CALIFORNIA
ENERGY
COMMISSION

LOW-RISE MULTIFAMILY BUILDING NEW CONSTRUCTION CHARACTERISTICS STUDY

CONSULTANT REPORT

JULY 2000
P400-00-012

Gray Davis, *Governor*

CALIFORNIA
ENERGY
COMMISSION

LOW-RISE
MULTIFAMILY BUILDING
NEW CONSTRUCTION
CHARACTERISTICS STUDY

CONSULTANT REPORT

JULY 2000
P400-00-012

Gray Davis, *Governor*

CALIFORNIA ENERGY COMMISSION

Prepared By:

Regional Economic
Research, Inc.
San Diego, CA
Contract No. 400-96-019

Prepared For:

Susan Draa,
Contract Manager

Jon Leber,
Project Manager

Michael Sloss,
Manager

NONRESIDENTIAL
BUILDINGS
OFFICE

Scott Matthews,
Deputy Director

ENERGY
EFFICIENCY
DIVISION

Steve Larson,
Executive Director

DEFINITION

"**LOW RISE MULTI-FAMILY BUILDING"**

A Low-Rise building is a building, other than a hotel/motel, that is of Occupancy Group R, Division 1, and is three stories or less, or that is of Occupancy Group R, Division 3, as stated in the Uniform Building Code.

LEGAL NOTICE – DISCLAIMER

ACKNOWLEDGEMENTS

This document**, "Low Rise Multifamily Building - New Construction Study"** was prepared by Regional Economic Research, Inc. (RER) under contract #400-96-019, for the California Energy Commission. Data was gathered primarily for use by the California Energy Commission in the development and implementation of building efficiency standards. The principal author of the report was Regional Economic Research, Inc. of San Diego, CA.

Staff from the Energy Commission's Nonresidential Buildings Office who provided Administrative and Technical support included Jon Leber, Project Manager, and Susan Draa, Contract Manager.

Table of Contents

Low-Rise Multifamily Building New Construction Characteristics Study

1. Overview

This report presents the results of Regional Economic Research's (RER) Multifamily Building Characteristics study conducted for the California Energy Commission (CEC) under Work Authorization 99-11. This research examines the typical construction practices and energy efficiency and performance trade-offs that are used in Title 24 compliance runs for low-rise multifamily residences.

The California Energy Standards for Low-Rise Residential Buildings apply to low-rise, multifamily as well as to single-family residences. Because the construction practices for these two residence types can differ significantly, particularly in the percent of glazing used, the CEC was interested in gathering information about the typical building practices used for low-rise multifamily buildings. These data were obtained from energy compliance analysis documentation, specifically the Computer Method Summary form (C-2R) completed by energy consultants. Data were collected from compliance runs that used either the 1995 or the 1998 Standards for low-rise multifamily buildings.[1,2] There were five major study tasks.

- ***Define Sample***. A controlled sample based on the number of multifamily units built in California since 1996 was developed to ensure that a representative sample of compliance documents was collected. The sample was stratified by climate zone and the records collected were monitored to ensure that a diversity of features, such as building orientation, number of stories and window types, was present in the sample.
- ***Identify and Recruit Energy Consultants.*** Energy consultants were recruited from the List of Certified Energy Consultants and other available sources. Contact lists, contact documentation (e.g., project flyers, letters, e-mails, scripts, etc.), participation agreements, and arrangements for issuing payments to the consultants were created by RER then approved by the CEC project manager.

[1] Energy Efficiency Standards for Residential and Non-Residential Buildings, California Energy Commission.

[2] The work scope originally specified collecting forms for buildings constructed in California after 1996, but was amended to the requirement above because most consultants did not know build dates.

- ***Collect Data.*** The energy consultants' C-2R compliance documentation sets were collected, tracked, logged in, and entered into an electronic database. This documentation included hardcopies of the C-2R forms and the corresponding electronic file(s) used to produce that C-2R. Consultants were paid $55 for each set of documents.
- ***Prepare C-2R Database.*** A key objective was to provide CEC staff with a database of the building shell and equipment characteristics of multifamily new construction, as gathered from the C-2R forms.
- ***Prepare and Analyze Data.*** Quality checks were conducted on the completed database of eligible sites. Data were then analyzed based on the following information:
  - typical percentage of fenestration being used in each climate zone relative to the requirements of the prescriptive packages.
  - typical construction practices with respect to prescriptive Package D values.
  - efficiency trade-offs, such as the energy efficiency measures removed from buildings that achieved compliance with fenestration quantities less than those in prescriptive Package D.

  These analyses were made with reference to the following Package D prescriptive requirements:
  - climate zones with a 20% glazing prescriptive allowance;
  - climate zones with a 16% glazing prescriptive allowance;
  - climate zones that have high performance shading requirements;
  - climate zones that allow standard draperies in all orientations.

The remainder of this report details the data collection effort and database development. It also includes a discussion of the analysis of the C-2R data, and presents the project results.

Accompanying this report are hard copies of consultant-provided C-2R forms. Useable forms are contained in Volumes 1 through 4. Volume 5 contains unusable forms. Each volume includes a table of contents and a summary of the forms contained in that binder.

2. Data

The following subsections describe the data development effort for this study, including details relating to six data tasks.

- Sample Design
- Recruiting Protocol
- Sample Tracking
- Completed Sample

- C-2R Database Development
- Data Validation

Sample Design

A major requirement of this study was ensuring that a representative sample of multifamily compliance records was collected. To accomplish this task, a sample stratified by climate zone was constructed. Data for this purpose were obtained from the Construction Industry Research Board (CIRB). The CIRB compiles information on the number of multifamily dwelling units from building permits as reported by California building departments. These data were mapped from building department to CEC climate zones (CZ) to compile a proxy for the number of multifamily units built in each climate zone from 1997 through 1999, and to develop a set of weights for the analysis. The results are presented in Table 1 showing the number of permitted multifamily dwelling units by year, the total permitted, the percent permitted by CZ, and the final number of target sites used for each CEC climate zone.

Table 1: Summary of Multifamily Building Permits by CEC Climate Zone

CEC Climate Zone	1997 # of MF Units	1998 # of MF Units	1999 # of MF Units*[3]	Total Permitted Units	Total Unit % by CZ	Final CZ Targets
1	78	55	32	165	0.19%	2
2	614	1,119	584	2,317	2.69%	5
3	4,683	4,768	4,421	13,872	16.14%	22
4	4,527	3,682	2,784	10,993	12.79%	20
5	141	155	153	449	0.52%	2
6	4,068	3,648	3,489	11,205	13.03%	19
7	2,881	2,833	5,261	10,975	12.77%	19
8	2,903	2,179	2,145	7,227	8.40%	13
9	1,001	1,671	1,268	3,940	4.58%	7
10	1,372	1,674	1,305	4,351	5.06%	8
11	1,025	1,538	922	3,485	4.05%	6
12	1,966	5,252	2,782	10,000	11.63%	17
13	887	1,163	547	2,597	3.02%	5
14	189	566	749	1,504	1.75%	5
15	303	475	650	1,428	1.66%	5
16	302	630	500	1,432	1.66%	5
Total	**26,940**	**31,408**	**27,592**	**85,940**	**100%**	**160**

[3] These values were current as of September 1999. For reference, from 1997-1999, the total number of multifamily units permitted (96,726) was about 26% of the single-family units permitted (280,748).

Sample targets were developed for each climate zone using a proportional sampling process, with a minimum of two in each climate zone. To ensure this minimum requirement, target values for climate zones with the largest targets were revised downward to maintain the overall total of 160. The final C-2R target values are presented in the last column of Table 1.

Recruiting Protocol

This subsection describes how the energy consultants were identified, contacted and recruited to provide the compliance records needed to meet the climate zone targets.

Energy Consultant List

RER recruited energy consultants from two sources.

- ***California Association of Building Energy Consultants (CABEC).*** RER used CABEC's on-line list of Certified Energy Analysts (CEAs). This list was screened to include only residential energy consultants. Screening reduced the list to 50 CEAs, 47 of which had e-mail addresses.
- ***MICROPAS Users' List.*** RER obtained a proprietary list of MICROPAS users from Enercomp, Inc. The list was provided for a fee on the conditions that it was only used for this specific project, and that only individual e-mails (addressed to a single person) were sent to those contacted. After screening out CEAs to avoid duplicates, the MICROPAS users' list contained 329 contacts, of which 195 (59%) had e-mail addresses.

A complete list of the consultants identified by these two sources and used for recruitment is included in the C-2R database contained in Appendix F.[4]

Recruitment Procedure

RER developed a program flyer for the targeted energy consultants (see Appendix B). The flyer included a discussion of the project, participation requirements, RER contact information, and an explanation of the compensation for participation.

RER distributed the program flyer via e-mail to each of the energy consultants, then followed up with each energy consultant to explain the projects and to attempt recruiting them to submit multifamily data. This process included three objectives.

---

[4] A complete list of the consultants identified by these two sources is contained in the "FINAL_MAILING _LIST" table of the C-2R database. To comply with Enercomp's request that their mailing list be used on a one-time basis, specific contact information, such as street addresses, telephone numbers, and e-mail addresses, were purged from this table.

- Determine which climate zone each consultant worked in to ensure that all climate zones would be represented in the data gathered.
- Collect data from each participating consultant, up to a maximum of 15 project files. Data consisted of a hardcopy C-2R and the corresponding compliance program input files that were used to generate the C-2R. Two consultants were allowed to exceed the 15-file limit because they had data for climate zones that fell short of the targets required.
- Maintain contact with participating energy consultants to ensure that the files and documentation are valid and are received in a timely manner, and that any questions or issues were addressed immediately.

In addition to satisfying climate zone targets, RER monitored the sample to ensure that a diversity of building types and features such as number of stories, building orientation, and fenestration assemblies was also represented in the sample.

Sample Tracking

As directed by the work statement, RER created a system to track the C-2R data sets received from each consultant. This system actively tracked, managed, and targeted recruitment efforts. It also tracked payments made and, for ineligible files, noted why they were not usable. A collection of linked Excel spreadsheets performed three tasks: tracking usable files, tracking unusable files, and tracking the total number of files. An example of the sheet used to track useable files (i.e., those meeting all the project requirements) is provided in Figure 1.

Figure 1: Sample C-2R Dataset Tracking Sheet

C.ZONE	GOAL	NUMBER OF USEABLE FILES RECEIVED / COMPANY: Abbay Technical Services	Blummitt Energy Associates, Inc	Fatber Energy Design	MB & A	John Ford Drafting	Haynal and Company, Inc	Energy Etc	Builder's Energy Services	Denise M. Kowal, P.E.	Southland Energy Consultants	Sol*Data Energy Consulting	Rick Maurer Title 24	Title 24 Data, Ltd	D & R Calcs	Energy Compliance Systems, Inc.	Red Tape Express	T-24 Energy Compliance Consultant	Pittman Air Conditioning, Inc	Consol, Inc	APP-TECH Inc	Terry Engineering	Victor Associates	Kristi DeBoi Energy Entineering	Central Coast Energy Compliance	Davis Energy Group	Black Energy Design	Bartler Heating & Air	Energy West	TOTAL PER CZ	NUM. AWAY FROM EACH CZ GOAL
1	2	4																												4	(2)
2	5											2								2								1		5	0
3	22		1	4			1												1	3			7				4			21	1
4	20		1	6															1	1			8				1			20	0
5	2																								3					3	(1)
6	19												3	1						1				1						6	13
7	19		8				9								2					3										22	(3)
8	13		1				2						4							2										9	4
9	7						1						2	3						2										8	(1)
10	8		2				5						1							5										13	(5)
11	6																											6		6	0
12	17			2								1								12						1		4		20	(3)
13	5																		2								1			3	2
14	5																													0	5
15	5												2																	2	3
16	5																													0	5
COMPANY TOT.		4	13	14	0	0	18	0	0	0	0	3	12	4	2	0	0	0	4	31	0	0	15	1	3	1	6	11	0	142	
DATE FILE RCVD.		early	2/4	1/24	x	x	early a	x	x	x	x	2/22	early	early	early	x	x	x	early	11/26	x	x	2/15	3/2	2/3	2/7	2/18	2/11	x		

Total Files Goal = 160
Total Files Received = 155
Total Useable Files Received = 142
Total Unusable Files Received = 13
Useable Percent to Total Goal = 88.75%

16%-NoShade
16%-Shade
20%-NoShade
20%-Shade
* "Early" indicates that files were received prior to 01/19

Completed Sample

As specified in the sample design, RER's targeted number of sites was 160 files, but due to time constraints, RER collected only 155 files.[5] A summary of the completed sample is presented in Table 2. As shown, seven of the regions (Climate Zones 3, 6, 8, 13, 14, 15 and 16) fell short of the sampling target, whereas nine of the regions (Climate Zones 1, 2, 4, 5, 7, 9, 10, 11 and 12) met or exceeded the sampling target.

Table 2: Summary of Collected C-2Rs

CEC CZ	Number of Consultants	Sample Target	Number Received	Number Usable	Number Unusable
1	1	2	4	4	0
2	3	5	5	5	0
3	7	22	22	21	1
4	6	20	20	20	0
5	1	2	3	3	0
6	4	19	6	6	4
7	4	19	22	22	0
8	4	13	9	9	0
9	4	7	8	8	5
10	4	8	13	13	0
11	1	6	6	6	1
12	5	17	20	20	1
13	2	5	3	3	0
14	0	5	0	0	0
15	1	5	2	2	0
16	0	5	0	0	1
Total	**16**	**160**	**155**	**142**	**13**

C-2R Database Development

A large component of this study involved the development of an ACCESS database to house the data from the C-2R forms. The database was structured to accept all information contained on the C-2R form in the various formats provided by each of the different compliance programs. As such, the general structure of the database follows that of the C-2R itself, and is summarized below.

[5] This sample was consistent with the original RFP requirements of completing up to 160 sites. Further, RER staff and the CEC project manager agreed on cut off dates for the data collection effort resulting in the completed sample size of 155.

- A unique identification number (LogID) was used for each C-2R data set. This LogID is the first field on every data table in the database. The name of the computer program input file, minus the file extension was used as the LogID.[6]
- High-level data information such as the source of the C-2R, total conditioned ft^2, number of dwelling units, etc. is contained in a single table.
- Prescriptive requirements and sample design parameters are contained in a single table.
- The data from each distinct section of the C-2R form is contained in separate tables. These sections of the C-2R include:
  - Basic Site Information
  - Energy Budget
  - Building Zones
  - Opaque Surface Construction Parameters (Wall/Roof/Floor/Door)
  - Perimeter Losses
  - Fenestration Parameters
  - Overhang/Side Fins
  - Thermal Mass/Slab Surfaces
  - Space Heating and Cooling Parameters
  - Domestic Hot Water System Parameters
  - Distribution System Parameters
  - Features/Comments and Notes

A complete description of the database format is contained in Appendix A.

Data Validation

RER conducted two major data validation analyses. The first ensured that the collected data passed the study criteria and were entered into the electronic database accurately. The second ensured that the compliance program input files provided by the consultants could be used to reproduce the corresponding C-2R forms that they provided, and which were to develop the database. Because the compliance software input files might be used in future analysis, the latter validation was critical to ensure that the compliance software input files matched the output used in this analysis.

Validation of Compliance Documentation and the C-2R Database

As stated earlier, RER received 155 completed compliance records. These records were screened on the basis of the study criteria. Of that number, 142 files were useable. Files were rejected for the following reasons.

---

6 For example, The LogID for the file EIGHTAPT.M45 (a MICROPAS input file) would have be "EIGHTAPT."

- The point-method, not the performance-method was used for compliance.
- The building was a duplex, which were specifically excluded from the study.
- The building did not comply or was not a multifamily unit.

Compliance records passing these screens were logged into the tracking system and the relevant data were entered into the C-2R database. RER then conducted a quality check of the database by performing range checks and by manually reviewing the data for reasonableness in the process of performing the analysis.

Validation of C-2R Input Files

RER performed a validation check of the submitted input files to ensure that these files were the ones used to generate the C-2R forms corresponding to these files. This validation was performed by running a sample of input files through the appropriate compliance software and regenerating a C-2R form. The files were validated by comparing the results on the original C-2R forms with the C-2R forms generated from this procedure. In all instances, the input files were validated by this process. The process also helped identify the fact that there are actually two input files required for MICROPAS runs. Appendix C provides a detailed description of the validation procedure and C-2R comparison results.

3. Data Analysis and Results

Results and objectives of this study were designed to address these three issues:

- The typical percentage of fenestration specified,
- The typical construction practices, and
- The efficiency and performance trade-offs used to achieve compliance.

These analyses were conducted with respect to the Residential Energy Efficiency Standards, Package D prescriptive requirements.[7] Furthermore, RER examined these issues based on climate zone groups, defined by their common prescriptive requirements:

- Climate zones with a 20% Glazing prescriptive allowance,
- Climate zones with a 16% Glazing prescriptive allowance,
- Climate zones that have high performance shading requirements, and
- Climate zones that allow standard draperies in all orientations.

7 Energy Efficiency Standards for Residential and Non-Residential Buildings, Tables 1-Z1 through 1-Z16.

Because the last two requirements essentially concern the same prescriptive parameter (i.e., shading), these requirements were changed to four "climate zone group" designations that were utilized by RER throughout the analysis.

- ***16%-No Shade.*** Climate zones with a prescriptive maximum 16% percent glazing allowance and no shading requirements. These zones are 1, 2, 5, and 16.
- ***16%-Shade.*** Climate zones with a prescriptive maximum 16% percent glazing allowance and shading requirements. These zones are 11 - 15.
- ***20%-No Shade.*** Climate zones with a prescriptive maximum 20% percent glazing allowance and no shading requirements. These zones are 3, 4, 6, and 7.
- ***20%-Shade.*** Climate zones with a prescriptive maximum 20% percent glazing allowance and shading requirements. These zones are 8 - 10.

These climate zone groups and prescriptive requirements are summarized in Table 3.

The following subsections describe the analysis effort for this study which include discussions of general sample characteristics, typical percent of fenestration used, typical construction practices as they relate to the prescriptive requirements, and an analysis of how these all relate to the trade-offs employed in the compliance runs.

Table 3: Prescriptive Requirements by Climate Zone Group

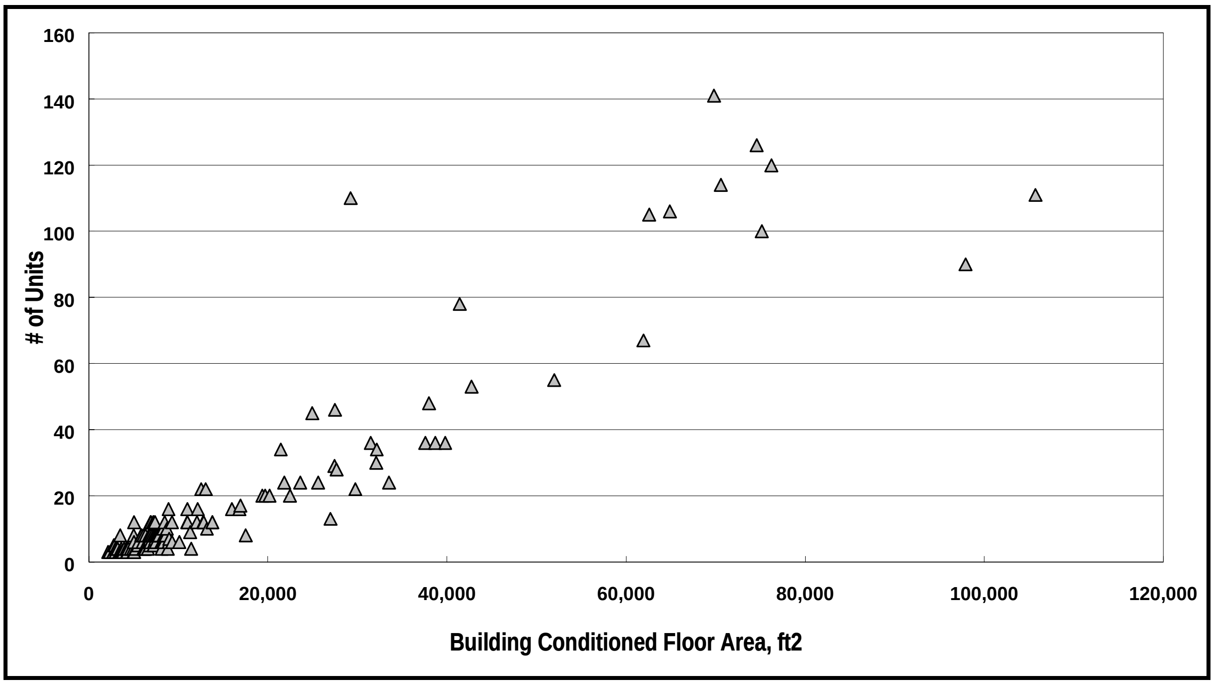
CZ Group	CEC CZ	Ceiling R-Value	Wall R-Value	Glazing Percent	Glazing U-Value	Solar Heat Gain Coefficient				Shading Coefficient			
						S	W	E	N	S	W	E	N
16%-No Shade	1	38	21	16	0.65					0.66	0.66	0.66	0.66
	2	30	13	16	0.65					0.66	0.66	0.66	0.66
	5	30	13	16	0.75					0.66	0.66	0.66	0.66
	16	38	21	16	0.60					0.66	0.66	0.66	0.66
16%-Shade	11	38	19	16	0.65		0.40	0.40		0.66	0.40	0.40	0.66
	12	38	19	16	0.65		0.40	0.40		0.66	0.40	0.40	0.66
	13	38	19	16	0.65		0.40	0.40		0.66	0.40	0.40	0.66
	14	38	21	16	0.65		0.40	0.40		0.66	0.40	0.40	0.66
	15	38	21	16	0.65	0.40	0.40	0.40		0.40	0.40	0.40	0.66
20%-No Shade	3	30	13	20	0.75					0.66	0.66	0.66	0.66
	4	30	13	20	0.75					0.66	0.66	0.66	0.66
	6	30	13	20	0.75					0.66	0.66	0.66	0.66
	7	30	13	20	0.75					0.66	0.66	0.66	0.66
20%-Shade	8	30	13	20	0.75		0.40	0.40		0.66	0.40	0.40	0.66
	9	30	13	20	0.75		0.40	0.40		0.66	0.40	0.40	0.66
	10	30	13	20	0.75		0.40	0.40		0.66	0.40	0.40	0.66

General Sample Characteristics

The following is a summary of the key characteristics of the data.

- Valid C-2Rs and input files for 142 buildings were obtained from 16 consultants.
- The number of usable files contributed by any one consultant ranged from 1 to 31.
- The number of consultants contributing files in a climate zone ranged from one to two consultants in climate zones 1, 5, 11, and 13; three to four consultants in climate zones 2 and 6 through 10; and five to seven consultants in climate zones 3, 4, and 12.
- The vast majority of the C-2Rs are for apartments (93 = 65%). Other building types represented include Senior Apartments (18), Condos/Townhomes/Quadplexes (27), Student Housing (1), Row Houses (1), Low-Income Housing (1), and a Live/Work building (1).
- A good distribution of building configurations was obtained judging by the building floor area/number of units combinations observed. They ranged from 2,168 ft^2/3 unit to 105,719 ft^2/111 unit residences. This is better illustrated in Figure 2, which presents total conditioned floor area versus number of dwelling units for all sites.

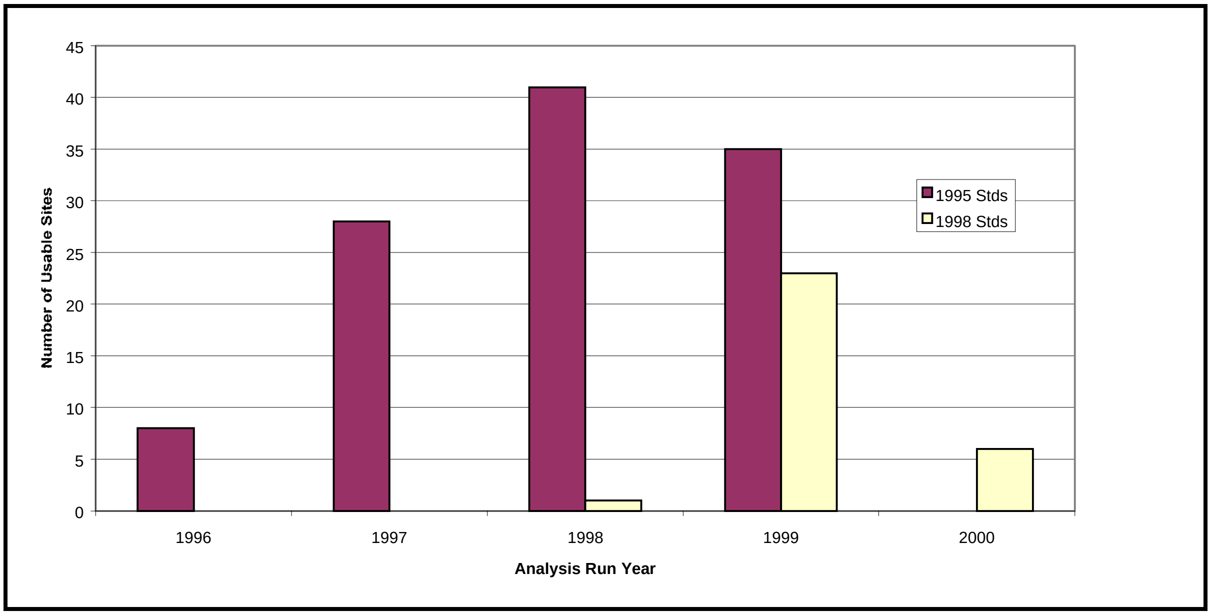
Figure 2: Sample Distribution, Total Floor Area vs. Number of Dwelling Units



- The computer programs represented and the number of usable files include:
  - **MICROPAS** 105 C-2Rs (74%) version 4.5/4.51/5.0 files
  - **COMPLY 24** 22 C-2Rs (16%) version 5.0/5.1 files
  - **EnergyPro** 15 C-2Rs (10%) version 1.0/2.0 files

  A further breakdown by the run year and version of the Standards (1995 or 1998) used for each site is shown in Figure 3.

Figure 3: Number of Sites by Compliance Run Year and Standards Year



Analysis of the Typical Percentage of Fenestration Specified

One primary concern expressed in the work statement was establishing a "typical" percent glazing value for each climate zone group. Percent glazing data are presented here on both an average basis in Table 4 and for all sites in Figure 4.

Table 4 presents average percent glazing values on both a prescriptive percent glazing basis and a climate zone group basis. The following observations can be made:

- On a prescriptive glazing percent basis, the average percent glazing values are significantly lower than the prescriptive values: 12.9 % average versus 16% prescriptive and 14.7 % average versus 20% prescriptive.
- The average percent glazing value is lower by 2 or 3 percentage points for climate zone groups with shading requirements (-*Shade*) than the average for the climate zone groups that have no shading requirements (-*No Shade).*
  - For the 16% climate zone group, 12.5 % (-*Shade*) versus 14.1% (-*No Shade*)
  - For the 20% climate zone group, 13.2 % (-*Shade*) versus 15.4% (-*No Shade*)

- For all climate zone groups, the range of percent glazing utilized is roughly the same for all climate zone groups – from a minimum of 7 to 8% to a maximum of 21 to 22% (with the exception of one site at 35.9%).[8]

Table 4: Percent Glazing by Prescriptive Values and CZ Group

Analysis Basis	Group Descriptions	Climate Zones included in Group	Average Percent Glazing	Minimum Percent Glazing	Maximum Percent Glazing	Count
Prescriptive Glazing Percent	16% Glazing	1, 2, 5, 11–16	12.9	6.7	21.8	43
	20% Glazing	3, 4, 6–10	14.7	8.2	35.9	99
CZ Group	16%-No Shade	1, 2, 5, 16	14.1	8.6	21.8	12
	16%-Shade	11–15	12.5	6.7	20.5	31
	20%-No Shade	3, 4, 6, 7	15.4	8.9	35.9	69
	20%-Shade	8, 9, 10	13.2	8.2	22.7	30

Figure 4 presents percent glazing values and their associated prescriptive values for all sites versus their respective climate zones and climate zone groups. These results suggest these conclusions:

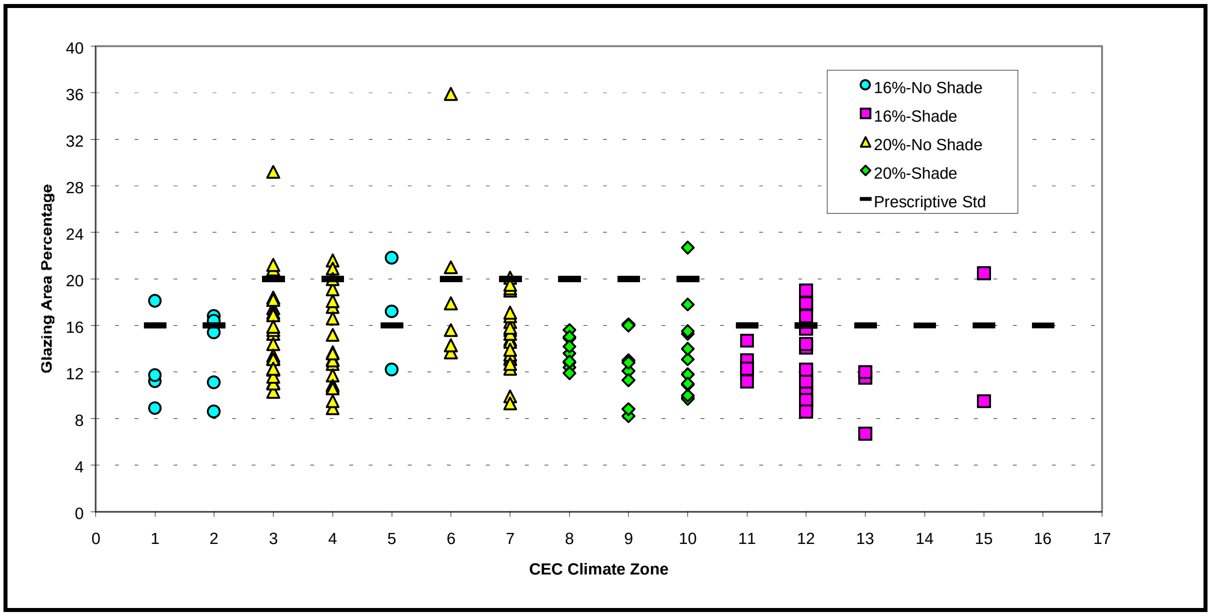
- The *20%-No Shade* group had the two sites with the highest percent glazing. [9]
- Sites in the *20%- Shade* group typically utilize the lowest glazing percentages. Glazing percentages for all but one site are below the prescriptive values. For all other climate zone groups, at least a few of the sites meet or exceed the prescriptive values.
- As also shown in Table 4, the "standard" range of percent glazing utilized is roughly the same for all climate zone groups; from a minimum of 7 to 8% to a maximum of 21 to 22%.

---

8 The site with 35.9% glazing is located in Venice, where a large glazing percentage could probably be expected to accommodate an ocean view. Glazing percentage calculations were checked and double-checked, so this value is correct.

9 These are sites 107488 at 35.9% and JE89296 at 29.2%

Figure 4: Percent Glazing Values by Climate Zone and Climate Zone Group



Analysis of Typical Construction Practices

"Typical construction practices" is interpreted as average values for all parameters covered by prescriptive standard values. These parameters - fenestration, building shell, HVAC equipment, and water heating equipment - are discussed in the following sections.

Typical Fenestration Construction Practice

Typical fenestration percent glazing and U-value practices are summarized in Table 5 and Figure 5 on the basis of climate zone groups and prescriptive U-value requirements. Note that shading is addressed in a separate section for reasons explained there.

Table 5 presents average glazing percentages and U-values by climate zone group and prescriptive U-value requirement. These results show:

- Fenestration U-values are typically higher than the prescriptive values in all climate zone groups except the *16%-No Shade* group. This difference is particularly significant for the *20%-Shade* climate zone group, with the average U-value close to 1 indicating a high level of single-pane fenestration being installed.
- The *16%-No Shade (CZ 5)* climate zone group is the only group where the average U-value is less than the prescriptive value. However, there are only three sites (indicated by *Count*) included in this category.

Figure 5 illustrates the full range of U-values encountered in the sample and codes the values by climate zone group. These results show:

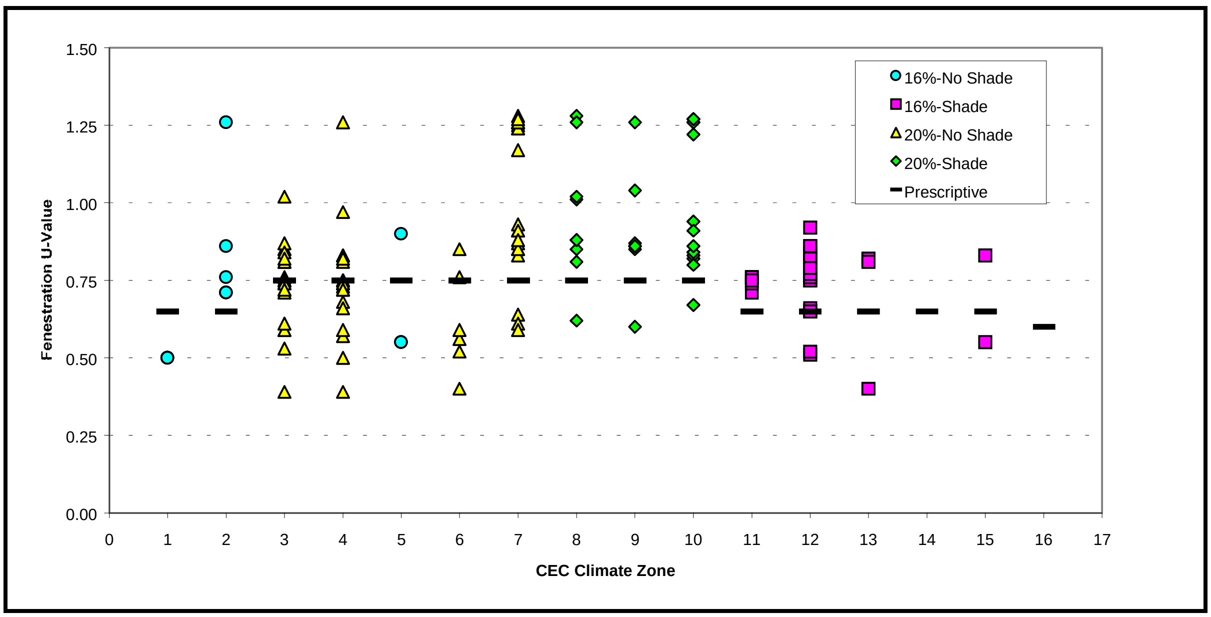
- For the *20%–Shade* and *20%–No Shade* climate zone groups, a significant number of buildings utilize single-pane windows, as indicated by the predominance of average U-values greater than 1.
- This is in contrast with the *16%–Shade* and *16%–No Shade* climate zone groups, for which U-values for almost all sites appear to be less than 1, although typically higher than the prescriptive U-values.

In addition to the percent glazing and U-value summaries presented here, limited data on the number of panes and frame type for windows was available from the MICROPAS C-2Rs. This information is presented in Appendix D.

Table 5: Typical Fenestration Construction Practices by Climate Zone Group

CZ Group	Climate Zones in Group	Count	Average Glazing Percent	Standard Glazing U-Value	Average Glazing U-values
16%-No Shade	1, 2	9	13.1	0.65	0.70
16%-No Shade	5	3	17.1	0.75	0.67
16%-Shade	11–15	31	12.5	0.65	0.74
20%-No Shade	3, 4, 6, 7	69	15.4	0.75	0.81
20%-Shade	8, 9, 10	30	13.2	0.75	0.96

Figure 5: Glazing U-values by Climate Zone and Climate Zone Group



Typical Shading Construction Practice

Establishing typical fenestration, internal, and external shading construction practices was complicated by the following situations:

- The 1995 Standards specified shading requirements in terms of a Shading Coefficient (SC), which was changed to a Solar Heat Gain Coefficient (SHGC) basis in the 1998 Standards. As a result, shading results for some of the sites are on an SC basis (112) and others are on an SHGC basis (30). No attempt was made to convert SCs to SHGCs for a common comparison.
- Older versions of MICROPAS (4.5 and 4.51) did not print the external shading devices and shading values on the C-2R. As such, results for external shading conditions could not be reported for these sites. These represent a significant part of the sample (85 sites). External shading type and shading values appear to be available in the input files, but due to time and budget constraints the data was not extracted from the input files.

However, as the results presented below show, shading is typically set to default values and not used as a trade-off tool, and as such, was excluded from any additional analysis.

Table 6 presents a high-level tabulation of internal and external shading approaches employed by sites in the sample. Values in the *Count* column represent the number of sites that used the combination of internal and external shading types indicated. Note that this ignores the actual internal/external shading values used in the compliance analysis for these types. However, that issue is addressed by Table 7. Also, note that the *External Shading Type* for those sites where the external shading type was not available is indicated as “Not on C-2R.” These results show the following:

- Where both internal and external shading devices can be determined, the vast majority of sites utilize standard internal/external shading devices (85 sites).
- Where both internal and external shading devices can be determined, the assumption of no internal/external shading devices as indicated by “None” is the second most typical configuration (15 sites).

Table 6: Typical Internal and External Shading Types

Count	Internal Shading Type	External Shading Type
84	Standard Drapes	Standard Bug Screen
57	Standard Drapes	Not on C-2R
37	None	Not on C-2R
15	None	None
9	Blinds	Not on C-2R
6	Standard Drapes	None
3	Blinds	Standard Bug Screen
2	Standard Drapes	Sunscreen w/ Weave
1	None	Standard Bug Screen
1	Roller Shades	Not on C-2R
1	Glass Block	Not on C-2R
1	Clear	Not on C-2R
1	Single Clear Default (R)	None

Table 7 presents a more detailed tabulation of internal and external shading combinations present in the sample. Internal and external shading types along with the corresponding shading values used in the compliance run are presented along with prescriptive shading values. Note that results are grouped based on SC, SHGC, and in addition, whether or not an external shading type was indicated on the C-2R (these sites are all SC based). These results show:

- Where a prescriptive shading value is specified, internal and external shading values are typically above the prescriptive values.
- The shading values associated with a particular type of shading are typically consistent, although a few variations are shown in the table. For instance, in the *20%-No Shade* climate zone group, there are 16 occurrences where an internal shading type of "None" was indicated, but a shading value of 0.78, which is more consistent with Standard Drapes, was used.

Table 7: Typical Shading Combinations by SC/SHGC and Climate Zone Group

Climate Zone Group	Count	Shade Units	Std Value	Internal Shading Type	Int Value	External Shading Type	Ext Value
16%-No Shade	9	SC	0.66	Standard Drapes	0.78	Not on C-2R	
(1, 2, 5, 16)	4	SHGC		Standard Drapes	0.68	Standard Bug Screen	0.76
16%-Shade	19	SC	0.4	Standard Drapes	0.78	Not on C-2R	
(11 – 15)	9	SHGC	0.40	Standard Drapes	0.68	Standard Bug Screen	0.76
	4	SC	0.4	Standard Drapes	0.78	Standard Bug Screen	0.87
	3	SHGC	0.40	Blinds	0.47	Standard Bug Screen	0.76
	1	SC	0.4	Blinds	0.25	Not on C-2R	
	1	SC	0.4	Glass Block	0.78	Not on C-2R	
	1	SC	0.4	None	1.00	None	1.00
	2	SC	0.4	Blinds	0.58	Not on C-2R	
20%-No Shade	30	SC	0.66	Standard Drapes	0.78	Standard Bug Screen	0.87
(3, 4, 6, 7)	27	SHGC		Standard Drapes	0.68	Standard Bug Screen	0.76
	17	SC	0.66	Standard Drapes	0.78	Not on C-2R	
	16	SC	0.66	None	0.78	Not on C-2R	
	12	SC	0.66	None	1.00	None	1.00
	6	SC	0.66	Standard Drapes	0.78	None	1.00
	5	SC	0.66	None	1.00	Not on C-2R	
	2	SC	0.66	Standard Drapes	0.78	Sunscreen w/ Weave	0.34
	2	SC	0.66	Blinds	0.58	Not on C-2R	
	2	SHGC		None	1.00	None	1.00
	1	SC	0.66	Clear	0.88	Not on C-2R	
	1	SC	0.66	None	1.00	Standard Bug Screen	0.87
	1	SC	0.66	Single Clear Default	0.92	None	1.00
	1	SC	0.66	None	0.88	Not on C-2R	
20%-Shade	12	SC	0.4	Standard Drapes	0.78	Not on C-2R	
(8, 9, 10)	15	SC	0.4	None	0.78	Not on C-2R	
	10	SHGC	0.40	Standard Drapes	0.68	Standard Bug Screen	0.76
	4	SC	0.4	Blinds	0.58	Not on C-2R	
	1	SC	0.4	Roller Shades	0.40	Not on C-2R	

Table 8 presents a tabulation of average fenestration, internal, and external shading values by climate zone group. As with the previous table, results are presented on the basis of SC, SHGC, and in addition, whether or not an external shading type was indicated on the C-2R, as indicated by the note “Not on C-2R”. These results show:

- Where a prescriptive shading value is specified, average fenestration, internal and external shading values are typically above the prescriptive values.

- Average fenestration shading values that are close to a value of 1.0 (0.97, 0.92, and 0.93) in 3 of the 4 climate zone groups reflects the common use of a default glass shading coefficient of 1.0.

Table 8: Typical Shading Values by Climate Zone Group SC/SHGC

Climate Zone Group	Count	Shading Unit	External Shading Note	Std Value	Fen. Value	Int Value	Ext Value
16%-No Shade (1, 2, 5, 16)	9	SC	Not on C-2R	0.66	0.97	0.78	
	3	SHGC			0.7	0.68	0.76
16%-Shade (11 – 15)	22	SC	Not on C-2R	0.4	0.86	0.75	
	2	SC		0.4	0.82	0.78	0.87
	7	SHGC		0.4	0.7	0.55	0.76
20%-No Shade (3, 4, 6, 7)	30	SC	Not on C-2R	0.66	0.92	0.76	
	25	SC		0.66	0.88	0.79	0.88
	14	SHGC			0.55	0.69	0.77
20%-Shade (8, 9, 10)	24	SC	Not on C-2R	0.4	0.93	0.76	
	6	SHGC		0.4	0.74	0.68	0.76

In conclusion, the results presented above are used as justification for excluding shading from any additional analysis.

Typical Wall and Roof Insulation Practices

Typical wall and roof insulation practices are summarized in Table 9. Note that the each of the *16%* climate zone groups have two levels of standard insulation values. The numbers shown in the *Count* field represent the number of sites contained in that climate zone group and prescriptive insulation level. These results show:

- Where the minimum prescriptive wall insulation R-value is R-13, wall insulation is typically installed to meet the standard.
- Where the minimum prescriptive wall insulation R-value is greater than 13, wall insulation is typically installed to a level less than the standard, although sometimes higher than R-13. The *16%-Shade* climate zone group is most affected by this practice.
- Across all climate zone groups, roof insulation is typically installed to a significantly lower level than the prescriptive minimum R-Value. The *16%-Shade* and *16%-No Shade* climate zone groups with a prescriptive 38 R-value are the most affected by this practice.

Table 9: Typical Building Shell Construction by CZ Group

Climate Zone Group (CZs in group)	Count	Standard Wall R-Value	Average Wall R-Value	Standard Ceiling R-Value	Average Ceiling R-Value
16%-No Shade (1, 2, 5, 16)	4	21	13	38	19
	8	13	13	30	27.2
16%-Shade (11 – 15)	29	19	14	38	26.3
	2	21	16	38	30
20%-No Shade (3, 4, 6, 7)	69	13	13.5	30	26
20%-Shade (8, 9, 10)	30	13	13	30	24.5

Typical Space Cooling System Practices

The cooling systems, duct description, and the efficiencies of those systems are summarized in Table 10 for each climate zone group. The numbers shown in the *Count* field represent the number of occurrences and not the number of actual systems installed. The descriptions contained in the *System Type* column are the original labels taken from the C-2Rs. The descriptions contained in the *Duct Location* column describe whether the system is non-ducted or ducted, and if ducted, where the ducts are located. The equipment efficiencies presented are averaged for the *System Type* and *Duct Locations* shown. *Standard Efficiencies* were determined from the Standards based on system descriptions, duct location descriptions, and efficiency units as they appeared on the C-2R form. The equipment efficiencies presented are averaged for the *System Type* and *Duct Locations* shown. These results suggest four conclusions:

- Standard efficiency, split-system, ducted air conditioners are the norm, except in the *16%-No Shade* climate zone group, where “No Cooling” is predominant.[10]
- There is a significant number (18) of “No Cooling” systems in the *20%-No Shade* climate zone group.
- There are very few applications of high-efficiency cooling equipment.
- There are three instances where the average efficiency is lower than the standard efficiency. The system and duct location descriptions, efficiency value and efficiency units are consistent with the information contained on the C-2R form. These discrepancies appear to be actual mistakes in the data and as such were not corrected.

[10] The energy standards require that even those residences that do not have a cooling system be run through the performance compliance analysis with a default efficiency cooling system assumed, hence the “No Cooling” System Type label.

Table 10: Typical Space Cooling System by Climate Zone Group

CZ Group (CZs in group)	Count	System Type	Duct Location	Avg Eff.	Std Eff.	Eff. Unit
16%-No Shade (1, 2, 5, 16)	7	No Cooling	DuctedUncond	10	10	SEER
	4	ACSplit	DuctedUncond	10	10	SEER
	1	ACSplit	NonDucted	10	10	SEER
16%-Shade (11 – 15)	20	ACSplit	DuctedUncond	10	10	SEER
	3	ACSplit	DuctedCond	10.7	10	SEER
	2	HPPackage	DuctedUncond	11.4	9.7	SEER
	1	ACPackage	DuctedUncond	9.7	9.7	SEER
	1	ACSplt	DuctedUncond	10	10	SEER
	1	AirCond	DuctedCond	10	10	SEER
	1	AirCond	DuctedUncond	10	10	SEER
	1	HPSplt	DuctedUncond	10	10	SEER
	1	PackAirCond	DuctedUncond	9.7	9.7	SEER
	1	RoomHtPump	DuctedCond	9.7	9.7	SEER
20%-No Shade (3, 4, 6, 7)	30	ACSplit	DuctedUncond	10	10	SEER
	18	No Cooling	DuctedUncond	10	10	SEER
	9	HPSplt	DuctedUncond	10	10	SEER
	5	AirCond	DuctedUncond	10	10	SEER
	3	ACSplit	DuctedCond	9.6	10	SEER
	3	HPSplit	DuctedUncond	10	10	SEER
	2	HPSplt	DuctedCond	10	10	SEER
	2	RoomAirCond	DuctedCond	10.8	9.7	SEER
	2	RoomHtPump	DuctedUncond	10.5	9.7	SEER
	1	ACPackage	NonDucted	9.7	9.7	SEER
	1	No Cooling	DuctedCond	10	10	SEER
	1	Room AC w/out Side Louvers	NonDucted	11.2	9.7	SEER
	1	Room Heat Pump	DuctedCond	11.5	9.7	SEER
	1	Room Heat Pump	NonDucted	8.2	8.2	EER
	1	RoomHtPump	DuctedCond	8.8	9.7	SEER
	1	SpltAirCond	DuctedCond	10	10	SEER
20%-Shade (8, 9, 10)	18	ACSplit	DuctedUncond	10	10	SEER
	5	AirCond	DuctedUncond	10	10	SEER
	2	AirCond	DuctedCond	10	10	SEER
	2	HeatPump	DuctedUncond	10	10	SEER
	1	ACPackage	NonDucted	9	9.7	SEER
	1	HPSplit	DuctedUncond	10	10	SEER
	1	No Cooling	DuctedUncond	10	10	SEER

Typical Space Heating System Practices

Results for space heating systems are presented in the same format as the space cooling systems. System type, duct description, and the efficiencies of those systems are summarized in Table 11 for each climate zone group. These results show:

- Ducted furnaces are the norm in climate zone groups *20%-Shade* and *20%-No Shade* climate zone groups.
- Hydronic systems are the norm for the *16%-No Shade* climate zone groups.
- Both ducted and non-ducted furnaces are typical for the *16%-No Shade* climate zone group.
- A significant number of systems in the *20%-No Shade* climate zone are non-ducted electric resistance heating. The *20%-Shade* climate zone group is the only other group where electric resistance heating is utilized.
- Heating equipment efficiencies are typically equal to or slightly higher than standard efficiency.

The significant number of electric resistance heating systems in the *20%-No Shade* climate zone group warranted special attention, since the standards are designed to discourage the use of electric resistance heating. The sites that utilized these systems were examined in detail and the following observations made:

- The majority of the 19 sites that utilized electric resistance heating were located in climate zones 3 and 4, and were obtained from two consultants. There was one site each in climate zones 7 and 10, each from a different consultant.
- Almost all of these sites utilized a percent glazing that was significantly less than the prescriptive value, typically on the order of 35% less, but as high as 55% less.
- For four of the sites, the electric resistance heating served only a portion, albeit typically the majority, of the site. These sites typically also had room heat pumps serving the remainder of the site not served by electric resistance heating.
- A majority of the sites utilized higher performance windows.
- All but two of the sites had positive water heating budget margins (i.e. the Standard budget was greater than the proposed budget). Proposed budgets were typically about 35% greater than the standard budget and much as 50% higher.

From these observations, it can be surmised that the decreased glazing percentages, higher-performance windows, and excess water heating budgets are being used to allow the trade-off to electric resistance space heating. This conclusion was confirmed by a conversation with one of the consultants that utilize these systems, who stated that use of a central water heating system and higher-performance windows is the only way you can get electric resistance space heating through the compliance analysis. He also stated that the use of electric resistance heating was driven by his clients desire to reduce first-costs.

Table 11: Typical Space Heating System by Climate Zone Group

CZ Group (CZs in group)	Count	System Type	Duct Location	Avg Eff.	Std Eff.	Eff. Unit
16%-No Shade (1, 2, 5, 16)	4	Furnace	DuctedUncond	0.80	0.78	AFUE
	4	Furnace	NonDucted	0.64	0.62	AFUE
	2	Hydronic	DuctedUncond	0.77	0.75	AFUE
	1	Gravity Wall Furnace	NonDucted	0.70	0.65	AFUE
	1	Hydronic	NonDucted	0.79	0.75	AFUE
16%-Shade (11 – 15)	21	Hydronic	DuctedUncond	0.76	0.75	AFUE
	3	Furnace	DuctedUncond	0.80	0.78	AFUE
	2	HPPackage	DuctedUncond	7.2	6.6	HSPF
	2	Hydronic	DuctedCond	0.76	0.75	AFUE
	1	CombHydro	NonDucted	0.59	0.59	EF
	1	HPSplt	DuctedCond	6.8	6.8	HSPF
	1	HPSplt	DuctedUncond	6.8	6.8	HSPF
	1	RoomHtPump	NonDucted	6.6	6.6	HSPF
20%-No Shade (3, 4, 6, 7)	26	Furnace	DuctedUncond	0.80	0.78	AFUE
	20	Electric	NonDucted	3.41	3.41	HSPF
	10	HPSplt	DuctedUncond	7.05	6.8	HSPF
	7	Hydronic	DuctedUncond	0.77	0.75	AFUE
	3	HPSplit	DuctedUncond	6.8	6.8	HSPF
	2	Gas	DuctedUncond	0.78	0.78	AFUE
	2	HeatPump	DuctedUncond	6.6	6.6	HSPF
	2	HPSplt	DuctedCond	7.0	6.8	HSPF
	2	Hydronic	DuctedCond	0.76	0.75	AFUE
	2	RoomHtPump	NonDucted	6.86	6.6	HSPF
	1	Boiler (See DHW)	DuctedUncond	0.80	0.78	AFUE
	1	Central Furnace	NonDucted	0.80	0.78	AFUE
	1	CombHydro	DuctedUncond	0.76	0.75	AFUE
	1	Combined Hydronic	NonDucted	0.59	0.59	EF
	1	Furnace	NonDucted	0.70	0.62	AFUE
	1	Furnace	DuctedCond	0.80	0.78	AFUE
	1	Furnace	NonDucted	0.63	0.62	AFUE
	1	RoomHtPump	DuctedUncond	6.6	6.6	HSPF
20%-Shade (8, 9, 10)	15	Furnace	DuctedUncond	0.79	0.78	AFUE
	8	Hydronic	DuctedUncond	0.75	0.75	AFUE
	3	HeatPump	DuctedUncond	6.73	6.6	HSPF
	3	Hydronic	DuctedCond	0.77	0.75	AFUE
	1	Electric	NonDucted	3.41	3.41	HSPF
	1	HPSplit	DuctedUncond	6.8	6.8	HSPF

Typical Water Heating System Practices

The typical water heating system practice was described by examining the distribution system type indicated on the C-2R form. Results are summarized in Table 12 for each climate zone group. The *Counts* column refers to the number of sites that used the distribution system type indicated. Results can be summarized by these three points:

- Standard water heaters are the predominant system type in all climate zone groups.
- In the *20%-No Shade* climate zone group, Recirc/Temp control type systems are also significant (22 sites versus 42 sites with standard systems).
- The presence of Recirc/NoControl and Recirc/Temp distribution systems types is significant because the water heating budget is substantially penalized for these distribution system types. This is shown in Table 13, which presents the factors applied to the water heating budget versus the distribution system employed. Factors are presented as both pre and post July 1999 values because the factors for multifamily residences changed significantly at that time.

Table 12: Typical Water Heating Systems

CZ Group (CZs in group)	Count	Distribution System Type
16%-No Shade (1, 2, 5, 16)	12	Standard
	2	Recirc/NoControl
16%-Shade (3, 4, 6, 7)	29	Standard
	3	Recirc/NoControl
	1	Meets CEC Standard
20%-No Shade (11-15)	42	Standard
	22	Recirc/Temp
	4	Recirc/NoControl
	2	Recirc/DemandPipeIn
	1	Mixed-Recirc/Temp
	1	Mixed-Standard
	1	No DHW
	1	Recirc/Time&Temp
20%-Shade (8, 9, 10)	31	Standard
	2	Recirc/NoControl
	1	Meets CEC Standard

Table 13: Water Heating Energy Budget Adjustment Factors

Distribution System Type	SF Post July '99	MF Post July '99	SF Pre July '99	MF Pre July '99
Standard	1.00	1.00	1.00	1.00
POU	0.82	1.00	0.82	0.82
HWR	0.82	1.00	0.82	0.82
PipeInsulation	0.92	0.92	0.92	0.92
ParallelPiping	0.86	0.86	0.86	0.86
Recirc/NoControl	1.52	1.52	1.52	1.52
Recirc/Timer	1.28	1.52	1.28	1.28
Recirc/Temp	1.05	1.05	1.05	1.05
Recirc/Demand	0.98	1.52	0.98	0.98
Recirc/Time+Temp	0.96	1.52	0.96	0.96
Recirc/Demand+HWR	0.80	1.52	0.80	0.80
Recirc/Demand+PipeInsulation	0.90	1.52	0.90	0.90

A more extensive characterization of water heating equipment based on whether an Energy Factor (EF) or a Recovery Efficiency was specified on the C-2R is included in Appendix E.

Analysis of Efficiency Trade-Offs to Achieve Compliance

In order to effectively evaluate trade-offs in performance, RER adopted the following approach.

1) First, the actual values for all performance parameters, as well as the water heating (DHW) and HVAC energy budgets, were "normalized" by their respective standard/prescriptive values.
2) These normalized parameters were assigned a "performance rating" value of +1, 0, or –1 to indicate whether they reflected higher performance (+1), equal performance (0), or lower performance (-1) than the prescriptive requirements.
3) Normalized margins (i.e., difference between standard prescriptive values and actual values) for all performance parameters were also determined.
4) This system made it easy to count the number of sites where such a trade-off was employed for a particular design parameter (glazing percent, glazing U-value, etc.) by simply summing the performance rating values. In addition, the normalized margins were used to assess the quality (i.e., percent deviation from the standard/prescriptive values) of the trade-offs.

Table 14 includes the definitions developed for each "performance rating" parameter covered by prescriptive requirements.

Table 14: Performance Rating Parameters

Performance Rating	Definition	Example
Percent Glazing[11]	+1 = % glazing > than prescriptive.	25%/20%
	-1 = % glazing < than prescriptive	14%/20%
Glazing U-value	+1 => U-Value is < than prescriptive	0.60/0.75
	-1 => U-Value is > than prescriptive	1.26/0.75
SC/SHGC[12]	+1 => SC/SHGC is < prescriptive	0.30/0.40
	-1 => SC/SHGC) is > prescriptive	0.78/0.40
R-Values	+1 => R-value is > prescriptive	30/19
	-1 => R-value is < prescriptive	13/19
Efficiencies	+1 => Efficiency is > prescriptive	11.5/10 SEER
	1 => Efficiency is < prescriptive	9/10 SEER
Energy Budgets[13] (DHW/HVAC)	+1 => Proposed budget < Standard	25.6/35.8 kBtu
	-1 => Proposed budget > Standard	45.3/35.8 kBtu

For example, given an actual wall R-value of 19 and a prescriptive requirement of 13:

- The normalized performance parameter would be 19/13 = 1.46.
- A "performance rating" factor of +1 would be assigned to this trade-off. This indicates that the performance of the parameter is higher than the standard value.
- The normalized margin would be (13-19)/13 = -0.462.

The same process would be repeated for every site, such that a value of +1, -1, or 0 could be generated for every prescriptive parameter.

Results of this approach are contained in Table 16 through Table 18 below. In particular, Table 15 characterizes trade-ups (a trade-off that improves performance)/trade-downs (a trade-off that decreases performance) for the entire sample. Table 16 presents a tabulation of the total number of trade-offs made for each prescriptive parameter by climate zone group.

[11] Percent glazing is the only exception to the higher/lower performance definition because the percentage of glazing is not really a performance parameter. This convention was chosen to emphasize that fact.

[12] Although shading was eliminated from the trade-off analysis, its definition is included here for reference.

[13] The water heating energy budget was used instead of water heating equipment efficiencies as a proxy for efficiency level.

Table 17 presents a tabulation of trade-ups/trade-downs for each prescriptive parameter by climate zone group. Table 18 presents the data from Table 17 as a percentage of the total number of trade-offs made for each prescriptive parameter by climate zone group.

Examples that illustrate how to read these tables are given below:

- In Table 15, from the first row under the *Glazing U-value* column, 122 (or 86%) of the 142 sites in the sample utilized lower-performance (Performance Rating factor = -1) glazing U-values.
- In Table 16 for the *16%-No Shade* climate zone group, 12 of the 12 sites in this group traded-off the glazing U-values. This includes both trade-ups and trade-downs in performance.
- In Table 17 for the *16%- Shade* climate zone group under *Wall R-Value,* 28 of the 31 sites in this group utilized lower-than-prescriptive (Performance Rating factor = -1) wall insulation.
- In Table 18 for the same example given above, the 28 of 31 represents 90% of the sites in this climate zone group and they are on average 29% (-0.290) below the prescriptive insulation value.

Important observations from the information presented in these tables include the following:

- For all climate zone groups except one (*16%-No Shade*), the percentage of sites that use percent glazing lower than the prescriptive value is quite high; from 83% to 92% (58% for *16%-No Shade*, still a majority). On average, these sites are the percent glazing utilized is about 30% less than prescriptive values.
- The percentage of sites that have positive DHW budget margins (Performance Rating = 1) is high; from 83% to 94% for all climate zone groups. This provides some indication that higher-than-prescriptive efficiency water heating equipment is utilized by all sites.
- For the *20% Glazing* climate zone groups, 55% of the sites also have positive HVAC budget margins (Performance Rating = 1). This could be an indication that both glazing and water heating positive budget margins are utilized for trade-offs.
- The percentage of sites with higher-than-minimum-efficiency space heating systems is significant, ranging from 57% to 92% by climate zone group. Efficiencies for these systems appear to be about 4% to 8% above the minimum prescriptive efficiency values.
- Lower efficiency space heating and cooling systems seem to also be indicated in the tables. However, as all HVAC equipment is required to meet federally established appliance standard minimum efficiencies, these discrepancies are probably due to errors in the C-2R analysis regarding the specification of system type, efficiency values, and efficiency parameters, rather than lower efficiency equipment.
- High efficiency cooling equipment is rarely used as a trade-off.

Although it is apparent from these observations that water heating and percent glazing trends are common, the features for which performance is traded-off are unique to each climate zone group. These unique trade-off situations are:

- In the *16%-No Shade* climate zone group, regarding glazing U-values, half the sites use lower performance glazing and the other half utilize higher performance glazing. For wall and roof insulation, trade-offs are always to lower performance (i.e., less insulation). In addition, roof insulation appears to be traded-off the most (50% of sites versus 33% of sites for wall insulation.
- In the *16%- Shade* climate zone group, 81% of the sites use lower performance glazing, 90% of the sites use significantly lower wall insulation levels, and 94% of the sites use significantly lower roof insulation levels. This trend is not surprising, since insulation levels for this climate zone group are the highest (Wall=R-19/21 and Roof = R-38).

- The *20%-No Shade* climate zone group shares some characteristics of the *16%-No Shade*. For example, regarding glazing U-values, about half the sites use lower performance glazing (51%) and the other half utilize higher performance glazing (41%). Wall insulation is relatively untouched, although in 10% of the sites the wall insulation is actually greater than the prescriptive minimum R-value. Roof insulation appears to be the next most significant trade-off after glazing U-value, although it is still a small percentage of the sites (38%).
- In the *20%- Shade* climate zone group, lower performance glazing (U-values) are heavily used. 90% of the sites utilize glazing that is on average 32% lower performance than the prescriptive requirement. Wall insulation is never traded-off. About 50% of the sites trade off roof insulation to lower levels.

Table 15: Trade-Off Counts and Percent of Total Sites for the Entire Sample

Perf. Rating	Perf. Rating Descrip.	Total Number of Sites (% of total number of sites)							
		Percent Glazing	Glazing U-value	Wall R-value	Ceiling R-value	Cooling Eff.	Heating Eff.	DHW Budget	HVAC Budget
-1	Lower performance	122 (86%)	93 (65%)	33 (23%)	76 (54%)	4 (3%)	18 (13%)	14 (10%)	66 (46%)
0	Same-as-Std performance	1 (1%)	8 (6%)	101 (71%)	66 (46%)	127 (89%)	44 (31%)	2 (1%)	3 (2%)
1	Higher performance	19 (13%)	41 (29%)	8 (6%)	0 (0%)	11 (8%)	80 (56%)	126 (89%)	73 (52%)

Table 16: Total Trade-Off Counts by Climate Zone Group

CZ Group (CZs in group)	Total Count	Average Glazing Percent	Glazing U-value	Wall R-value	Ceiling R-value	Cooling Eff.	Heating Eff.	DHW Budget	HVAC Budget
16%-No Shade (1, 2, 5, 16)	12	14.1	12	4	6	0	11	11	12
16%-Shade (11 – 15)	31	12.5	29	29	29	3	22	31	30
20%-No Shade (3, 4, 6, 7)	69	15.4	63	8	26	9	46	69	68
20%-Shade (8, 9, 10)	30	13.2	30	0	15	3	19	29	29

Table 17: Trade-Off Counts by Climate Zone Group

CZ Group (CZs in group) [Total # of sites]	Perf Rating	Perf. Rating Description	Glazing Percent	Glazing U-value	Wall R-value	Ceiling R-value	Cooling Efficiency	Heating Efficiency	DHW Budget	HVAC Budget
16%-No Shade	-1	Lower performance	7	6	4	6	0	0	0	7
(1, 2, 5, 16)	0	Same-as-prescriptive	0	0	8	6	12	1	1	0
[12]	1	Higher performance	5	6	0	0	0	11	11	5
16%-Shade	-1	Lower performance	26	25	28	29	1	2	2	19
(11 – 15)	0	Same-as-prescriptive	0	2	2	2	28	9	0	1
[31]	1	Higher performance	5	4	1	0	2	20	29	11
20%-No Shade	-1	Lower performance	60	35	1	26	2	5	8	30
(3, 4, 6, 7)	0	Same-as-prescriptive	1	6	61	43	60	25	0	1
[69]	1	Higher performance	8	28	7	0	7	39	61	38
20%-Shade	-1	Lower performance	29	27	0	15	1	2	4	10
(8, 9, 10)	0	Same-as-prescriptive	0	0	30	15	27	10	1	1
[30]	1	Higher performance	1	3	0	0	2	18	25	19

Table 18: Trade-Offs as Percent of Total Sites in Climate Zone Group and Average Prescriptive Difference

CZ Group (CZs in group) [Total # of sites]	Perf Ratg	Perf. Rating Description	Percent of Sites in CZ Group (average fractional deviation from standard)							
			Glazing Percent	Glazing U-value	Wall R-value	Ceiling R-value	Cool Efficiency	Heating Efficiency	DHW Budget	HVAC Budget
16%-No Shade (1, 2, 5, 16) [12]	-1	Lower performance	58% (-0.271)	50% (-0.321)	33% (-0.381)	50% (-0.387)	0%	0%	0%	58% (-0.087)
	0	Same-as-prescriptive	0%	0%	67%	50%	100%	8%	8%	0%
	1	Higher performance	42% (0.083)	50% (0.220)	0%	0%	0%	92% (0.034)	92% (0.094)	42% (0.045)
16%-Shade (11 – 15) [31]	-1	Lower performance	84% (-0.297)	81% (-0.214)	90% -(0.290)	94% (-0.314)	3% (-0.052)	6% (-0.009)	6% (-0.056)	61% (-0.100
	0	Same-as-prescriptive	0%	6%	6%	6%	90%	29%	0%	3%
	1	Higher performance	16% (0.160)	13% (0.252)	3% (0.105)	0%	6% (0.301)	65% (0.022)	94% (0.134)	35% (0.132)
20%-No Shade (3, 4, 6, 7) [69]	-1	Lower performance	87% (-0.282)	51% (-0.269)	1% (-0.262)	38% (-0.354)	3% (-0.192)	7% (-0.014)	12% (-0.056)	43% (-0.313)
	0	Same-as-prescriptive	1%	9%	88%	62%	87%	36%	0%	1%
	1	Higher performance	12% (0.276)	41% (0.209)	10% (0.388)	0%	10% (0.075)	57% (0.031)	88% (0.188)	55% (0.222)
20%-Shade (8, 9, 10) [30]	-1	Lower performance	97% (-0.348)	90% (-0.323)	0%	50% (-0.367)	3% (-0.072)	7% (-0.013)	13% (-0.015)	33% (-0.059)
	0	Same-as-prescriptive	0%	0%	100%	50%	90%	33%	3%	3%
	1	Higher performance	3% (0.135)	10% (0.168)	0%	0%	7% (0.006)	60% (0.024)	83% (0.071)	63% (0.130)

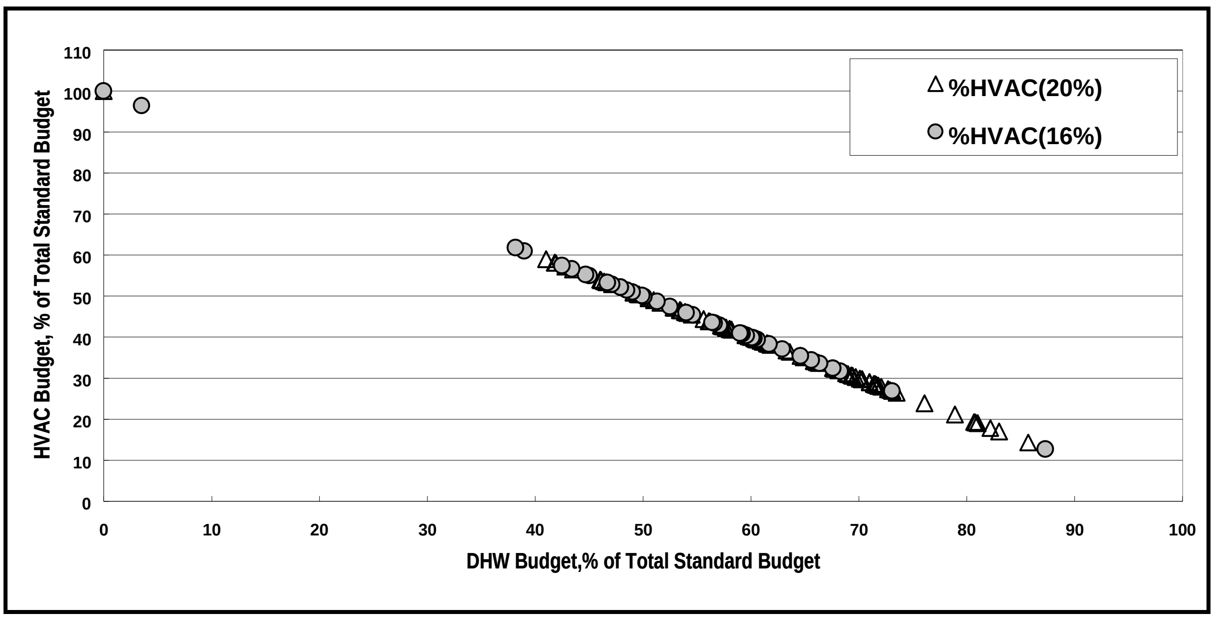
Water Heating and HVAC as a Percentage of Total Energy Budget

As a final examination of trade-offs, RER analyzed the relationship between the water heating (DHW) and HVAC standard design energy budgets. Since the energy budgets represent the maximum potential for any trade-offs that might occur, one could hypothesize that a comparison of these budgets might yield additional information about tradeoff strategies. For instance, if it turned out that typically water heating was a larger percentage of the total energy budget, then it would make sense that water heating was always targeted for a positive trade-off (i.e., increased efficiency).

Figure 6 graphs the standard HVAC and water heating energy budgets as a percent of the total standard design energy budget and shows these four conclusions:

- Water heating is typically 40 to 75% of the overall energy budget, and in fact is almost never less than 35%.
- Points at the far left of the graph (high HVAC, low or zero DHW budget percentages) are in the *16% Glazing* climate zone group.
- Almost all water heating dominated sites (i.e., DHW budget is >75% of the total standard energy budget) are in the *20% Glazing* climate zone groups.
- Because water heating is typically the largest part of the standard budget, a trade-up in efficiency will yield maximum benefit.

Figure 6: HVAC and DHW Percentage of Total Standard Energy Budget



4. Conclusions

The *performance method* for achieving Title-24 compliance offers the opportunity for the designers of multifamily buildings make efficiency trade-offs between energy using equipment and building shell measures. Further, these trade-offs can result in the use of equipment and/or building shell measures with energy efficiency characteristics that are below the requirements of the *prescriptive method* for compliance. In particular, our analysis indicates that glazing percentages less than the prescriptive values and water heating systems that use less energy than the standard energy budget are typically used to make trade-offs to lower performance fenestration systems (i.e., U-values), wall/roof insulation, and occasionally even space heating equipment. The following summarizes our finding that building designers typically use less glazing areas and higher performing water heating systems leaving the opportunity for trade-offs.

- The majority of multifamily buildings (86%) use a percent glazing that is below the prescriptive value. For those sites where a lower-than-prescriptive percent glazing is used, the percent glazing used is typically 30% less than the prescriptive value.
- Almost all multifamily buildings have positive DHW budget margins (89%). For those sites with positive DHW budget margins, the margin is typically about 10% above the Standard DHW budget. In addition, water heating is typically about 40 to 75% of the total standard energy budget for multifamily residences, and in fact is almost never less than 35%. The reductions in the DHW budget can be achieved either by using a higher efficiency stand-alone unit or centralized water heating system and/or by using system controls that yield energy budget credits.

Although the lower percent glazing areas and higher water heating efficiency levels are most prevalent, higher-than-minimum-efficiency space heating systems may also play a small role in trade-offs. Again, for all climate zone groups, a significant percentage of the buildings have higher performance heating systems.[14] The percentage of sites with higher-than-minimum-efficiency space heating systems ranges from 53% to 65% by climate zone group. However, efficiencies for these systems are typically only 2% to 4% above the minimum prescriptive efficiency values.

It is apparent from our analysis that high-efficiency water heating and relatively lower percent glazing are used most often as the vehicles for trade-offs in the energy design process. However, the energy features for which performance is traded-off seem to be unique to each climate zone group. For example:

---

[14] The percentage of sites with higher-than-minimum-efficiency space heating systems ranges from 53% to 65% by climate zone group. However, efficiencies for these systems are typically only 2 to 4% above the minimum prescriptive efficiency values.

- In the *16%-No Shade* climate zone group, trade-offs are made primarily to lower performance glazing U-values and roof insulation. Wall insulation is also traded-off, but not to the extent that glazing U-values and roof insulation are.
- In the *16%- Shade* climate zone group, glazing U-values, wall insulation, and roof insulation are heavily traded-off. In fact, these parameters are treaded-off in roughly 90% of the sites. This trend is not surprising, since insulation levels for this climate zone group are the highest (Wall=R-19/21 and Roof = R-38).
- Trade-offs for the *20%-No Shade* climate zone group are more subtle than for the other climate zone groups. Glazing U-values are the most predominant and some trade-offs in roof insulation are also made. Trade-offs on a percentage-of-site basis appear to be the lowest
- In the *20%- Shade* climate zone group, trade-offs to lower performance glazing (U-values) are heavily used. Trade-offs to lower ceiling insulation levels are also used in about half the sites.
- In the *20%-Shade* and *20%-No Shade* climate zone groups, a trade-off to electric resistance heating was found. According to the energy consultants concerned, this trade-off was made primarily because of the low first cost of electric resistance systems. This trade-off was made possible by sharp reductions in glazing percentage, the use of higher performance glazing (lower U-values), and water heating systems that maximize the DHW budget margin.