same as combination 18*, except common walls insulated to RSI-1.93



* Description of sunspace: 12% parent space converted to a sunspace with 13 cm thick concrete slab floor; common walls as per Combinations 10,11, and 12; back wall has 9 m² window to parent space; sunspace glazing double and -7% of total flow area; parent space glazing (all double low E); S-2% of total floor area, N-2%, and E and W (where applicable)-1.5%.

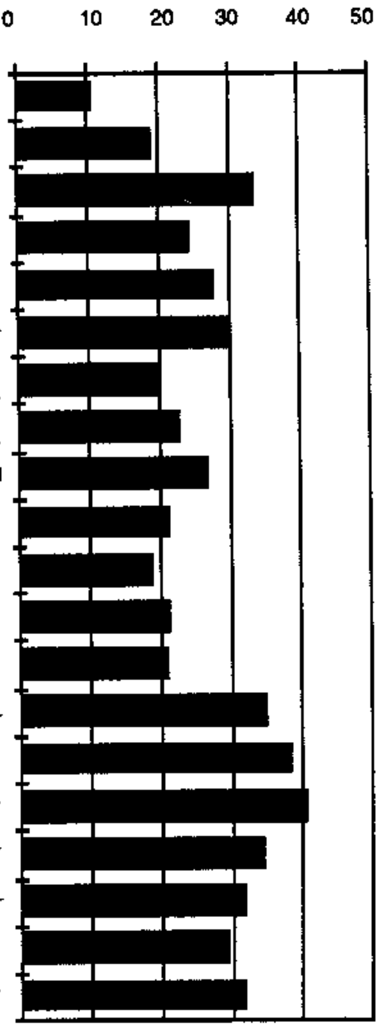
5.7: Copenhagen Row House Energy-Saving Combinations

Base Building: Single-Family Attached Row House

Insulation Levels:	RSI - 3.3 walls, 1.93 floor, 3.3 ceiling	Infiltration Rate:	0.4 ACH
Window Type:	Double glazing	Window Area:	10% of floor area, equal distribution on N, S, and W walls
Solar Access:	Restricted, 60% exposure all windows	Shading Coefficient:	1.0 Winter, 1.0 Summer

Heavyweight Construction

Heating Season Energy Savings Compared to the Base Building(%)



Combination Number and Description		Summer Impact
1)	Provide full solar access for all windows	⊖
2)	Add double low E glazing on all windows; heating season shading factor = 1.0, cooling season shading factor = 0.3; (These shading factors used on all other buildings)	⊖
3)	Add RSI-0.9 movable insulation on all windows from 8:00 pm to 6:00 am; during winter	⊖
4)	Increase S glazing to 6% of floor area, N and W - 2%; free mass; double low E glazing on all windows (double low E on all other buildings as well)	⊖
5)	Increase S glazing to 9%, N and W - 2%; 62.4 m² of 10 cm thick concrete (65% of floor area)	⊖
6)	Increase S glazing to 12%, N and W - 2%; 124.8 m² of 10 cm thick concrete (130% of floor area)	⊖
7)	Increase S glazing to 6%, W - 0%; no additional mass (free mass only)	⊖
8)	Increase S glazing to 6%, N - 0%, W - 6%; no additional mass (free mass only)	⊖
9)	Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N and W-2%	⊖
10)	Sunspace * with uninsulated common walls. (See description of sunspace below)	⊖
11)	Same as combination 10*, except common walls are 10 cm thick solid concrete	⊖
12)	Same as combination 10*, except common walls insulated to RSI-1.93	⊖
13)	Eliminate W wall to convert from end to mid unit; 5% of floor area in N glass, 5% in S glass.	⊖
14)	Increase S glazing to 6% of floor area, N is 2%; free mass	⊖
15)	Increase S glazing to 9%, N - 2%; 62.4 m² of 10 cm thick concrete (65% of floor area)	⊖
16)	Increase S glazing to 12%, N - 2%; 124.8 m² of 10 cm thick concrete (130% of floor area)	⊖
17)	Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N - 2%	⊖
18)	Sunspace* with uninsulated common walls. (See description of sunspace below)	○
19)	Same as combination 18*, except common walls are 10 cm thick solid concrete	⊖
20)	Same as combination 18*, except common walls insulated to RSI-1.93	○

* Description of sunspace: 12% parent space converted to a sunspace with 13 cm thick concrete slab floor; common walls as per Combinations 10,11, and 12; back wall has 9 m² window to parent space; sunspace glazing double and -7% of total flow area; parent space glazing (all double low E); S-2% of total floor area, N-2%, and E and W (where applicable)-1.5%.

5.8: Copenhagen Row House Energy-Saving Combinations

Base Building: Single-Family Attached Row House

Insulation Levels:	RSI - 3.3 walls, 1.93 floor, 3.3 ceiling	Infiltration Rate:	0.4 ACH
Window Type:	Double glazing	Window Area:	10% of floor area, equal distribution on N, S, and W walls
Solar Access:	Restricted, 60% exposure all windows	Shading Coefficient:	1.0 Winter, 1.0 Summer

Lightweight Construction

Combination Number and Description

1) Provide full solar access for all windows
2) Add double low E glazing on all windows; heating season shading factor = 1.0, cooling season shading factor = 0.3; (These shading factors used on all other buildings)
3) Add RSI-0.9 movable insulation on all windows from 8:00 pm to 6:00 am; during winter
4) Increase S glazing to 6% of floor area, N and W - 2%; free mass; double low E glazing on all windows (double low E on all other buildings as well)
5) Increase S glazing to 9%, N and W - 2%; 62.4 m² of 10 cm thick concrete (65% of floor area)
6) Increase S glazing to 12%, N and W - 2%; 124.8 m² of 10 cm thick concrete (130% of floor area)
7) Increase S glazing to 6%, W - 0%; no additional mass (free mass only)
8) Increase S glazing to 6%, N - 0%, W - 6%; no additional mass (free mass only)
9) Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N and W-2%
10) Sunspace * with uninsulated common walls. (See description of sunspace below)
11) Same as combination 10*, except common walls are 10 cm thick solid concrete
12) Same as combination 10*, except common walls insulated to RSI-1.93
13) Eliminate W wall to convert from end to mid unit; 5% of floor area in N glass, 5% in S glass.
14) Increase S glazing to 6% of floor area, N is 2%; free mass
15) Increase S glazing to 9%, N - 2%; 62.4 m² of 10 cm thick concrete (65% of floor area)
16) Increase S glazing to 12%, N - 2%; 124.8 m² of 10 cm thick concrete (130% of floor area)
17) Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N - 2%
18) Sunspace* with uninsulated common walls. (See description of sunspace below)
19) Same as combination 18*, except common walls are 10 cm thick solid concrete
20) Same as combination 18*, except common walls insulated to RSI-1.93

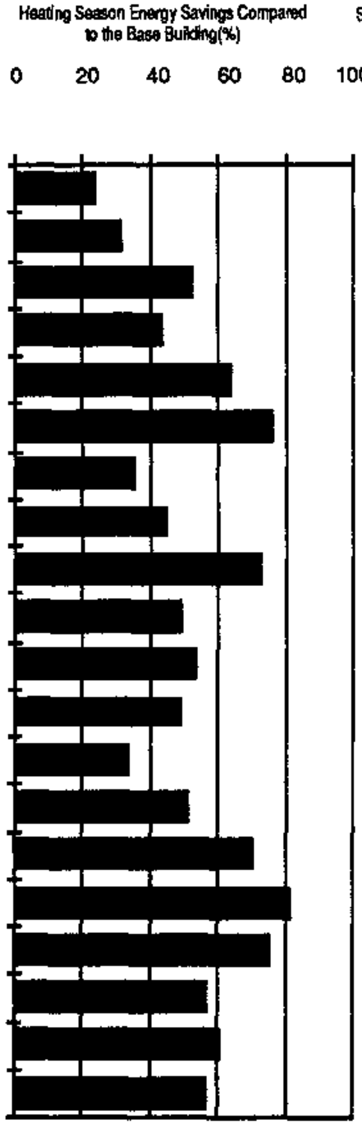
* Description of sunspace: 12% parent space converted to a sunspace with 13 cm thick concrete slab floor; common walls as per Combinations 10,11, and 12; back wall has 9 m² window to parent space; sunspace glazing double and -7% of total flow area; parent space glazing (all double low E); S-2% of total floor area, N-2%, and E and W (where applicable)-1.5%.

5.9: Denver Row House Energy-Saving Combinations

Base Building: Single-Family Attached Row House

Insulation Levels:	RSI - 3.3 walls, 1.93 floor, 3.3 ceiling	Infiltration Rate:	0.4 ACH
Window Type:	Double glazing	Window Area:	10% of floor area, equal distribution on N, S, and W walls
Solar Access:	Restricted, 60% exposure all windows	Shading Coefficient:	1.0 Winter, 1.0 Summer

Heavyweight Construction



Combination Number and Description		Summer Impact
1)	Provide full solar access for all windows	⊖
2)	Add double low E glazing on all windows; heating season shading factor = 1.0, cooling season shading factor = 0.3; (These shading factors used on all other buildings)	⊕
3)	Add RSI-0.9 movable insulation on all windows from 8:00 pm to 6:00 am; during winter	⊖
4)	Increase S glazing to 6% of floor area, N and W - 2%; free mass; double low E glazing on all windows (double low E on all other buildings as well)	⊖
5)	Increase S glazing to 9%, N and W - 2%; 62.4 m^2 of 10 cm thick concrete (65% of floor area)	⊖
6)	Increase S glazing to 12%, N and W - 2%; 124.8 m^2 of 10 cm thick concrete (130% of floor area)	⊖
7)	Increase S glazing to 6%, W - 0%; no additional mass (free mass only)	⊖
8)	Increase S glazing to 6%, N - 0%, W - 6%; no additional mass (free mass only)	⊖
9)	Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N and W- 2%	⊖
10)	Sunspace * with uninsulated common walls. (See description of sunspace below)	⊕
11)	Same as combination 10*, except common walls are 10 cm thick solid concrete	⊕
12)	Same as combination 10*, except common walls insulated to RSI-1.93	⊕
13)	Eliminate W wall to convert from end to mid unit; 5% of floor area in N glass, 5% in S glass.	⊖
14)	Increase S glazing to 6% of floor area, N is 2%; free mass	○
15)	Increase S glazing to 9%, N - 2%; 62.4 m^2 of 10 cm thick concrete (65% of floor area)	⊖
16)	Increase S glazing to 12%, N - 2%; 124.8 m^2 of 10 cm thick concrete (130% of floor area)	⊖
17)	Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N - 2% -	⊖
18)	Sunspace* with uninsulated common walls. (See description of sunspace below)	⊕
19)	Same as combination 18*, except common walls are 10 cm thick solid concrete	⊕
20)	Same as combination 18*, except common walls insulated to RSI-1.93	⊕

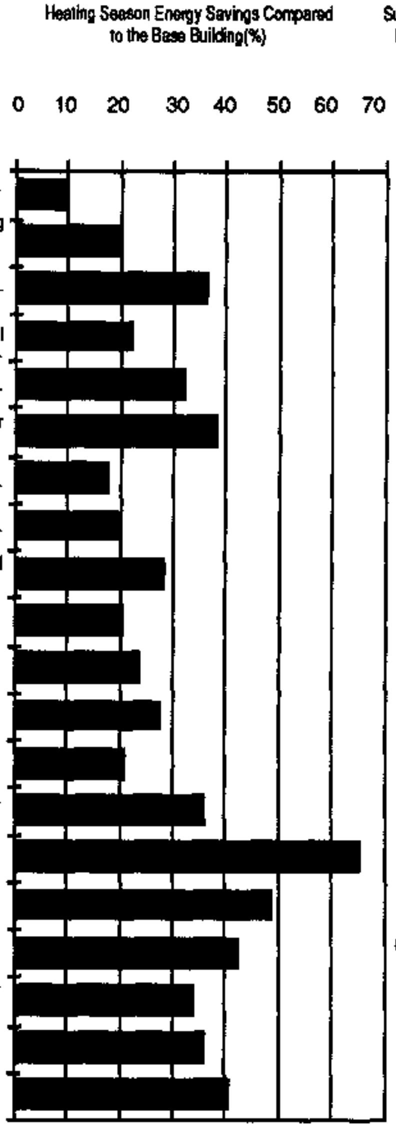
* Description of sunspace: 12% parent space converted to a sunspace with 13 cm thick concrete slab floor; common walls as per Combinations 10,11, and 12; back wall has 9 m^2 window to parent space; sunspace glazing double and -7% of total flow area; parent space glazing (all double low E); S-2% of total floor area, N-2%, and E and W (where applicable)-1.5%.

5.10: Denver Row House Energy-Saving Combinations

Base Building: Single-Family Attached Row House

Insulation Levels:	RSI - 3.3 walls, 1.93 floor, 3.3 ceiling	Infiltration Rate:	0.4 ACH
Window Type:	Double glazing	Window Area:	10% of floor area, equal distribution on N, S, and W walls
Solar Access:	Restricted, 60% exposure all windows	Shading Coefficient:	1.0 Winter, 1.0 Summer

Lightweight Construction



Combination Number and Description	Summer Impact
1) Provide full solar access for all windows	⊖
2) Add double low E glazing on all windows; heating season shading factor = 1.0, cooling season shading factor = 0.3; (These shading factors used on all other buildings)	⊕
3) Add RSI-0.9 movable insulation on all windows from 8:00 pm to 6:00 am; during winter	⊖
4) Increase S glazing to 6% of floor area, N and W - 2%; free mass; double low E glazing on all windows (double low E on all other buildings as well)	⊕
5) Increase S glazing to 9%, N and W - 2%; 62.4 m² of 10 cm thick concrete (65% of floor area)	⊕
6) Increase S glazing to 12%, N and W - 2%; 124.8 m² of 10 cm thick concrete (130% of floor area)	⊕
7) Increase S glazing to 6%, W - 0%; no additional mass (free mass only)	⊕
8) Increase S glazing to 6%, N - 0%, W - 6%; no additional mass (free mass only)	⊕
9) Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N and W-2%	⊖
10) Sunspace * with uninsulated common walls. (See description of sunspace below)	⊕
11) Same as combination 10*, except common walls are 10 cm thick solid concrete	⊕
12) Same as combination 10*, except common walls insulated to RSI-1.93	⊕
13) Eliminate W wall to convert from end to mid unit; 5% of floor area in N glass, 5% in S glass.	⊖
14) Increase S glazing to 6% of floor area, N is 2%; free mass	⊕
15) Increase S glazing to 9%, N - 2%; 62.4 m² of 10 cm thick concrete (65% of floor area)	⊕
16) Increase S glazing to 12%, N - 2%; 124.8 m² of 10 cm thick concrete (130% of floor area)	⊕
17) Add 25 cm thermal storage wall sized at 10% of floor area; Increase S glazing to 6%, N - 2%	○
18) Sunspace* with uninsulated common walls. (See description of sunspace below)	⊕
19) Same as combination 18*, except common walls are 10 cm thick solid concrete	⊕
20) Same as combination 18*, except common walls insulated to RSI-1.93	⊕

* Description of sunspace: 12% parent space converted to a sunspace with 13 cm thick concrete slab floor; common walls as per Combinations 10,11, and 12; back wall has 9 m² window to parent space; sunspace glazing double and -7% of total flow area; parent space glazing (all double low E); S-2% of total floor area, N-2%, and E and W (where applicable)-1.5%.

5.11: Geneva Row House Energy-Saving Combinations

Base Building: Single-Family Attached Row House

Insulation Levels:	RSI - 3.3 walls, 1.93 floor, 3.3 ceiling	Infiltration Rate:	0.4 ACH
Window Type:	Double glazing	Window Area:	10% of floor area, equal distribution on N, S, and W walls
Solar Access:	Restricted, 60% exposure all windows	Shading Coefficient:	1.0 Winter, 1.0 Summer

Heavyweight Construction

Combination Number and Description

1) Provide full solar access for all windows
2) Add double low E glazing on all windows; heating season shading factor = 1.0, cooling season shading factor = 0.3; (These shading factors used on all other buildings)
3) Add RSI-0.9 movable insulation on all windows from 8:00 pm to 6:00 am; during winter
4) Increase S glazing to 6% of floor area, N and W - 2%; free mass; double low E glazing on all windows (double low E on all other buildings as well)
5) Increase S glazing to 9%, N and W - 2%; 62.4 m^2 of 10 cm thick concrete (65% of floor area)
6) Increase S glazing to 12%, N and W - 2%; 124.8 m^2 of 10 cm thick concrete (130% of floor area)
7) Increase S glazing to 6%, W - 0%; no additional mass (free mass only)
8) Increase S glazing to 6%, N - 0%, W - 6%; no additional mass (free mass only)
9) Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N and W-2%
10) Sunspace * with uninsulated common walls. (See description of sunspace below)
11) Same as combination 10*, except common walls are 10 cm thick solid concrete
12) Same as combination 10*, except common walls insulated to RSI-1.93
13) Eliminate W wall to convert from end to mid unit; 5% of floor area in N glass, 5% in S glass.
14) Increase S glazing to 6% of floor area, N is 2%; free mass
15) Increase S glazing to 9%, N - 2%; 62.4 m^2 of 10 cm thick concrete (65% of floor area)
16) Increase S glazing to 12%, N - 2%; 124.8 m^2 of 10 cm thick concrete (130% of floor area)
17) Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N - 2% -
18) Sunspace* with uninsulated common walls. (See description of sunspace below)
19) Same as combination 18*, except common walls are 10 cm thick solid concrete
20) Same as combination 18*, except common walls insulated to RSI-1.93

Heating Season Energy Savings Compared to the Base Building(%)

Summer Impact

* Description of sunspace: 12% parent space converted to a sunspace with 13 cm thick concrete slab floor; common walls as per Combinations 10,11, and 12; back wall has 9 m^2 window to parent space; sunspace glazing double and -7% of total flow area; parent space glazing (all double low E); S-2% of total floor area, N-2%, and E and W (where applicable)-1.5%.

5.12: Geneva Row House Energy-Saving Combinations

Combination 13 duplicates the base building in a middle unit row house configuration. Due to the smaller heating load, the passive solar measures provide even greater energy-savings than the end unit configuration. This holds true throughout the remainder of the combinations.

Combinations 14 through 16 duplicate the features of 4 through 6, in a middle unit configuration. The same patterns of energy-savings repeat, with a greater magnitude due to the reduction in heating load. Combinations 17 through 20 echo the features of combinations 9 through 12 with a thermal storage wall and three sunspace designs. Again, the magnitude of savings is greater, but the general patterns remain the same.

5.3 MULTIFAMILY ATTACHED HOUSING CONFIGURATION

Figures 5.13 to 5.18 address the passive solar features of a single-family apartment unit in end and middle unit configurations. The performance improvement is expressed as a percentage energy-savings compared to the base building, and is

The passive solar combinations analyzed for apartment units are the same as those studies for row house units. Combinations 1 through 12 are used on an end unit and combinations 13 through 20 are used on a middle unit.

The results for apartment units are nearly parallel to those for row house units. Small variations occur because the floor and ceiling of the apartment are not exposed to ambient air temperatures. This causes glazing and insulation changes in the remaining surfaces which are exposed to outdoor air to have a proportionally greater effect.

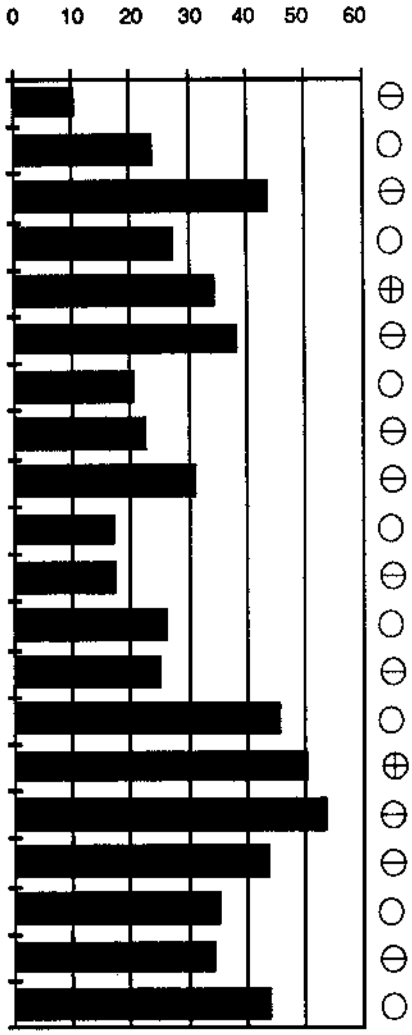
Base Building: Multifamily Apartment

Insulation Levels:	RSI - 3.3 walls, 1.93 floor, 3.3 ceiling	Infiltration Rate:	0.4 ACH
Window Type:	Double glazing	Window Area:	10% of floor area, equal distribution on N, S, and W walls
Solar Access:	Restricted, 60% exposure all windows	Shading Coefficient:	1.0 Winter, 1.0 Summer

Lightweight Construction

Heating Season Energy Savings Compared to the Base Building(%)

Combination Number and Description	Summer Impact
1) Provide full solar access for all windows	⊖
2) Add double low E glazing on all windows; heating season shading factor = 1.0, cooling season shading factor = 0.3; (These shading factors used on all other buildings)	○
3) Add RSI-0.9 movable insulation on all windows from 8:00 pm to 6:00 am; during winter	⊖
4) Increase S glazing to 6% of floor area, N and W - 2%; free mass; double low E glazing on all windows (double low E on all other buildings as well)	○
5) Increase S glazing to 9%, N and W - 2%; 62.4 m² of 10 cm thick concrete (65% of floor area)	⊕
6) Increase S glazing to 12%, N and W - 2%; 124.8 m² of 10 cm thick concrete (130% of floor area)	⊖
7) Increase S glazing to 6%, W - 0%; no additional mass (free mass only)	○
8) Increase S glazing to 6%, N - 0%, W - 6%; no additional mass (free mass only)	⊖
9) Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N and W-2%	⊖
10) Sunspace * with uninsulated common walls. (See description of sunspace below)	○
11) Same as combination 10*, except common walls are 10 cm thick solid concrete	⊖
12) Same as combination 10*, except common walls insulated to RSI-1.93	○
13) Eliminate W wall to convert from end to mid unit; 5% of floor area in N glass, 5% in S glass.	⊖
14) Increase S glazing to 6% of floor area, N is 2%; free mass	○
15) Increase S glazing to 9%, N - 2%; 62.4 m² of 10 cm thick concrete (65% of floor area)	⊕
16) Increase S glazing to 12%, N - 2%; 124.8 m² of 10 cm thick concrete (130% of floor area)	⊖
17) Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N - 2% -	⊖
18) Sunspace* with uninsulated common walls. (See description of sunspace below)	○
19) Same as combination 18*, except common walls are 10 cm thick solid concrete	⊖
20) Same as combination 18*, except common walls insulated to RSI-1.93	○



* Description of sunspace: 12% parent space converted to a sunspace with 13 cm thick concrete slab floor; common walls as per Combinations 10,11, and 12; back wall has 9 m² window to parent space; sunspace glazing double and -7% of total flow area; parent space glazing (all double low E); S-2% of total floor area, N-2%, and E and W (where applicable)-1.5%.

5.13: Copenhagen Solar Apartment Energy-Saving Combinations

Base Building: Multifamily Apartment

Insulation Levels:	RSI - 3.3 walls, 1.93 floor, 3.3 ceiling	Infiltration Rate:	0.4 ACH
Window Type:	Double glazing	Window Area:	10% of floor area, equal distribution on N, S, and W walls
Solar Access:	Restricted, 60% exposure all windows	Shading Coefficient:	1.0 Winter, 1.0 Summer

Heavyweight Construction

Combination Number and Description

1) Provide full solar access for all windows
2) Add double low E glazing on all windows; heating season shading factor = 1.0, cooling season shading factor = 0.3; (These shading factors used on all other buildings)
3) Add RSI-0.9 movable insulation on all windows from 8:00 pm to 6:00 am; during winter
4) Increase S glazing to 6% of floor area, N and W - 2%; free mass; double low E glazing on all windows (double low E on all other buildings as well)
5) Increase S glazing to 9%, N and W - 2%; 62.4 m² of 10 cm thick concrete (65% of floor area)
6) Increase S glazing to 12%, N and W - 2%; 124.8 m² of 10 cm thick concrete (130% of floor area)
7) Increase S glazing to 6%, W - 0%; no additional mass (free mass only)
8) Increase S glazing to 6%, N - 0%, W - 6%; no additional mass (free mass only)
9) Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N and W-2%
10) Sunspace * with uninsulated common walls. (See description of sunspace below)
11) Same as combination 10*, except common walls are 10 cm thick solid concrete
12) Same as combination 10*, except common walls insulated to RSI-1.93
13) Eliminate W wall to convert from end to mid unit; 5% of floor area in N glass, 5% in S glass.
14) Increase S glazing to 6% of floor area, N is 2%; free mass
15) Increase S glazing to 9%, N - 2%; 62.4 m² of 10 cm thick concrete (65% of floor area)
16) Increase S glazing to 12%, N - 2%; 124.8 m² of 10 cm thick concrete (130% of floor area)
17) Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N - 2% -
18) Sunspace* with uninsulated common walls. (See description of sunspace below)
19) Same as combination 18*, except common walls are 10 cm thick solid concrete
20) Same as combination 18*, except common walls insulated to RSI-1.93

* Description of sunspace: 12% parent space converted to a sunspace with 13 cm thick concrete slab floor; common walls as per Combinations 10,11, and 12; back wall has 9 m² window to parent space; sunspace glazing double and -7% of total flow area; parent space glazing (all double low E); S-2% of total floor area, N-2%, and E and W (where applicable)-1.5%.

5.14: Copenhagen Solar Apartment Energy-Saving Combinations

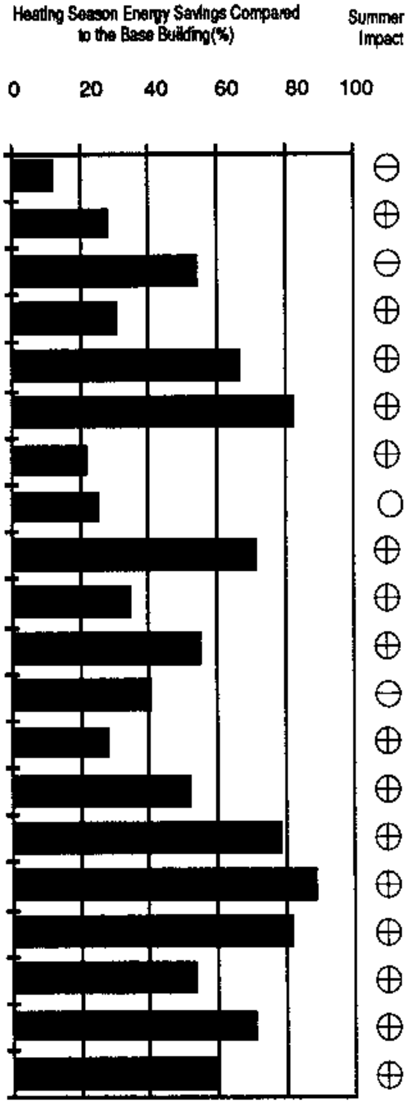
Base Building: Multifamily Apartment

Insulation Levels:	RSI - 3.3 walls, 1.93 floor, 3.3 ceiling	Infiltration Rate:	0.4 ACH
Window Type:	Double glazing	Window Area:	10% of floor area, equal distribution on N, S, and W walls
Solar Access:	Restricted, 60% exposure all windows	Shading Coefficient:	1.0 Winter, 1.0 Summer

Lightweight Construction

Combination Number and Description

1) Provide full solar access for all windows ⊖
2) Add double low E glazing on all windows; heating season shading factor = 1.0, cooling season shading factor = 0.3; (These shading factors used on all other buildings) ⊕
3) Add RSI-0.9 movable insulation on all windows from 8:00 pm to 6:00 am; during winter ⊖
4) Increase S glazing to 6% of floor area, N and W - 2%; free mass; double low E glazing on all windows (double low E on all other buildings as well) ⊕
5) Increase S glazing to 9%, N and W - 2%; 62.4 m² of 10 cm thick concrete (65% of floor area) ⊕
6) Increase S glazing to 12%, N and W - 2%; 124.8 m² of 10 cm thick concrete (130% of floor area) ⊕
7) Increase S glazing to 6%, W - 0%; no additional mass (free mass only) ⊕
8) Increase S glazing to 6%, N - 0%, W - 6%; no additional mass (free mass only) ○
9) Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N and W- 2% ⊕
10) Sunspace * with uninsulated common walls. (See description of sunspace below) ⊕
11) Same as combination 10*, except common walls are 10 cm thick solid concrete ⊕
12) Same as combination 10*, except common walls insulated to RSI-1.93 ⊖
13) Eliminate W wall to convert from end to mid unit; 5% of floor area in N glass, 5% in S glass. ⊕
14) Increase S glazing to 6% of floor area, N is 2%; free mass ⊕
15) Increase S glazing to 9%, N - 2%; 62.4 m² of 10 cm thick concrete (65% of floor area) ⊕
16) Increase S glazing to 12%, N - 2%; 124.8 m² of 10 cm thick concrete (130% of floor area) ⊕
17) Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N - 2% - ⊕
18) Sunspace* with uninsulated common walls. (See description of sunspace below) ⊕
19) Same as combination 18*, except common walls are 10 cm thick solid concrete ⊕
20) Same as combination 18*, except common walls insulated to RSI-1.93 ⊕



* Description of sunspace: 12% parent space converted to a sunspace with 13 cm thick concrete slab floor; common walls as per Combinations 10,11, and 12; back wall has 9 m² window to parent space; sunspace glazing double and -7% of total flow area; parent space glazing (all double low E); S-2% of total floor area, N-2%, and E and W (where applicable)-1.5%.

5.15: Denver Solar Apartment Energy-Saving Combinations

Base Building: Multifamily Apartment

Insulation Levels:	RSI - 3.3 walls, 1.93 floor, 3.3 ceiling	Infiltration Rate:	0.4 ACH
Window Type:	Double glazing	Window Area:	10% of floor area, equal distribution on N, S, and W walls
Solar Access:	Restricted, 60% exposure all windows	Shading Coefficient:	1.0 Winter, 1.0 Summer

Heavyweight Construction

Combination Number and Description

1) Provide full solar access for all
2) Add double low E glazing on all windows; heating season shading factor = 1.0, cooling season shading factor = 0.3; (These shading factors used on all other buildings)
3) Add RSI-0.9 movable insulation on all windows from 8:00 pm to 6:00 am; during winter
4) Increase S glazing to 6% of floor area, N and W - 2%; free mass; double low E glazing on all windows (double low E on all other buildings as well)
5) Increase S glazing to 9%, N and W - 2%; 62.4 m² of 10 cm thick concrete (65% of floor area)
6) Increase S glazing to 12%, N and W - 2%; 124.8 m² of 10 cm thick concrete (130% of floor area)
7) Increase S glazing to 6%, W - 0%; no additional mass (free mass only)
8) Increase S glazing to 6%, N - 0%, W - 6%; no additional mass (free mass only)
9) Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N and W-2%
10) Sunspace * with uninsulated common walls. (See description of sunspace below)
11) Same as combination 10*, except common walls are 10 cm thick solid concrete
12) Same as combination 10*, except common walls insulated to RSI-1.93
13) Eliminate W wall to convert from end to mid unit; 5% of floor area in N glass, 5% in S glass.
14) Increase S glazing to 6% of floor area, N is 2%; free mass
15) Increase S glazing to 9%, N - 2%; 62.4 m² of 10 cm thick concrete (65% of floor area)
16) Increase S glazing to 12%, N - 2%; 124.8 m² of 10 cm thick concrete (130% of floor area)
17) Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N - 2% -
18) Sunspace* with uninsulated common walls. (See description of sunspace below)
19) Same as combination 18*, except common walls are 10 cm thick solid concrete
20) Same as combination 18*, except common walls insulated to RSI-1.93

* Description of sunspace: 12% parent space converted to a sunspace with 13 cm thick concrete slab floor; common walls as per Combinations 10,11, and 12; back wall has 9 m² window to parent space; sunspace glazing double and -7% of total flow area; parent space glazing (all double low E); S-2% of total floor area, N-2%, and E and W (where applicable)-1.5%.

5.16: Denver Solar Apartment Energy-Saving Combinations

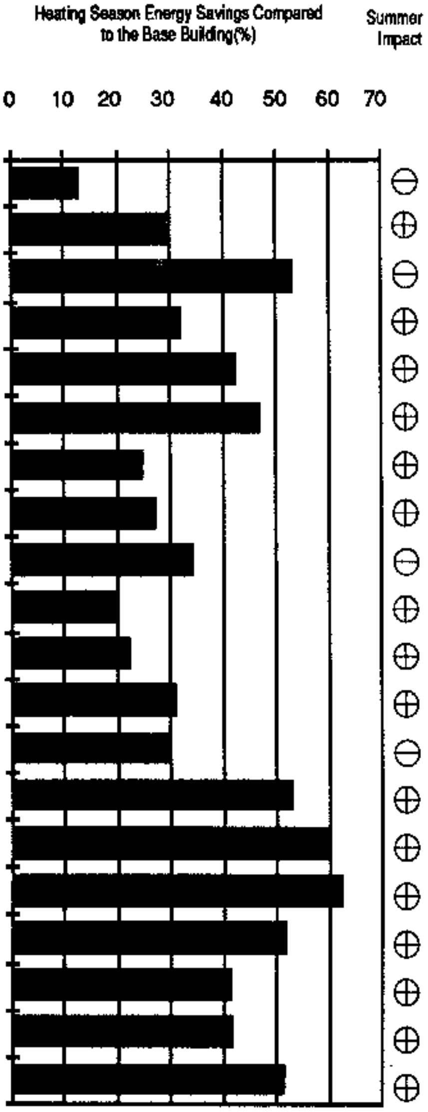
Base Building: Multifamily Apartment

Insulation Levels:	RSI - 3.3 walls, 1.93 floor, 3.3 ceiling	Infiltration Rate:	0.4 ACH
Window Type:	Double glazing	Window Area:	10% of floor area, equal distribution on N, S, and W walls
Solar Access:	Restricted, 60% exposure all windows	Shading Coefficient:	1.0 Winter, 1.0 Summer

Lightweight Construction

Combination Number and Description

1) Provide full solar access for all windows
2) Add double low E glazing on all windows; heating season shading factor = 1.0, cooling season shading factor = 0.3; (These shading factors used on all other buildings)
3) Add RSI-0.9 movable insulation on all windows from 8:00 pm to 6:00 am; during winter
4) Increase S glazing to 6% of floor area, N and W - 2%; free mass; double low E glazing on all windows (double low E on all other buildings as well)
5) Increase S glazing to 9%, N and W - 2%; 62.4 m² of 10 cm thick concrete (65% of floor area)
6) Increase S glazing to 12%, N and W - 2%; 124.8 m² of 10 cm thick concrete (130% of floor area)
7) Increase S glazing to 6%, W - 0%; no additional mass (free mass only)
8) Increase S glazing to 6%, N - 0%, W - 6%; no additional mass (free mass only)
9) Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N and W-2%
10) Sunspace * with uninsulated common walls. (See description of sunspace below)
11) Same as combination 10*, except common walls are 10 cm thick solid concrete
12) Same as combination 10*, except common walls insulated to RSI-1.93
13) Eliminate W wall to convert from end to mid unit; 5% of floor area in N glass, 5% in S glass.
14) Increase S glazing to 6% of floor area, N is 2%; free mass
15) Increase S glazing to 9%, N - 2%; 62.4 m² of 10 cm thick concrete (65% of floor area)
16) Increase S glazing to 12%, N - 2%; 124.8 m² of 10 cm thick concrete (130% of floor area)
17) Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N - 2%
18) Sunspace* with uninsulated common walls. (See description of sunspace below)
19) Same as combination 18*, except common walls are 10 cm thick solid concrete
20) Same as combination 18*, except common walls insulated to RSI-1.93



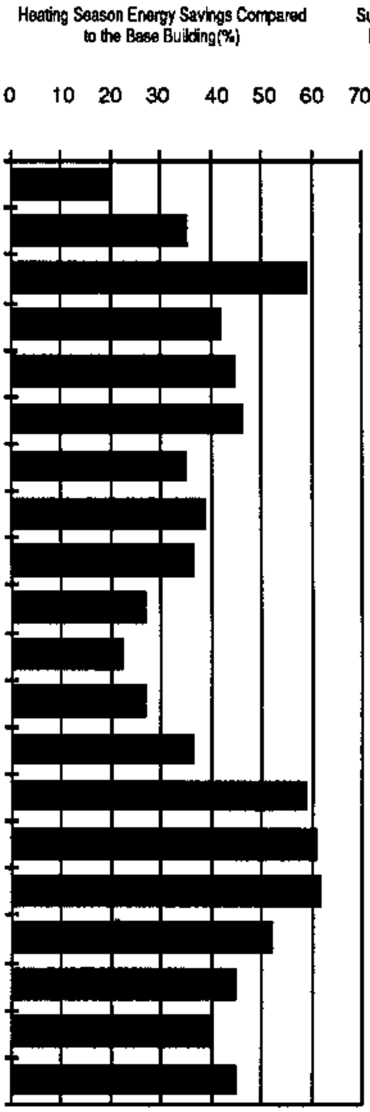
* Description of sunspace: 12% parent space converted to a sunspace with 13 cm thick concrete slab floor; common walls as per Combinations 10,11, and 12; back wall has 9 m² window to parent space; sunspace glazing double and -7% of total flow area; parent space glazing (all double low E); S-2% of total floor area, N-2%, and E and W (where applicable)-1.5%.

5.17: Geneva Solar Apartment Energy-Saving Combinations

Base Building: Multifamily Apartment

Insulation Levels:	RSI - 3.3 walls, 1.93 floor, 3.3 ceiling	Infiltration Rate:	0.4 ACH
Window Type:	Double glazing	Window Area:	10% of floor area, equal distribution on N, S, and W walls
Solar Access:	Restricted, 60% exposure all windows	Shading Coefficient:	1.0 Winter, 1.0 Summer

Heavywieght Construction



Combination Number and Description	Summer Impact
1) Provide full solar access for all windows	⊖
2) Add double low E glazing on all windows; heating season shading factor = 1.0, cooling season shading factor = 0.3; (These shading factors used on all other buildings)	⊕
3) Add RSI-0.9 movable insulation on all windows from 8:00 pm to 6:00 am; during winter	⊖
4) Increase S glazing to 6% of floor area, N and W - 2%; free mass; double low E glazing on all windows (double low E on all other buildings as well)	○
5) Increase S glazing to 9%, N and W - 2%; 62.4 m² of 10 cm thick concrete (65% of floor area)	⊖
6) Increase S glazing to 12%, N and W - 2%; 124.8 m² of 10 cm thick concrete (130% of floor area)	⊖
7) Increase S glazing to 6%, W - 0%; no additional mass (free mass only)	○
8) Increase S glazing to 6%, N - 0%, W - 6%; no additional mass (free mass only)	⊖
9) Add 25 cm thermal storage wall sized at 10% of floor area; Increase S glazing to 6%, N and W- 2%	⊖
10) Sunspace * with uninsulated common walls. (See description of sunspace below)	⊕
11) Same as combination 10*, except common walls are 10 cm thick solid concrete	⊕
12) Same as combination 10*, except common walls insulated to RSI-1.93	⊕
13) Eliminate W wall to convert from end to mid unit; 5% of floor area in N glass, 5% in S glass.	⊖
14) Increase S glazing to 6% of floor area, N is 2%; free mass	⊕
15) Increase S glazing to 9%, N - 2%; 62.4 m² of 10 cm thick concrete (65% of floor area)	⊖
16) Increase S glazing to 12%, N - 2%; 124.8 m² of 10 cm thick concrete (130% of floor area)	⊖
17) Add 25 cm thermal storage wall sized at 10% of floor area; increase S glazing to 6%, N - 2% -	⊖
18) Sunspace* with uninsulated common walls. (See description of sunspace below)	⊕
19) Same as combination 18*, except common walls are 10 cm thick solid concrete	⊕
20) Same as combination 18*, except common walls insulated to RSI-1.93	⊕

* Description of sunspace: 12% parent space converted to a sunspace with 13 cm thick concrete slab floor; common walls as per Combinations 10,11, and 12; back wall has 9 m² window to parent space; sunspace glazing double and -7% of total flow area; parent space glazing (all double low E); S-2% of total floor area, N-2%, and E and W (where applicable)-1.5%.

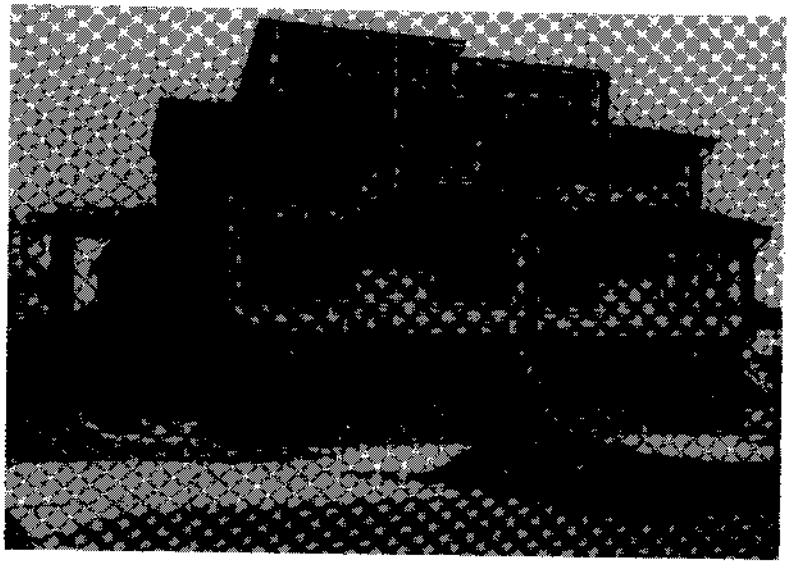
5.18: Geneva Solar Apartment Energy-Saving Combinations

CONCLUSIONS

A major conclusion of IEA research on passive and hybrid solar low energy residential design is that significant energy savings and improvement in comfort can be achieved by adhering to a few simple principles of energy design. These energy design principles or guidelines can be integrated into residential architecture while enhancing design flexibility and choice, affordability, durability, air quality, amenity and comfort, and marketability.

Another conclusion from the IEA research is that simple energy-saving strategies, such as improved envelope insulation levels or use of high performance glazings, are generally more effective and economical than complex energy-saving strategies. This conclusion points out the need to fully understand the energy use requirements in residential buildings and to develop solutions that are durable, affordable, and reliable to meet these requirements -- be they simple or complex solutions.

The reader is encouraged to obtain the National Design Guidelines Booklet appropriate to his or her location. This booklet will provide location-specific advice and guidelines for designing energy-efficient, passive solar homes. The reader is also encouraged to obtain the other booklets in the Design Information Series. They will provide extremely valuable information concerning the design, construction, use, and evaluation of energy-efficient, passive solar homes.



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