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Authors

Arasteh, Dariush
Huang, Joe
Mitchell, Robin
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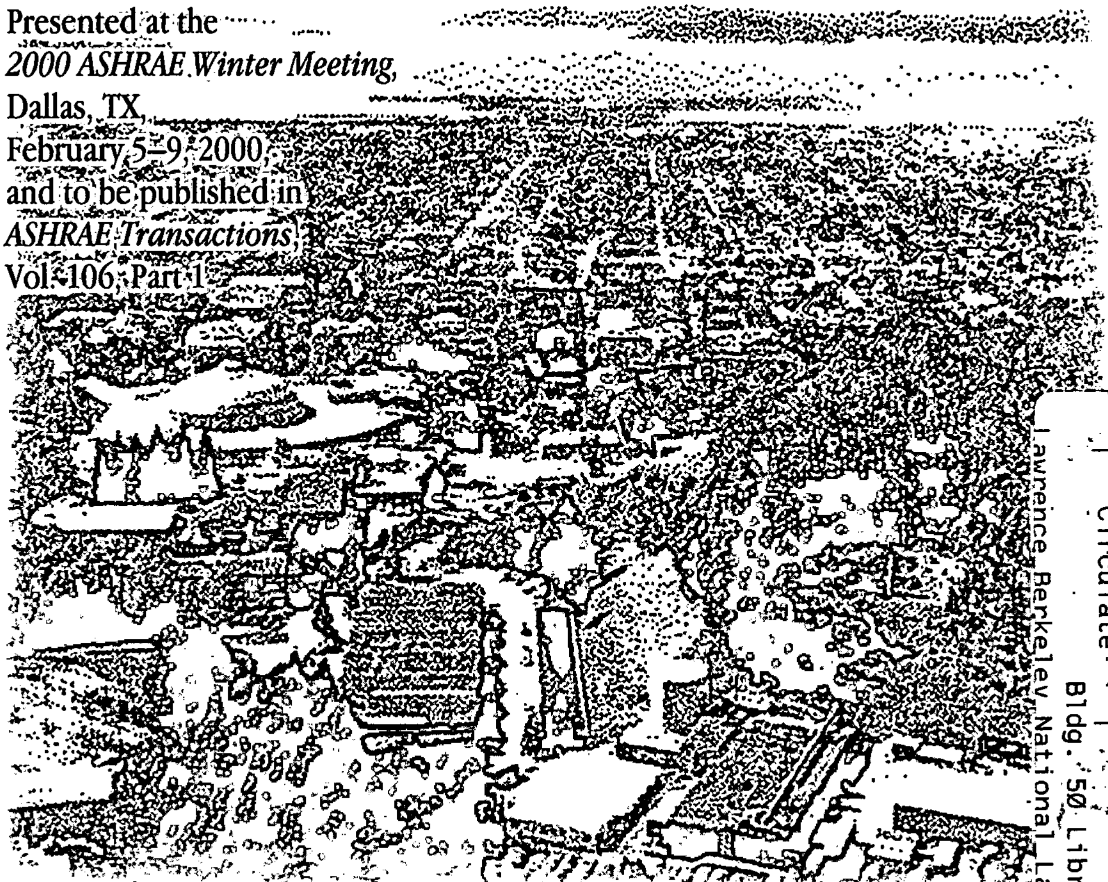

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Dariush Arasteh, Joe Huang, Robin Mitchell, Bob Clear, and Christian Kohler
Building Technologies Department
Environmental Energy Technologies Division
Ernest Orlando Lawrence Berkeley National Laboratory
University of California
1 Cyclotron Road
Berkeley CA 94720

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A Database of Window Annual Energy Use in Typical North American Single Family Houses

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Abstract

This paper documents efforts by the National Fenestration Rating Council to develop a database on annual energy impacts of windows in a typical new, single family, single story residence in various U.S. and Canadian climates. The result is a database of space heating and space cooling energies for 14 typical windows in 52 North American climates. (Future efforts will address the effects of skylights.) This paper describes how this database was created, documents the assumptions used in creating this database, elaborates on assumptions, which need further research, examines the results, and describes the possible uses of the database.

Introduction

Over the past several years, the National Fenestration Rating Council (NFRC) has developed technical procedures for determining the thermal performance properties of fenestration products. These properties document the thermal performance of the product in response to specific physical effects. U-Factors define heat transfer as a function of temperature differences, Solar Heat Gain Coefficients are the fraction of incident solar radiation transmitted into the space, and Air Infiltration measures heat transfer as a function of a pressure differential.

For the consumer or layperson looking to understand the energy (heating and/or cooling) impacts of specific windows in typical residential applications, and to select an appropriate window for their application, they must balance the positive and negative effects of these three parameters. For example, during the heating season, solar gains through a window can often counter heat lost through a window due to temperature differences (U-factor effect) and pressure differences (Air Infiltration effect). During the cooling season, solar heat gains are the dominant source of unwanted heat gain in a typical residential building; U-factors and Air-Infiltration rates play an additional role, typically minor.

Over the past several years, members of the National Fenestration Rating Council's Annual Energy Subcommittee developed a simulation-based procedure to evaluate the energy (and associated cost) impacts of windows and other fenestration products. The result is a database of heating and cooling energies for 13 typical and one hypothetical windows in 52 North American climates. (Future efforts will address the effects of skylights.) This paper describes how this database was created, documents the assumptions used in creating this database, elaborates on assumptions, which need further research, examines the results, and describes the possible uses of the database. This paper builds on previous efforts by the NFRC to develop an annual energy rating system (Crooks 1995).

Background

Since the 1970s, simulation tools have been used to quantify energy use in buildings and to study the absolute and relative effects of different building components. Physical testing of these effects would be extremely time-consuming and expensive. Numerous experimental studies have been carried out to develop the algorithms for these simulation tools and to validate the end results. Sullivan 1998, validates relevant DOE-2 algorithms, the simulation tool chosen for this study, as a means to quantify the space heating and space cooling energy impacts of windows.

Equally important to the tool are the assumptions used in the modeling process. From previous simulation studies (Sullivan 1987, Sullivan 1985, Selkowitz 1984), numerous factors have been shown to influence a given window's energy use in residential buildings. These include, but are not limited to:

- Climate
- Orientation
- Shading devices, overhangs, and obstructions
- Shell characteristics (wall, roof, and foundation insulation levels; air leakage)

- Thermal mass
- HVAC equipment (sizing, performance, occupancy schedule and temperature setpoints)
- Internal Loads

Methodology—Development of Final Modeling Assumptions

The NFRC Annual Energy Subcommittee's objective was to develop a database of space heating and space cooling energy use for a prototypical new house throughout the United States. From this database, a simplified index was to be developed. At the time of this writing, the database has been developed and is the subject of this paper. Ongoing efforts within the NFRC are aimed at developing a simplified annual energy rating based on this database; these efforts are not the subject of this paper and will be reported on separately in the future.

Climate is perhaps the most critical modeling parameter. A previous study identified 45 discrete U.S. climates, each with a representative city and weather tape (Huang 1986). As part of the NFRC process, two of these 45 climates were each split into two zones and a third climate was added, resulting in 48 U.S. zones. Four Canadian climates were added, resulting in a total of 52 cities. Figure 1 shows this on a map of the U.S. and southern Canada.

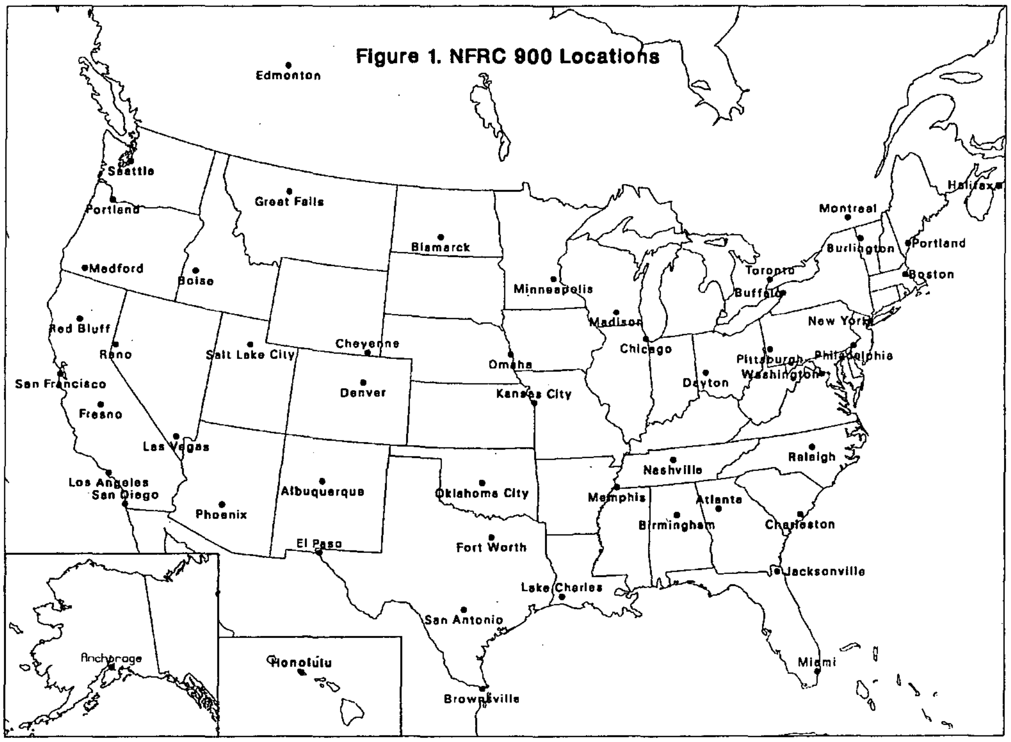

Figure 1. NFRC 900 Locations

The characteristics of the typical house to be modeled were next to be defined. These characteristics represent, in the judgement of the NFRC Task group working on this, a new single family house. Some building construction parameters vary appropriately with climate. These characteristics are documented in Tables 1 and 2.

Table 1. Final NFRC 900 assumptions comparison from July 1998

Floor Area (and dimensions)	1540 ft^2 (143m^2) (a) 41.5 ft x 41.5 ft x 8 ft (12.6m x 12.6m x 2.4m)
Foundation	Vary the foundation based on location. See Table 2 for a list of locations and foundations.
Insulation	Wall and Ceiling insulation levels based on the R-values from the 1993 Model Energy Code. See Table 2 for these R-values.
Infiltration	ELA=0.77 ft^2 (0.58 ACH)
Structural Mass	3.5 lb/ft^2 (17.1 kg/m^2) in accordance with the Model Energy Code
Internal Mass - Furniture	8.0 lbs/ft^2 (39.0 kg/m^2) in accordance with the Model Energy Code.
Window Area (% Floor Area)	15%
Window Type	Variable
Window Distribution	Equal
Solar Gain Reduction	Four effects included(b): -1 ft (0.3m) overhang on all four orientations; -a 67% transmitting same-height obstruction 20 ft (6.1m) away intended to represent adjacent buildings; -Interior shades (Seasonal SHGC multiplier, summer value = 0.80, winter value = 0.90); -To account for other sources of solar heat gain reduction (insect screens, trees, dirt, building & window self-shading), the SHGC multiplier was further reduced by 0.1. This results in a final winter SHGC multiplier of 0.8 and a final summer SHGC multiplier of 0.7.
HVAC System	Furnace & A/C, Heat Pump
HVAC System Sizing	For each climate, system sizes are fixed for all window options. Fixed sizes are based on the use of DOE-2 autosizing for a house with the most representative window for that specific climate. Autosizing multiplier of 1.3 used. (c)
HVAC Efficiency	AFUE = 0.78 A/C SEER = SEER=10.0
Duct Losses	Heating: 10% (fixed) Cooling: 10% (fixed)
Part-Load Performance	New part load curves for use with DOE-2 developed (Henderson 1999).
Thermostat Settings	Heating: 70°F (21.1°C); Cooling: 78°F (25.6 °C) Basement: Heating 62°F (16.7 °C); Cooling: 85°F (29.4 °C)
Night Heating Setback	65°F (18.3 °C); 11 PM – 6 AM(d)
Internal Loads	56 kBtu/day (59.1 MJ/day) Sensible 12.2 kBtu/day (13.2 MJ.day) Latent
Natural Ventilation	Enthalpic – Sherman-Grimsrud; 78°F (25.6 °C)/ 72°F (22.2 °C) based on four days history(e)
Weather Data	TMY2(f)
Number of Locations	48 US cities, 4 Canadian cities
Calculation Tool	DOE-2.1E, ver. 94

(a) The NFRC 900 model assumed a house measuring 28' x 55' (8.5m x 16.8m) or 1540 square feet (143 square meters). Because the windows in the house are equally split between the four cardinal directions, the total perimeter length of this house is also equally split among the four orientations, resulting in 41.5 perimeter feet (12.6m) on each side of the house. While such an "average" house may be physically impossible to build, it can be used in this modeling exercise.

(b) These assumptions are intended to represent the average solar heat gain reduction for a large sample of houses. A one-foot overhang is assumed on all four orientations in order to represent the average of a two-foot overhang and no overhang. A 67% transmitting obstruction 20 feet (6.1m) away on all 4 orientations represents the average of obstructions 20 feet (6.1m) away from 1/3 of the total windows and no obstructions in front of the remaining 2/3 of the windows. An interior shade is assumed to have a Solar Heat Gain Coefficient multiplier of 0.7 and is assumed to be deployed 1/3 of the time in the winter and 2/3 of the time in the summer, leading to the SHGC multiplier of 0.9 in the winter and 0.8 in the summer. To account for the solar heat gain reducing effects from "other sources" (screens, trees, dirt, and building and window self viewing), the SHGC multiplier was further reduced by 0.1 throughout the year; this amounts to a 12.5% decrease in the summer and an 11.1 % decrease in the winter. The final SHGC multipliers (0.8 in the winter and 0.7 in the summer) thus reflect the combined effects of shading devices and these "other sources."

(c) For each climate, DOE-2's autosizing feature was used with the window most likely to be installed in new construction. Table 2 shows the required prescriptive U-factors for windows for the 52 climates. For climates where the U-factor requirement is greater than or equal to 1.0 Btu/hr-ft^2-F (5.67W/m^2-C), window type 1 (Al, single glazing) was used for the sizing. For all climates where the U-factor requirement is between 0.65 Btu/hr-ft^2-F (3.69W/m^2-C) and 1.0 Btu/hr-ft^2-F (5.67W/m^2-C), window type 13 (al, double) was used for sizing. All climates with U-factor requirements at or below 0.6 Btu/hr-ft^2-F (3.41W/m^2-C), as well as the four Canadian climates, used window type 5 (wood or vinyl double) for sizing.

(d) A moderate setback of 65°F (18.3 °C) was used in recognition of the fact that all houses may not use night setbacks. Recent studies of residential indoor conditions have shown that nighttime temperatures are significantly lower than those during the day in the heating season (Ref: "Occupancy Patterns and Energy Consumption in New California Houses," Berkeley Solar Group for the California Energy Commission, 1990).

(e) NFRC 900-1998 uses a feature in DOE-2 that allows the ventilation temperature to switch between a higher heating (or winter) and a lower cooling (or summer) temperature based on the cooling load over the previous four days.

(f) There are 239 TMY2 locations with average weather data compiled from 30+ years of historical weather data. (Ref: *TMY2 User's Manual*, National Renewable Energy Laboratory, Golden, CO, 1995), but only 55 WYEC2 locations (Ref: *WYEC2 User's Manual*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, CA, 1997). The two weather data sets are of comparable reliability, for internal consistency and in order to draw upon a larger data set, we choose to use only TMY2 weather tapes.

Table 2. Foundation Type and Envelope Insulation Default Values for NFRC900-98 (typical of new construction)

ST	City	Foundation	Ceiling R-value hr-ft^2 °F/Btu (m^2 °C/W)	Wall R-value hr- ft^2 °F/Btu (m^2 °C/W)	Floor R-value hr- ft^2-°F/Btu (m^2 °C/W)	Slab Insul. R hr- ft^2-°F/Btu (m^2 °C/W)	Bsmt Wall R hr- ft^2 °F/Btu (m^2 °C/W)	Model Energy Code Zone	Window U-factor Btu/hr- ft^2 °F/ (W/ m^2 °C)
AK	Anchorage	Bsmt	38 (6.7)	19 (3.3)	--	--	30 (5.3)	17	0.40 (2.3)
AL	Birmingham	Slab, Crawl, Bsmt	38 (6.7)	14 (2.5)	19 (3.3)	6 (1.1)	6 (1.1)	6	0.70 (4.0)
AZ	Phoenix	Slab	30 (5.3)	11 (1.9)	--	0	--	3	0.90 (5.1)
CA	Fresno	Slab, Crawl, Bsmt	38 (6.7)	14 (2.5)	--	6 (1.1)	6 (1.1)	6	0.70 (4.0)
CA	Los Angeles	Slab, Crawl, Bsmt	26 (4.6)	11 (1.9)	11 (1.9)	0	--	4	0.75 (4.3)
CA	Red Bluff	Slab, Crawl, Bsmt	38 (6.7)	14 (2.5)	--	6 (1.1)	6 (1.1)	6	0.70 (4.0)
CA	San Diego	Slab, Crawl, Bsmt	30 (5.3)	11 (1.9)	11 (1.9)	0	--	3	0.90 (5.1)
CA	San Francisco	Slab, Crawl, Bsmt	38 (6.7)	14 (2.5)	19 (3.3)	6 (1.1)	--	6	0.70 (4.0)
CO	Denver	Bsmt, Crawl	38 (6.7)	19 (3.3)	26 (4.6)	--	11 (1.9)	13	0.40 (2.3)
DC	Washington	Bsmt	38 (6.7)	19 (3.3)	--	--	9 (1.6)	10	0.55 (3.1)
FL	Jacksonville	Slab	30 (5.3)	11 (1.9)	--	0	--	3	0.90 (5.1)
FL	Miami	Slab	19 (3.3)	11 (1.9)	--	0	--	1	1.10 (6.2)
GA	Atlanta	Slab, Bsmt, Crawl	38 (6.7)	19 (3.3)	13 (2.3)	2 (0.4)	5 (0.9)	7	0.65 (3.7)
HI	Honolulu	Slab	19 (3.3)	11 (1.9)	--	0	--	1	1.10 (6.2)
ID	Boise	Bsmt, Crawl	38 (6.7)	19 (3.3)	19 (3.3)	--	9 (1.6)	12	0.40 (2.3)
IL	Chicago	Bsmt	38 (6.7)	19 (3.3)	--	--	14 (2.5)	14	0.40 (2.3)
LA	Lake Charles	Slab	26 (4.6)	11 (1.9)	--	0	--	4	0.75 (4.3)
MA	Boston	Bsmt	38 (6.7)	19 (3.3)	--	--	11 (1.9)	13	0.40 (2.3)
ME	Portland	Bsmt	38 (6.7)	19 (3.3)	--	--	15 (2.6)	15	0.40 (2.3)
MN	Minneapolis	Bsmt	38 (6.7)	19 (3.3)	--	--	15 (2.6)	15	0.40 (2.3)
MO	Kansas City	Bsmt	38 (6.7)	19 (3.3)	--	--	8 (1.4)	11	0.45 (2.6)
MT	Great Falls	Bsmt	38 (6.7)	19 (3.3)	--	--	15 (2.6)	15	0.40 (2.3)
NC	Raleigh	Crawl, Slab, Bsmt	38 (6.7)	19 (3.3)	13 (2.3)	2 (0.4)	5 (0.9)	7	0.65 (3.7)
ND	Bismarck	Bsmt	38 (6.7)	19 (3.3)	--	--	28 (4.9)	16	0.40 (2.3)
NE	Omaha	Bsmt	38 (6.7)	19 (3.3)	--	--	11 (1.9)	13	0.40 (2.3)
NM	Albuquerque	Slab	38 (6.7)	19 (3.3)	--	3 (0.5)	--	9	0.60 (3.4)

Table 2 (Continued). Foundation Type and Envelope Insulation Default Values for NFRC900-98 (typical of new construction)

ST	City	Foundation	Ceiling R-value hr- ft^2 °F/Btu (m^2 °C/W)	Wall R-value hr- ft^2 °F/Btu (m^2 °C/W)	Floor R-value hr- ft^2-°F/Btu (m^2 °C/W)	Slab Insul. R hr- ft^2-°F/Btu (m^2 °C/W)	Bsmt Wall R hr- ft^2 °F/Btu (m^2 °C/W)	Model Energy Code Zone	Window U-factor Btu/hr- ft^2 °F/ (W/ m^2 °C)
NV	Las Vegas	Slab, Crawl	30 (5.3)	14 (2.5)	11 (1.9)	0	--	5	0.70 (4.0)
NV	Reno	Slab, Crawl	38 (6.7)	19 (3.3)	19 (3.3)	4 (0.7)	--	12	0.40 (2.3)
NY	Buffalo	Bsmt	38 (6.7)	19 (3.3)	--	--	14 (2.5)	14	0.40 (2.3)
NY	New York City	Bsmt, Slab	38 (6.7)	19 (3.3)	--	2 (0.4)	8 (1.4)	11	0.45 (2.6)
OH	Dayton	Bsmt, Slab, Crawl	38 (6.7)	19 (3.3)	19 (3.3)	4 (0.7)	9 (1.6)	12	0.40 (2.3)
OK	Oklahoma City	Slab	38 (6.7)	19 (3.3)	--	2 (0.4)	--	7	0.65 (3.7)
OR	Medford	Crawl, Bsmt	38 (6.7)	19 (3.3)	19 (3.3)	--	8 (1.4)	11	0.45 (2.6)
OR	Portland	Crawl, Bsmt	38 (6.7)	19 (3.3)	19 (3.3)	--	9 (1.6)	10	0.55 (3.1)
PA	Philadelphia	Bsmt	38 (6.7)	19 (3.3)	--	--	9 (1.6)	10	0.55 (3.1)
PA	Pittsburgh	Bsmt	38 (6.7)	19 (3.3)	--	--	9 (1.6)	12	0.40 (2.3)
SC	Charleston	Craw, Slabl	30 (5.3)	14 (2.5)	11 (1.9)	0	--	5	0.70 (4.0)
TN	Memphis	Crawl, Bsmt, Slab	38 (6.7)	19 (3.3)	13 (2.3)	2 (0.4)	5 (0.9)	7	0.65 (3.7)
TN	Nashville	Crawl, Bsmt, Slab	38 (6.7)	19 (3.3)	19 (3.3)	2 (0.4)	7 (1.2)	8	0.65 (3.7)
TX	Brownsville	Slab	19 (3.3)	13 (2.3)	--	0	--	2	1.10 (6.2)
TX	El Paso	Slab	38 (6.7)	14 (2.5)	--	6 (1.1)	--	6	0.70 (4.0)
TX	Fort Worth	Slab	30 (5.3)	14 (2.5)	--	0	--	5	0.70 (4.0)
TX	San Antonio	Slab	26 (4.6)	11 (1.9)	--	0	--	4	0.75 (4.3)
UT	Salt Lake City	Bsmt	38 (6.7)	19 (3.3)	--	--	9 (1.6)	12	0.40 (2.3)
VT	Burlington	Bsmt	38 (6.7)	19 (3.3)	--	--	15 (2.6)	15	0.40 (2.3)
WA	Seattle	Bsmt, Crawl	38 (6.7)	19 (3.3)	19 (3.3)	--	9 (1.6)	10	0.55 (3.1)
WI	Madison	Bsmt	38 (6.7)	19 (3.3)	--	--	15 (2.6)	15	0.40 (2.3)
WY	Cheyenne	Bsmt	38 (6.7)	19 (3.3)	--	--	15 (2.6)	15	0.40 (2.3)
	Edmonton	Bsmt	38 (6.7)	19 (3.3)	--	--	15 (2.6)		N/A
	Halifax	Bsmt	38 (6.7)	19 (3.3)	--	--	15 (2.6)		N/A
	Montreal	Bsmt	38 (6.7)	19 (3.3)	--	--	15 (2.6)		N/A
	Toronto	Bsmt	38 (6.7)	19 (3.3)	--	--	15 (2.6)		N/A

While the task group used the best information it could find available for the modeling task, it was clear to all members of the task group that some assumptions deserved further substantive research but that these issues could not be resolved in the near future. As a result, a list of issues for further research was created. It is the hope that research over the next several years will help identify improvements in these areas. Research on these long-term issues will probably lead to the use of more regionally variable assumptions. The list of future research and modeling refinement topics is documented in Appendix 1. These research topics are mostly modeling assumption issues although some are modeling algorithm issues.

Thirteen typical windows were defined that were intended to cover the range of commercially available glazing and frame technologies, as well as products expected on the market in upcoming years. One additional hypothetical window with atypical solar properties (#14) was added for better coverage of potential window conditions. Table 3 lists these window products with their resulting U-factors and Solar Heat Gain Coefficients for the standard residential model size. In each climate, each of the 14 windows was modeled with three different air infiltration rates: 0, 1, and 2 cfm/lin ft (0, 1.55, and 3.10 l/s-m). This range of U-factor and SHGCs and variation in air infiltration (AI) rates was intended to allow for future regressions of heating or cooling energy use as a function of U-factor, SHGC and AI. A base case intended to represent typical worst case practice was also run (this translated into Window #1 with an air infiltration rate of 0.65 cfm/lf (1.01 l/s-m). [Note: NFRC has already decided to report residential product U-factors and SHGCs to only one size, even if size effects are significant. Thus, this annual energy data does not consider size effects as such effects are not part of the base NFRC process.]

Results

The results of each run are summarized in a database. For illustrative purposes, a sample page for one climate is included as Table 4. The spreadsheet can be downloaded from the worldwide web at *windows.lbl.gov.*

Table 3: Representative Windows used

Window #	# of glazing layers	Glazing Description	Frame Type	Frame U-factor Btu/hr-ft^2-F (W/m^2-C)	Spacer	Total U-factor Btu/hr-ft^2-F (W/m^2-C)	Total SHGC	Air Leakage Typical; Cfm/sf (l/s-m^2)
1	1	DS clear	Aluminum	1.9 (10.8)	NA	1.30 (9.1)	0.74	0.98 (2.28)
2	1	DS bronze	Aluminum	1.9 (10.8)	NA	1.30 (9.1)	0.63	0.98 (2.28)
3	2	DS clear, air, DS clear	Al-TB	1.0 (5.7)	Alum.	0.64 (3.6)	0.63	0.56 (1.30)
4	2	DS bronze, air, DS clear	Al-TB	1.0 (5.7)	Alum.	0.64 (3.6)	0.51	0.56 (1.30)
5	2	DS clear, air, DS clear	Wood	0.4 (2.3)	Alum.	0.49 (2.8)	0.57	0.56 (1.30)
6	2	DS bronze, air, DS clear	Wood	0.4 (2.3)	Alum.	0.49 (2.8)	0.46	0.56 (1.30)
7	2	DS clear, air, DS pyrolitic e=.20	Vinyl	0.3 (1.7)	Stainless	0.33 (1.9)	0.52	0.15 (0.23)
8	2	DS sputtered e=.08, Ar, DS clear	Vinyl	0.3 (1.7)	Stainless	0.30 (1.7)	0.42	0.15 (0.34)
9	2	DS selective e=.04, Ar, DS clear	Vinyl	0.3 (1.7)	Stainless	0.29 (1.6)	0.3	0.15 (0.34)
10	2	DS sputtered e=.10, Ar, DS clear	Vinyl	0.3 (1.7)	Stainless	0.31 (1.7)	0.22	0.15 (0.34)
11	3	DS e=.08, Kr, DS, Kr, DS e=.08	Insulated	0.2 (1.1)	Insulated	0.15 (0.9)	0.36	0.08 (0.18)
12	3	all layers:e=.04 & Ts=.6; Kr gaps	Super Ins.	0.12 (0.7)	Insulated	0.12 (0.7)	0.34	0.08 (0.18)
13	2	DS clear, air, DS clear	Al	1.9 (10.8)	Alum.	0.87 (4.9)	0.66	0.56 (1.30)
14	1	fictitious tinted DS	Vinyl	0.3 (1.7)	NA	0.89 (5.1)	0.35	0.56 (1.30)

Notes:

(1) All windows analyzed as NFRC Size AA Casements

(2) DS = double strength 1/8" (3mm) thick glasss

(3) All gaps in windows 3-12 are 0.5" (13mm) for air and Argon, 0.375" (9.5mm) for Kr; Window #12 has 0.5" (13mm) gaps; Window #13 has a 0.375" (9.5mm) gap.

(4) Frame widths are: Aluminum: 2" (51mm); Wood or Vinyl: 2.5" (64mm); Insulated: 2" (51mm); Super Insulated: 2" (51mm)

(5) SHGC assumes 0.5 frame absorptance

(6) Edge performance calculated with WINDOW 4.1; Aluminum spacers used Edge Correlation 1; Stainless uses Correlation 2 and Insulated Spacer has edge Correlation 4

Table 4. Sample Page of NFRC900 Database for Denver, Colorado

10 Aug 98 version	Window Condition				Fan	Heat	Heat	PkHt	PkHt	Furn		Cool	Cool	PkCl	PkCool	A/C		Fan	PkFan
(0.8/0.7 shading)					Size	Fuel	Load	Fuel	Load	Cap.	Heat	Elec	Load	Elec	Load	Cap.	A/C	Elec	Elec
Location	No.	U-Fac	SHGC	CFM/ft	CFM	MBtu	MBtu	kBtu	kBtu	kBtu	Eff.	kWh	MBtu	kW	kBtu	kBtu	Eff	kWh	kW
CO_Denver	1	1.30	0.74	0.65	817	63.22	47.54	54.91	40.23	44.85	0.752	733	6.77	2.18	17.77	27.24	2.708	140	0.10
CO_Denver	1	1.30	0.74	0	817	60.62	45.63	53.53	39.19	44.85	0.753	733	6.78	2.15	17.57	27.24	2.709	136	0.10
CO_Denver	2	1.30	0.63	0	817	63.39	47.73	53.56	39.21	44.85	0.753	611	5.61	2.01	16.39	27.24	2.692	136	0.10
CO_Denver	3	0.64	0.63	0	817	45.54	34.51	46.85	34.27	44.85	0.758	635	5.87	1.85	15.12	27.24	2.709	106	0.08
CO_Denver	4	0.64	0.51	0	817	48.51	36.77	46.86	34.28	44.85	0.758	509	4.68	1.70	13.83	27.24	2.693	106	0.08
CO_Denver	5	0.49	0.57	0	817	42.14	32.00	44.85	32.83	44.85	0.759	573	5.30	1.71	13.93	27.24	2.710	97	0.08
CO_Denver	6	0.49	0.46	0	817	44.94	34.14	44.86	32.84	44.85	0.760	459	4.22	1.57	12.83	27.24	2.694	98	0.08
CO_Denver	7	0.33	0.52	0	817	36.02	27.45	41.86	30.69	44.85	0.762	555	5.14	1.60	13.05	27.24	2.712	86	0.08
CO_Denver	8	0.30	0.42	0	817	37.20	28.38	41.20	30.22	44.85	0.763	441	4.07	1.45	11.79	27.24	2.701	83	0.07
CO_Denver	9	0.29	0.30	0	817	39.89	30.43	40.93	30.02	44.85	0.763	327	3.00	1.26	10.29	27.24	2.690	84	0.07
CO_Denver	10	0.31	0.22	0	817	43.84	33.41	41.77	30.62	44.85	0.762	264	2.40	1.18	9.63	27.24	2.668	88	0.08
CO_Denver	11	0.15	0.36	0	817	32.79	25.09	38.37	28.20	44.85	0.765	396	3.66	1.32	10.73	27.24	2.706	74	0.07
CO_Denver	12	0.12	0.34	0	817	30.81	23.61	37.18	27.35	44.85	0.766	384	3.54	1.26	10.27	27.24	2.702	70	0.07
CO_Denver	13	0.87	0.66	0	817	51.12	38.65	49.15	35.96	44.85	0.756	646	5.97	1.94	15.86	27.24	2.707	116	0.09
CO_Denver	14	0.89	0.35	0	817	59.00	44.61	48.95	35.81	44.85	0.756	363	3.30	1.52	12.34	27.24	2.664	119	0.09
CO_Denver	1	1.30	0.74	1	817	64.64	48.58	55.65	40.78	44.85	0.752	732	6.76	2.19	17.87	27.24	2.705	143	0.10
CO_Denver	2	1.30	0.63	1	817	67.44	50.71	55.67	40.80	44.85	0.752	611	5.61	2.05	16.70	27.24	2.691	143	0.10
CO_Denver	3	0.64	0.63	1	817	49.46	37.42	48.88	35.75	44.85	0.757	631	5.83	1.89	15.43	27.24	2.709	112	0.09
CO_Denver	4	0.64	0.51	1	817	52.51	39.73	48.89	35.76	44.85	0.757	508	4.67	1.73	14.14	27.24	2.695	113	0.09
CO_Denver	5	0.49	0.57	1	817	46.05	34.91	46.90	34.31	44.85	0.758	569	5.26	1.76	14.34	27.24	2.706	104	0.08
CO_Denver	6	0.49	0.46	1	817	48.92	37.10	46.91	34.32	44.85	0.758	457	4.20	1.61	13.13	27.24	2.691	105	0.08
CO_Denver	7	0.33	0.52	1	817	39.88	30.33	43.93	32.17	44.85	0.760	547	5.07	1.65	13.46	27.24	2.713	92	0.08
CO_Denver	8	0.30	0.42	1	817	41.12	31.29	43.27	31.70	44.85	0.761	437	4.02	1.49	12.10	27.24	2.697	90	0.08
CO_Denver	9	0.29	0.30	1	817	43.84	33.38	43.00	31.50	44.85	0.761	325	2.98	1.30	10.59	27.24	2.684	90	0.08
CO_Denver	10	0.31	0.22	1	817	47.84	36.39	43.83	32.10	44.85	0.761	264	2.41	1.22	9.93	27.24	2.669	95	0.08
CO_Denver	11	0.15	0.36	1	817	36.66	27.99	40.45	29.68	44.85	0.763	391	3.61	1.36	11.03	27.24	2.702	80	0.07
CO_Denver	12	0.12	0.34	1	817	34.65	26.50	39.26	28.83	44.85	0.765	377	3.48	1.30	10.58	27.24	2.703	76	0.07
CO_Denver	13	0.87	0.66	1	817	55.09	41.58	51.16	37.43	44.85	0.755	645	5.95	1.98	16.16	27.24	2.704	123	0.09
CO_Denver	14	0.89	0.35	1	817	63.08	47.62	50.96	37.29	44.85	0.755	363	3.30	1.55	12.65	27.24	2.662	126	0.09
CO_Denver	1	1.30	0.74	2	817	68.68	51.55	57.74	42.37	44.85	0.751	731	6.75	2.23	18.18	27.24	2.704	150	0.10
CO_Denver	2	1.30	0.63	2	817	71.53	53.70	57.75	42.39	44.85	0.751	610	5.60	2.08	17.00	27.24	2.691	150	0.10
CO_Denver	3	0.64	0.63	2	817	53.43	40.35	50.89	37.23	44.85	0.755	629	5.81	1.93	15.73	27.24	2.707	119	0.09
CO_Denver	4	0.64	0.51	2	817	56.53	42.70	50.90	37.24	44.85	0.755	506	4.65	1.77	14.44	27.24	2.693	120	0.09
CO_Denver	5	0.49	0.57	2	817	49.99	37.84	48.93	35.79	44.85	0.757	566	5.22	1.80	14.64	27.24	2.704	111	0.09
CO_Denver	6	0.49	0.46	2	817	52.91	40.05	48.94	35.80	44.85	0.757	457	4.20	1.65	13.44	27.24	2.690	112	0.09
CO_Denver	7	0.33	0.52	2	817	43.76	33.22	45.98	33.65	44.85	0.759	544	5.04	1.69	13.77	27.24	2.712	99	0.08
CO_Denver	8	0.30	0.42	2	817	45.06	34.23	45.33	33.17	44.85	0.760	434	3.99	1.52	12.40	27.24	2.696	97	0.08
CO_Denver	9	0.29	0.30	2	817	47.83	36.34	45.06	32.98	44.85	0.760	322	2.95	1.34	10.89	27.24	2.682	97	0.08
CO_Denver	10	0.31	0.22	2	817	51.87	39.39	45.88	33.58	44.85	0.759	263	2.39	1.26	10.22	27.24	2.665	102	0.08
CO_Denver	11	0.15	0.36	2	817	40.56	30.90	42.52	31.16	44.85	0.762	389	3.58	1.38	11.26	27.24	2.698	87	0.08
CO_Denver	12	0.12	0.34	2	817	38.55	29.40	41.34	30.31	44.85	0.763	375	3.45	1.34	10.89	27.24	2.696	83	0.07
CO_Denver	13	0.87	0.66	2	817	59.09	44.53	53.15	38.91	44.85	0.754	643	5.94	2.02	16.47	27.24	2.705	130	0.10
CO_Denver	14	0.89	0.35	2	817	67.19	50.64	52.96	38.76	44.85	0.754	362	3.29	1.59	12.95	27.24	2.665	133	0.10

Figures 2a and 2b show space heating and space cooling energy use for eight representative climates that span the range of 52 climates covered in this database. Results for the most efficient window and the least efficient window are plotted in order to give an idea of the approximate energy impacts of windows in the house. Results are plotted for a typical window air infiltration rate of 0.3 cfm/lf (0.46 l/s-m); this was determined by a linear interpolation between 0 and 1 cfm/lf (0 and 1.55 l/s-m). The amount of space heating or space cooling energy used by the house can vary by up to a factor of two, depending on which window is chosen. Thus, window annual energy impacts on a house are significant. Note that site-cooling electricity is converted to source energy using a multiplier of 3.24 (DOE 1998). The use of source energy roughly correlates to U.S. national average utility costs; however, local costs can skew the relationship between gas and electricity costs by a factor of approximately two.

Figures 3a and 3b show the impacts of air infiltration rates on space heating and space cooling energy use; it should be noted that extreme minimum and maximum air infiltration rates are being plotted and even for these extreme differences, the impacts on energy use are minimal. The energy use displayed in Figures 3a and 3b is for the window most typical of new construction (Windows 5, 13 or 1 depending on climate). Impacts from U-factor and solar heat gain coefficient together are much more significant (see Figures 4a and 4b) than that from infiltration; the relative impacts of U-factor and SHGC vary with climate. However, infiltration is likely to be a more significant factor in multi-story apartment buildings and in high-rise residential buildings where wind and stack effects are more significant.

Figures 4a and 4b show total annual energy (space heating and space cooling) for all 14 windows (see Table 3) for the climatic extremes of Madison, WI and Phoenix, AZ. Results are plotted for a typical air infiltration rate of 0.3 cfm/lf (0.46 l/s-m). In the heating dominated climate of Madison, WI, lower U-factors result in less energy use although there is a tradeoff between higher SHGCs and lower U-factors (compare Windows 7 and 9). In the cooling dominated climate of Phoenix, total energy use is a strong function of SHGC only.

Conclusions

The development of this database represents the first step in getting fair, accurate, and credible information on the heating and cooling energy impacts of windows to consumers and specifiers. It was developed by a task group, which represented all the diverse interests of the U.S. window and glass industries and had available to it the knowledge base in this field. As evident by the topics in Appendix 1, there is much that can still be done to improve the accuracy of this database; however the existing version represents the best available information and should be used by consumers, code bodies or voluntary programs whenever the need for such information arises in the near term.

As an expansion of this process a simple computer program, RESFEN, which provides the user with case specific energy data for a wider variety of building configurations, was developed. RESFEN 3.1 uses the same base modeling assumptions and building analysis tool (DOE-2.1E) and thus produces results consistent with the NFRC database. RESFEN 3.1 also allows the user to vary key parameters (window properties, window distribution, and shading/overhangs/obstructions by orientation, house size, and vintage) in order to deliver case specific annual energy (and cost) results. RESFEN is described in more detail at *http:\\windows.lbl.gov* and in Huang 1998.

Future efforts are aimed at improving the accuracy of the modeling process by addressing the list of issues documented in Appendix 1. A logical next step would be to prioritize the research issues in Appendix 1 so that we know which issues influence window energy use most significantly. NFRC is also in the process of exploring how this data can be condensed into a simplified rating.

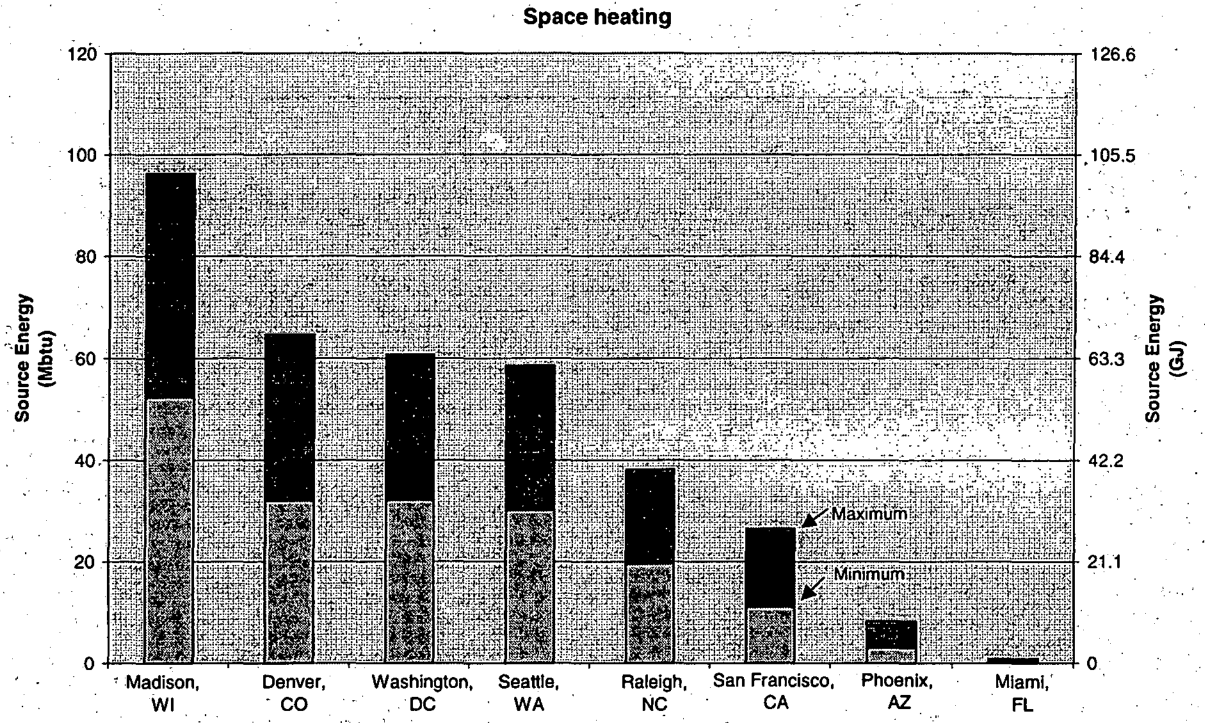

Figure 2a - Whole house annual space heating energy use, maximum corresponds with the window with the highest energy use, minimum corresponds with the lowest energy use.

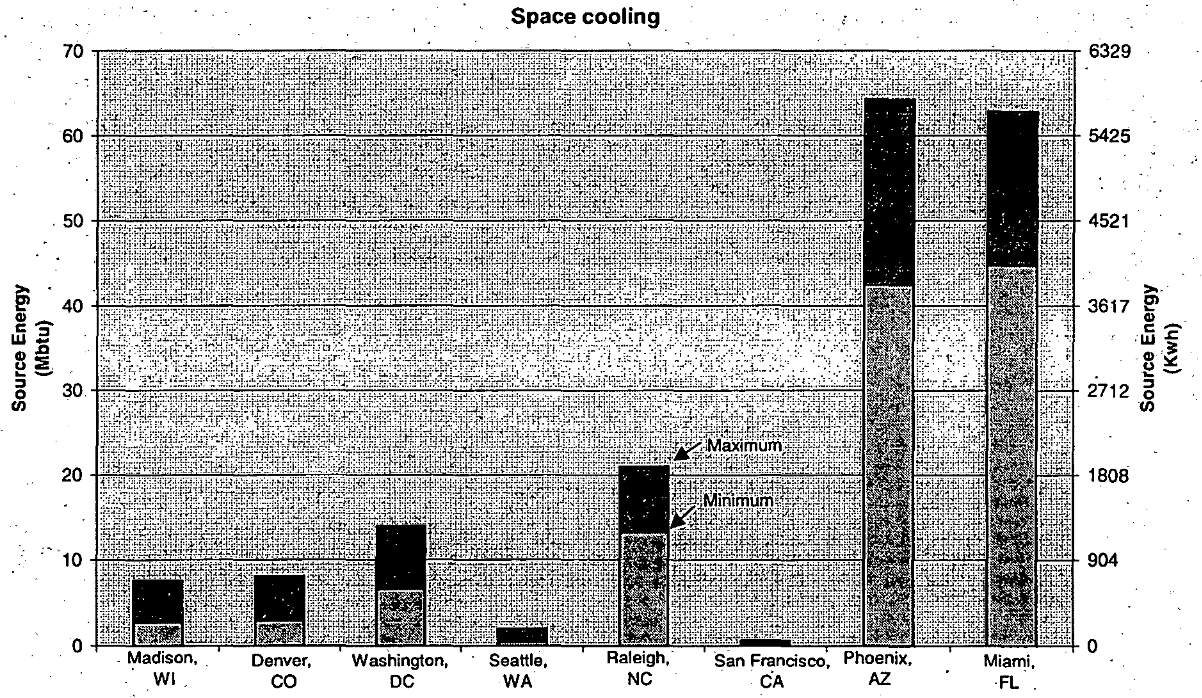

Figure 2b - Whole house annual space cooling energy use, maximum corresponds with the window with the highest energy use, minimum corresponds with the lowest energy use.

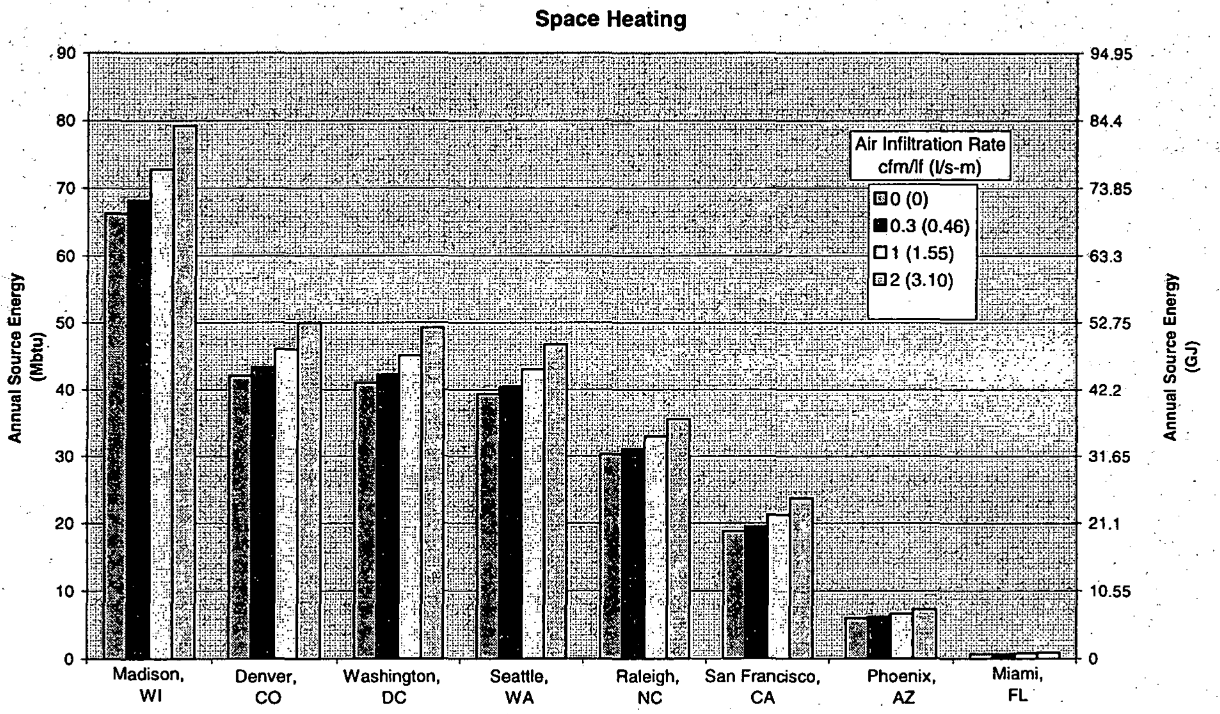

Figure 3a - Whole house annual space heating energy use, with varying air infiltration rates. Energy use displayed is for window most typical of new construction (MEC); #5 in Madison, Denver, Washington and Seattle, #13 in Raleigh, San Francisco and Phoenix, #1 in Miami

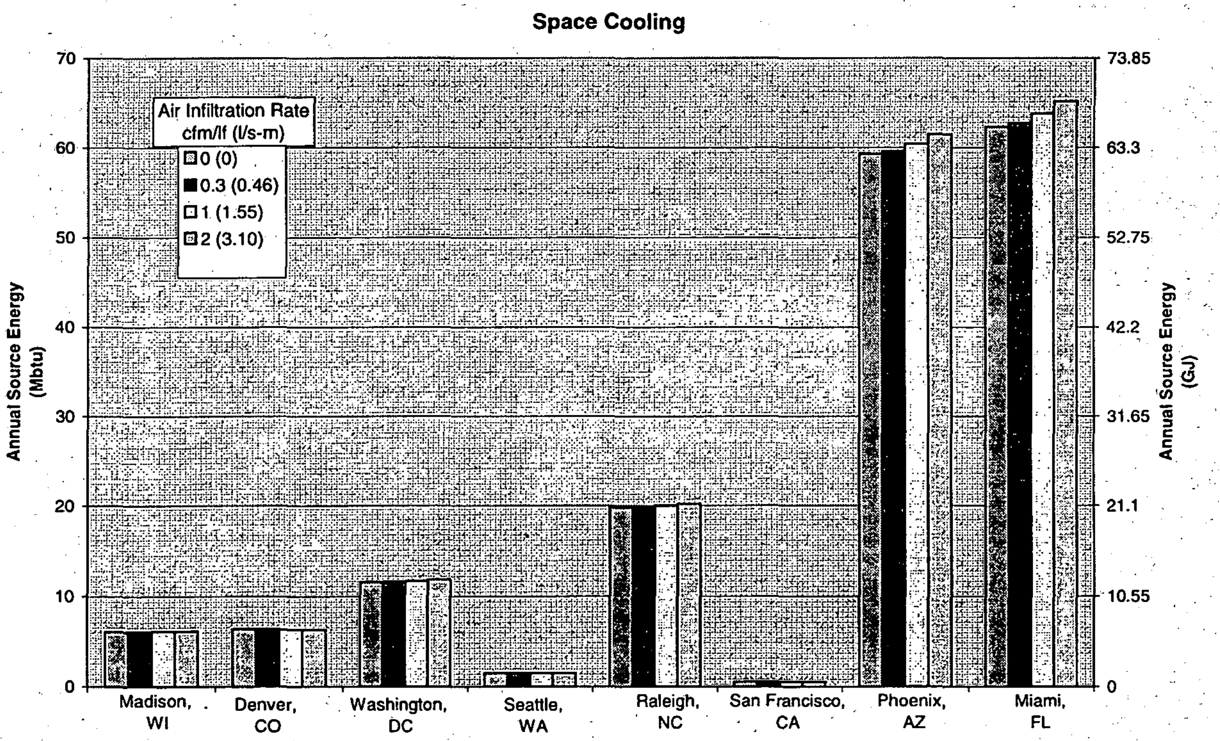

Figure 3b - Whole house annual space cooling energy use, with varying air infiltration rates. Energy use displayed is for window most typical of new construction (MEC); #5 in Madison, Denver, Washington and Seattle, #13 in Raleigh, San Francisco and Phoenix, #1 in Miami

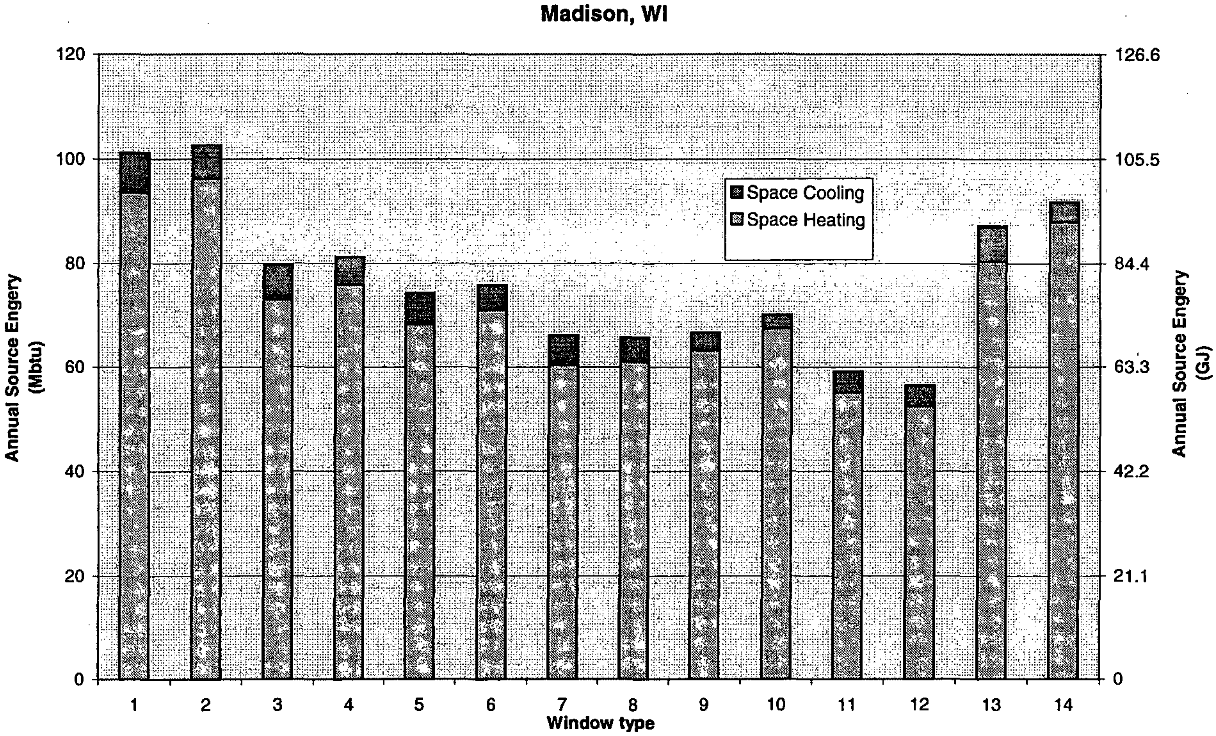

Figure 4a - Whole house annual space heating and space cooling energy use in Madison, WI, for different window types (infiltration=0.3 cfm/lf (0.46 l/s-m))

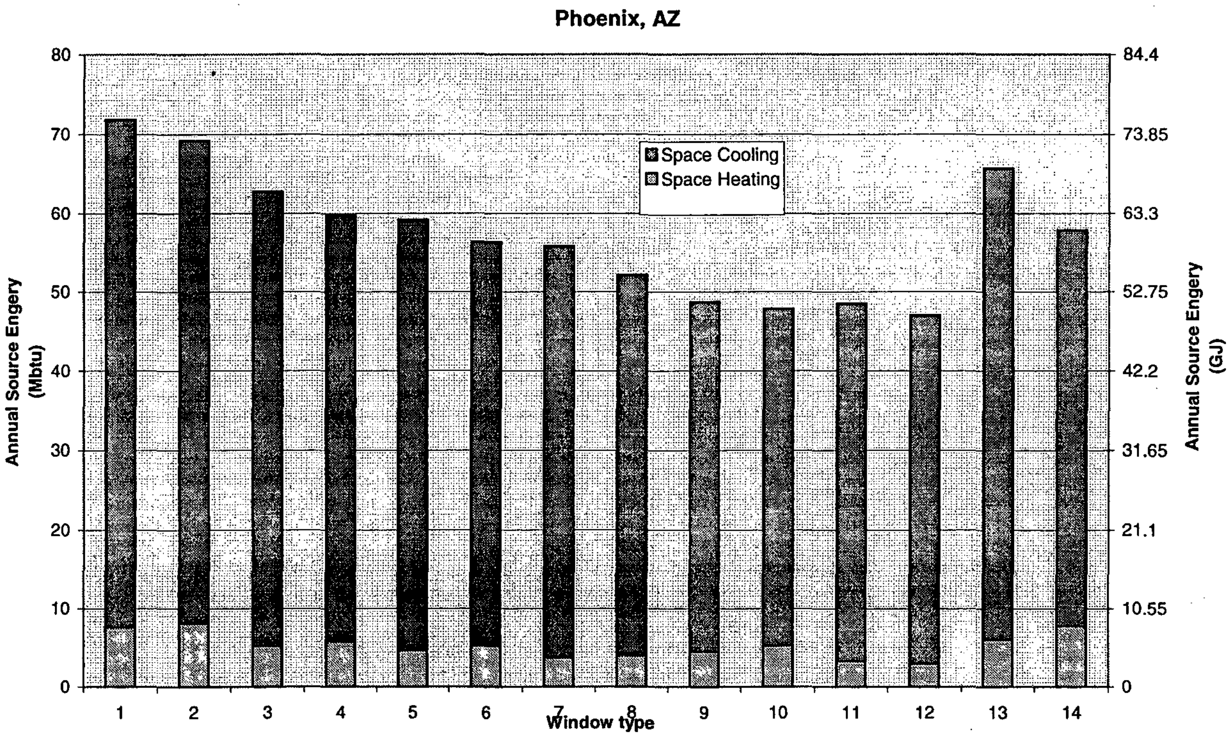

Figure 4b - Whole house annual space heating and space cooling energy use in Phoenix, AZ, for different window types (infiltration=0.3 cfm/lf (0.46 l/s-m))

Acknowledgements

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Appendix 1: Long Term Issues for NFRC 900

LT-1) Additional House model refinements
The model used was a model of a new single family house, with energy measures and heating/cooling equipment typical of houses built to the 1992 Model Energy Code (MED, also see LT-8). It is not necessarily representative of existing houses with little or no insulation and/or with inefficient equipment. It is also not necessarily representative of multi-family housing. Research is needed to develop models for building types which will represent these other cases. Our prototypical house is representative of the average new single story house – the implications of variations in new construction (as well as variations from the average existing poorly insulated house) need to be considered.

LT-2) Additional equipment performance refinements
As part of the efforts to date, a small research project (Henderson 1999) was conducted to define the part-load operating characteristics of typical space heating and space cooling systems (new and existing). The issue of how equipment is sized however, deserves further attention. It was assumed that equipment is not downsized when efficient windows are installed (this needs to be studied with more rigor). The part load curve research should be reviewed by the industry and updated, if necessary. This work relates to item LT-10 below on duct losses.

LT-3) Additional Window types
The database made use of 14 generic window products in all climates. Not all of these windows are realistic for all climates. Others need to be defined for specific climates. This item relates to item LT-7 below on local building practices.

LT-4) Comparison with monitored data in various climates
Reviewers of early versions of the NFRC900 database commented that in some climates, space cooling loads were high compared to typical monitored data (Reilly 1998). Improvements were made to the modeling assumptions (typical shades, trees, and overhangs were added in and the cooling part-load curves were updated). These assumptions are reflected in Table 1 and in the final NFRC900 database. Final cooling load results were judged to be much more in line with typical monitored data. Further efforts however to compare monitored data with simulated data are necessary in order to maintain confidence in the NFRC900 procedures; effort is required to understand the monitoring process and assess the quality of the monitored data. New monitoring and demonstration projects may be required.

LT-5: Solar transmission: The amount of solar gains entering a space is one of the most significant factors for this analysis. The DOE-2 models account for solar spectral and angular transmission effects; however there are procedures being developed (variations in solar spectral irradiance by climate, angular selectivity) which can improve the accuracy of these models.

LT-5a: Solar Gain Reductions: Typical overhangs, obstructions, and shading devices were assumed with the same values used throughout all climates. In reality, these solar heat gain reduction elements vary depending on region. These assumptions should be reviewed and regionally specific assumptions should be developed.
Research has also indicated that there are other phenomena which reduce (or increase) solar gain. The effects of solar heat gain reductions from trees, dirt, screens, self shading are included; further research is needed to better understand these effects. The procedure for modeling solar reflectance off snow needs to be validated.

LT-6) Climate issues:
The 48 US Climates used as part of this analysis were based on a climate sensitivity study as part of a similar project (Huang 1986). The four Canadian climates were chosen by the task group; a better understanding of Canadian climates is necessary.
There are two types of weather types which could be used for this analysis, WYEC2 and TMY2 weather tapes. A significant effort was spent to understand the effects between the two types of tapes (Huang 1998). The TMY2 tapes were chosen since an analysis of WYEC2 and TMY2 tapes raised less concerns about the TMY2 tapes. Further research on solar availability data documented on weather tapes is required.

LT-7) Window Orientation and Distribution: The analysis assumed an equal window orientation on each of the four cardinal orientations. It was suggested that houses typically do not have equal window orientation. This issues needs to be researched and typical distributions need to be defined. Once defined, the effects of unequal distribution vs. equal distribution on energy consumption need to be understood.

LT-8) What Defines Typical House Characteristics: The analysis used the Model Energy Code (MEC) assumptions across the entire US to define typical energy-efficiency measures. In some cases, due to the use of different building practices (stricter codes or no codes), this is not typical construction. Further discussion about whether to use typical MEC code levels or typical building practice levels is needed; to some degree this decision depends on whether the data is aggregiated geographically (for an index) or if it is intended to be used to understand space heating and space cooling issues at specific locations.

LT-9) Window to Floor Area Percentage: The modeling process included an assumption that the typical window area was 15% of the floor area and that this was true for all climates. This assumption should be examined on a regional basis. In addition, the assumption that window performance, as a function of window area, is constant, is reasonable to first order; performance for windows with more or less area will be different.

LT-10) Duct Leakage: At the time this study was performed, studies on duct leakage indicated that a value of 10% should be used but that ongoing research may lead to different conclusions. This parameter should be revisited based on the most up-to-date literature.

LT-11) House size: The house size and shape were assumed to be constant throughout the entire US. Typical house sizes and shapes vary with region. Regional house prototypes could be developed.

LT-12) Natural Ventilation:
An enthalpic natural ventilation algorithm is included in the model. This needs to be verified against regional operating and construction practices.
LT-12a) Air to Mass Heat Transfer: The DOE-2 algorithms which calculate the heat transfer between air and mass should be validated, and if necessary, inproved.

LT-13) Window Type Assumptions.
A casement window was assumed to represent all windows for this analysis. The operator type influences the air leakage rate (both initial and long term) as well as the total product U-factor and SHGC (due to glass to frame area ratios). The significance of this assumption depends on how the data is used. Different window types can be defined as a function of region.

LT-14) Long Term Performance implications
This rating is designed to inform the buyer of the best choice for their specific project. As such, it should include effects from longterm performance degradation. Effects which can influence long term energy use include but are not limited to air leakage over time (different for different operators – see LT-13), gas filling and sealing, sealant integrity.

LT-15) Solar Utilizability:
DOE-2 includes algorithms for calculating what happens to solar gains once they enter a room (absorbed by mass, raise the air temperature). These algorithms influence the utilizability of solar gains for heating as well as the cooling load impacts of solar gains. A validation of these algorithms and possible refinement should be considered.

ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY
ONE CYCLOTRON ROAD | BERKELEY, CALIFORNIA 94720

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