



A Window on **Green Architecture:**
the role of residential windows
in global climate change

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11 march 2004

What is Green Architecture?

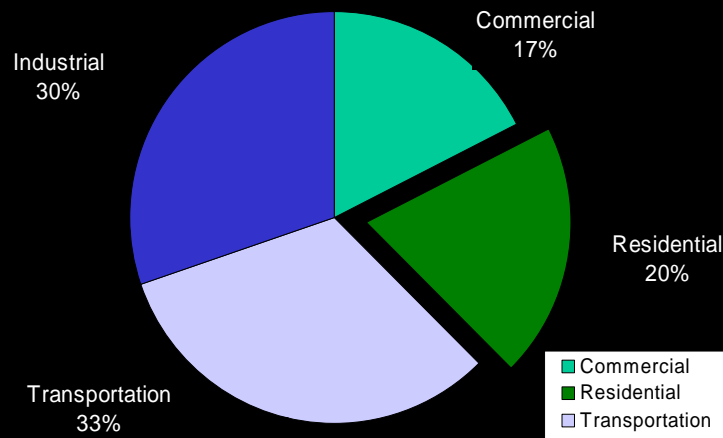


- Reduces the impacts of buildings and architecture on the environment
- Environmental impact through energy consumption.

Climate Change Basics

- Fossil Fuels → CO₂
- Near doubling of CO₂ levels enhances greenhouse effect.
- Carbon dioxide is most important US GHG.

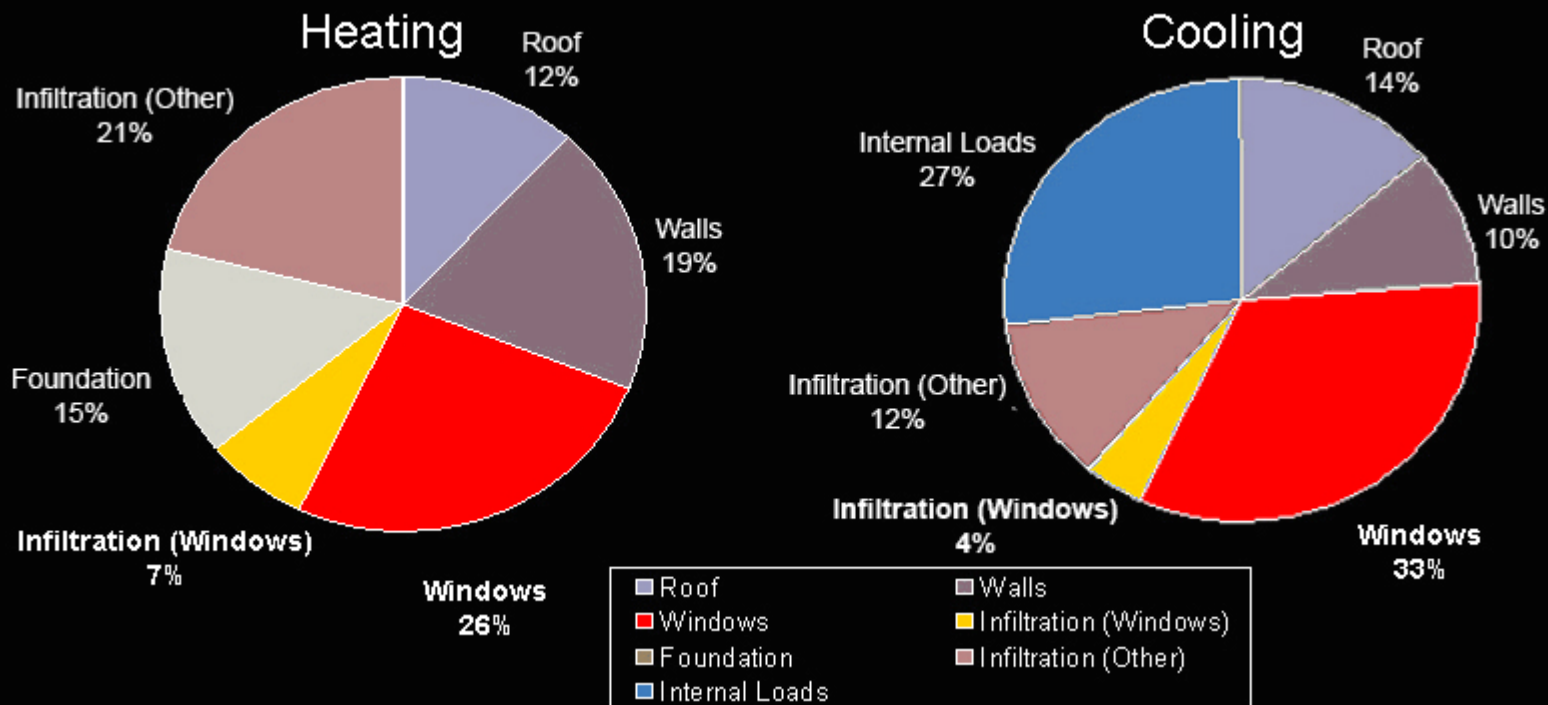
US Carbon Emissions by Sector, 2000



- 105 million US homes responsible for 5% of world carbon emissions.

What consumes energy in US homes?

- 40% of energy consumption is for heating and cooling.
- What drives this energy consumption?



Thesis Questions

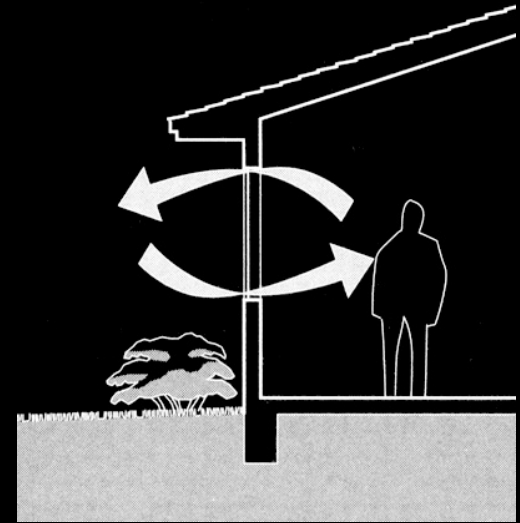


- What are the carbon emissions associated with residential windows in the US?
- How can advanced technologies reduce current window-related carbon emissions?

Why are Windows Inefficient?

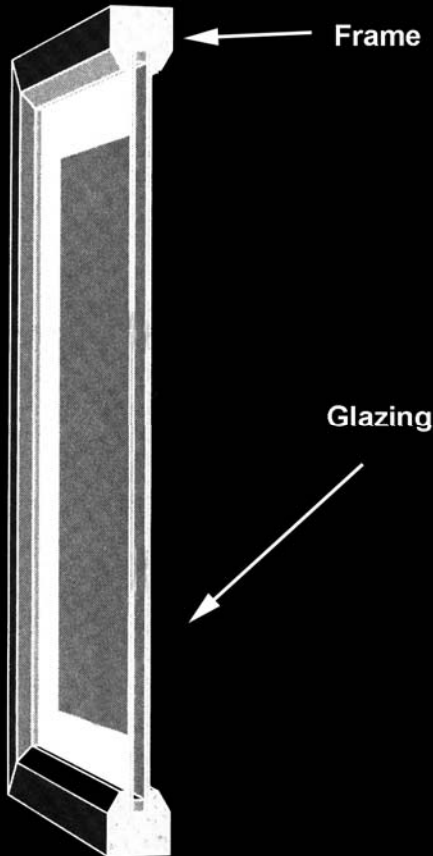
- Why are windows energy inefficient?
 - Heat loss
 - Solar heat gain
 - Infiltration

- How do you quantify performance?
 - U factor
 - Solar Heat Gain Coefficient

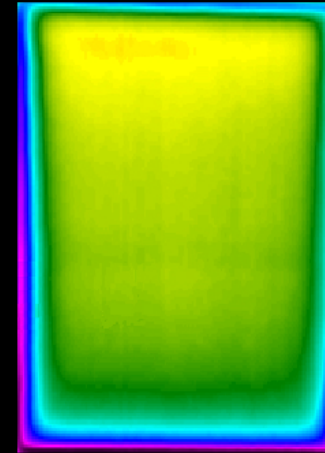


High performance window technologies

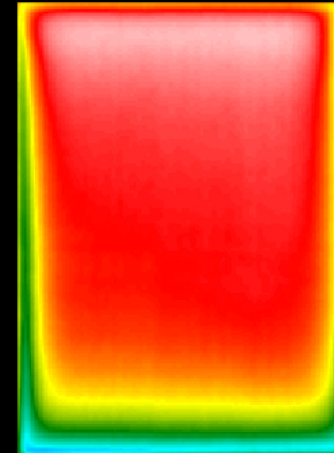
- Low – e coatings
- Spectrally selective glazing
- Insulating frames



Clear Double Pane
w/ Al frame



Double Pane, Low - e
w/ insulating frame



Sample window technologies

	<i>U – factor</i>	<i>SHGC</i>
• Bad: Single pane glass	1.00	0.70
• Good: Double pane glass with insulating frame	0.63	0.62
• High Performance: Low – e glazing	0.32	0.53 / 0.29
• <i>Crème de la crème</i> : “Superwindows”	0.18	0.40 / 0.25

Future window technologies

- Improve today's line of windows: focus on U and SHGC → “Ultra Windows”
- “Dynamic Window” concept

Energy Savings from Future Technologies

- Dynamic windows for North, Central US.
- “Ultra” windows for southern US.
- 20% lower energy consumption than today’s best.
- Windows become energy assets.

From energy to carbon

- DOE: Residential windows in US responsible for 2.9 EJ consumption.
 - 44 Tg (0.7% of global anthropogenic emissions)
 - Single Family: **32** Tg (0.5%)
- Remember this number!

Why regional analysis?

- Carbon emissions from electricity vary regionally
- Window choice regional
- Climate and home construction regional as well

- **Consequence:**
 - **Need a regional approach**

Methods: RECS Survey

DOE conducts Residential Energy Consumption Survey (RECS)

– Reports:

- Energy bills for heating and cooling for 8,000 representative homes in the US.
- Energy consumption is broken down by fuel.
- 1993 survey has extra details on windows.

Refining the Model

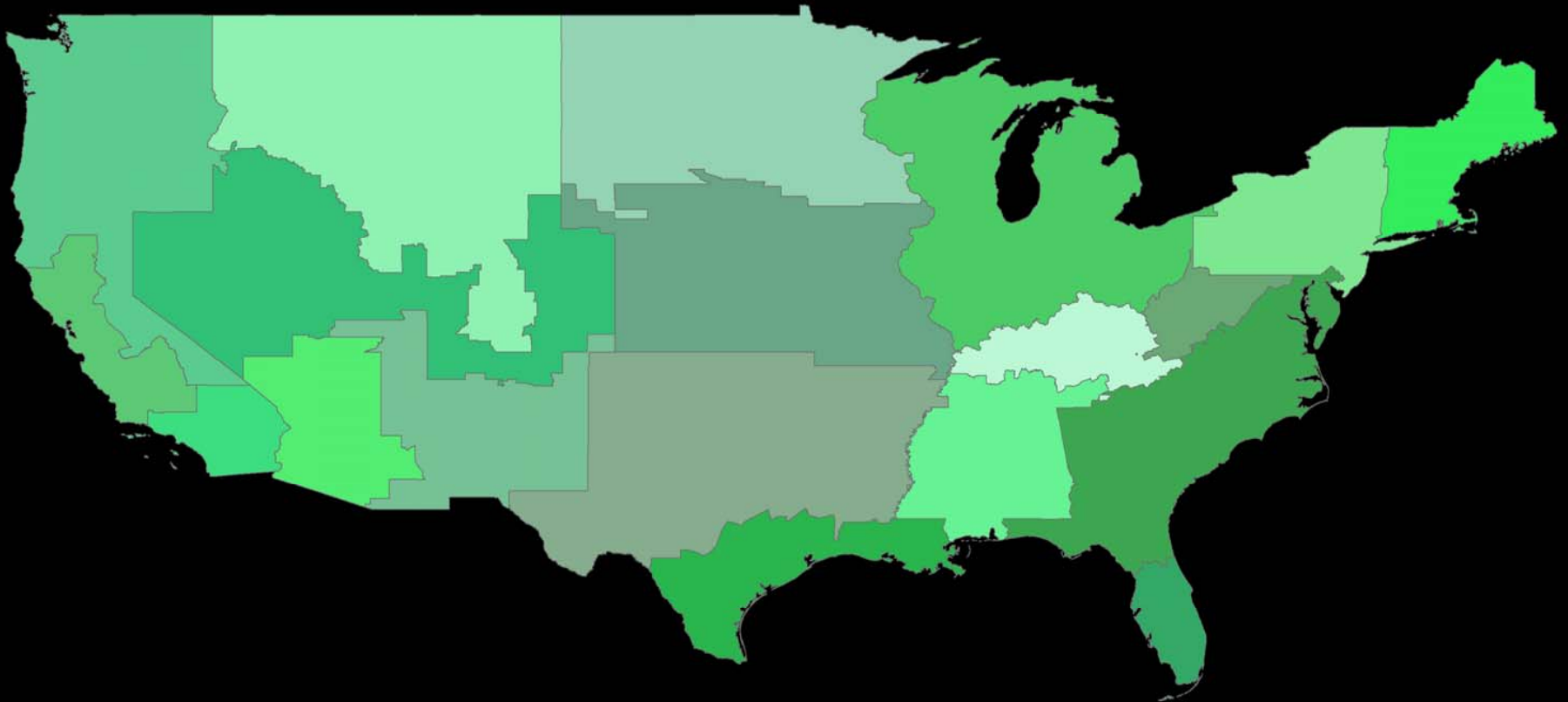
- RECS still doesn't tell us about window energy consumption.
- *How do we get this?*
- “Window Percentage”

The need for simulations

- How much of a home's heating and cooling energy consumption is due to windows?
- This should vary by:
 - *Climate*
 - *Home construction*
 - *Window Choice*
 - *All regional factors*

Analysis Regions

- Climatic and political divisions important.
- 19 regions, represented by 16 city climates



Simulation Design: DOE – 2

- Used DOE-2 energy simulation software
- “Prototype Homes” simulate regional construction for each of 16 cities.
- 8 prototype “vintages” based on RECS
 - Represent a variety of ages and sizes for homes.
- 23 Windows

Window Selection

<i>Type</i>	Aluminum		Insulated Metal		Wood / Vinyl	
	U	SHGC	U	SHGC	U	SHGC
Single Pane	1.16	0.76	1.00	0.70	0.84	0.64
Double Pane	0.76	0.56	0.63	0.62	0.49	0.56
Double Pane w/ Low E	0.61	0.64	0.50	0.58	0.37	0.53
Double Pane w/ Selective	0.59	0.37	0.47	0.33	0.29	0.29
Triple Pane	0.61	0.61	0.49	0.56	0.36	0.51
Triple Pane w/ Low E	0.52	0.47	0.41	0.43	0.29	0.38
Triple Pane w/ Selective	0.52	0.32	0.41	0.29	0.28	0.25
Advanced Technologies						
<i>Type</i>	U		SHGC			
Ultra, High Solar Gain	0.10		0.35			
Ultra, Low Solar Gain	0.10		0.1			

- 3 Major Frame types
- Range of glazing technologies from low-tech to high-performance to futuristic

DOE-2 Results

- Cooling: 6 – 98 %
- Heating: -30 – 30 %
- Combination of climate, window, and rest of home.

```
C:\WINDOWS\System32\cmd.exe
107
boma dq 3HI 130.28 4.15 1.59 -1.31 2.19 1012 79 152 134
156
boma dq 3LO 136.51 4.87 3.02 1.10 3.45 837 49 99 88
103

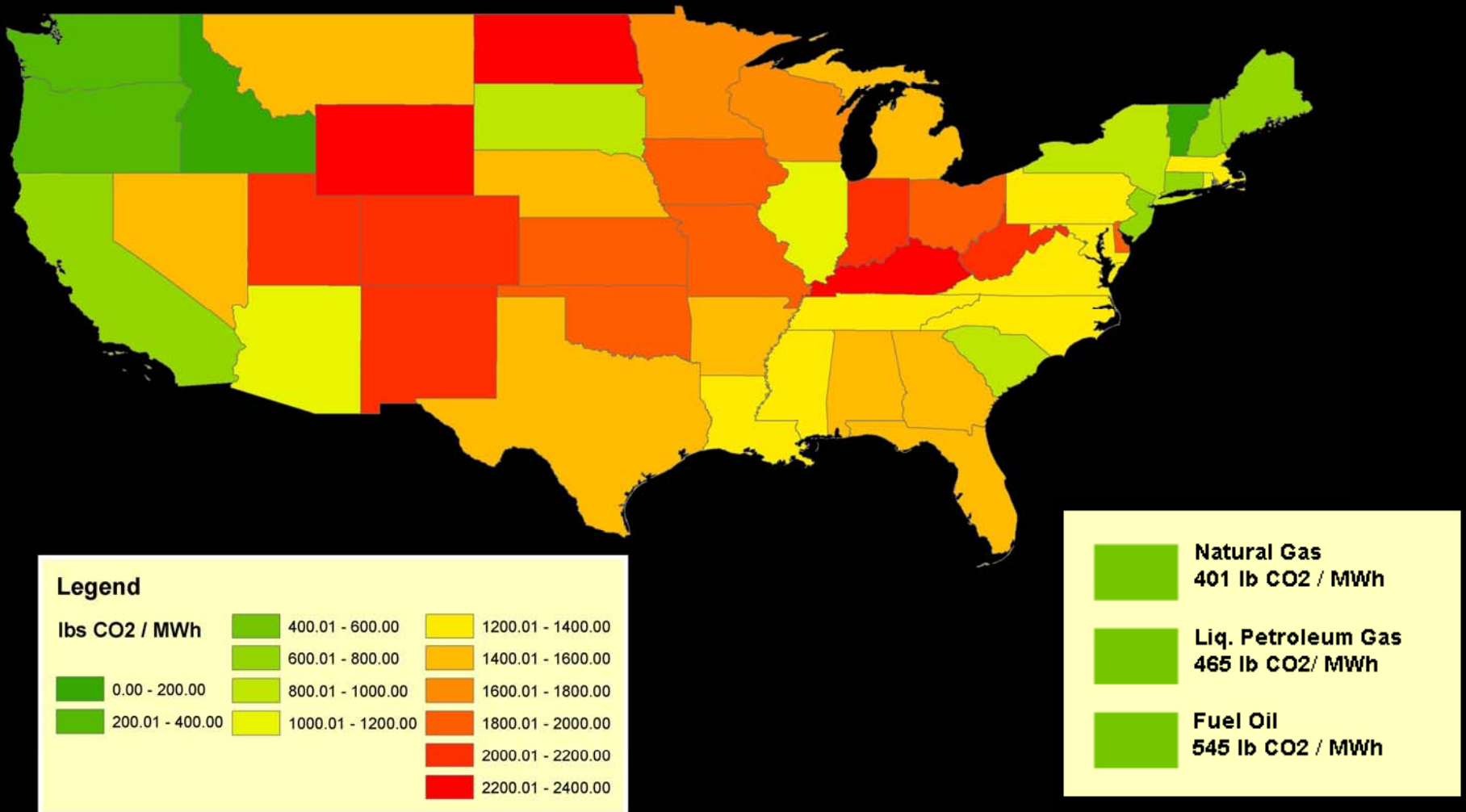
Homes were run on:
Tue 02/10/2004
04:12 PM
City Uintage Window MBtu_Heat_Total kWh_Cool_Total kWh_Cool_N kWh_Cool_E kWh_Cool_S kWh_Cool_W MBtu_Heat_N MBtu_Heat_E MBtu_Heat_S MBtu_Heat_W
boma a 2CL 170.92 5.21 3.32 1.64 3.94 1364 55 104 99
115
boma a 2HI 165.88 3.89 2.15 0.54 2.70 1351 53 101 96
111
boma a 2LO 170.15 4.28 3.17 2.22 3.52 1189 33 58 60
boma a 3HI 160.55 2.20 0.87 -0.38 1.26 1268 43 81 77
88
boma a 3LO 163.56 2.54 1.58 0.71 1.86 1170 33 54 55
64
boma a1 2CL 104.05 5.77 3.74 1.74 4.38 939 68 123 113
130
boma a1 2HI 98.42 4.28 2.40 0.50 2.95 922 67 120 109
126
boma a1 2LO 103.17 4.70 3.49 2.38 3.85 740 33 63 58
68
boma a1 3HI 92.47 2.38 0.91 -0.57 1.34 824 46 90 81
95
boma a1 3LO 95.84 2.74 1.71 0.71 2.01 718 34 58 54
64
boma b 2CL 182.03 8.49 5.27 2.19 6.23 1314 111 177 164
223
boma b 2HI 173.21 6.15 3.16 0.21 3.99 1291 111 174 161
218
boma b 2LO 180.93 6.87 4.99 3.33 5.52 1020 57 100 94
129
boma b 3HI 163.99 3.22 0.92 -1.34 1.55 1144 70 131 120
172
boma b 3LO 169.45 3.85 2.23 0.75 2.67 984 52 89 84
118
boma b1 2CL 135.18 8.89 5.69 2.46 6.68 1149 112 189 172
206
boma b1 2HI 126.04 6.51 3.56 0.46 4.42 1122 107 182 167
197
boma b1 2LO 133.68 7.17 5.28 3.49 5.82 832 55 97 92
105
boma b1 3HI 116.23 3.40 1.10 -1.31 1.71 969 83 146 135
157
boma b1 3LO 121.69 3.98 2.36 0.75 2.78 793 48 86 81
94
boma b1q 2CL 235.36 15.78 9.92 4.09 11.64 1643 197 344 321
372
boma b1q 2HI 219.03 11.43 6.00 0.38 7.47 1593 192 334 310
359
boma b1q 2LO 233.18 12.58 9.07 5.89 10.05 1087 96 170 158
184
```

From Energy to Carbon

- Variety of fuels used for heating:
 - Natural Gas
 - LPG
 - Oil
 - Electricity
- Cooling uses Electricity
- Emissions factors

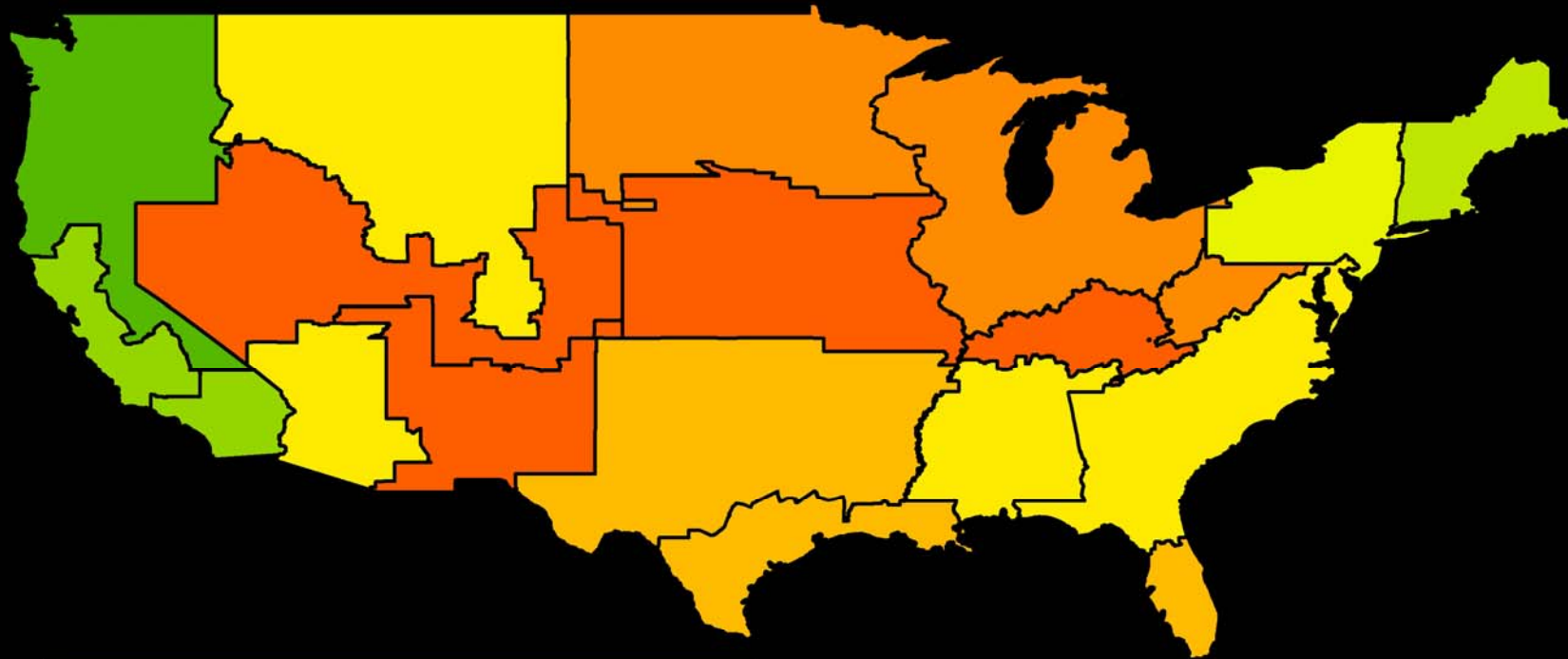
How clean is our fuel?

- Electricity varies widely and dirtier than other fuels.



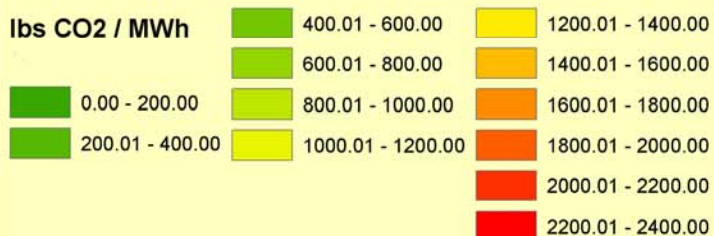
Emissions Factors: A Problem

- Solution: GIS analysis



Legend

lbs CO₂ / MWh



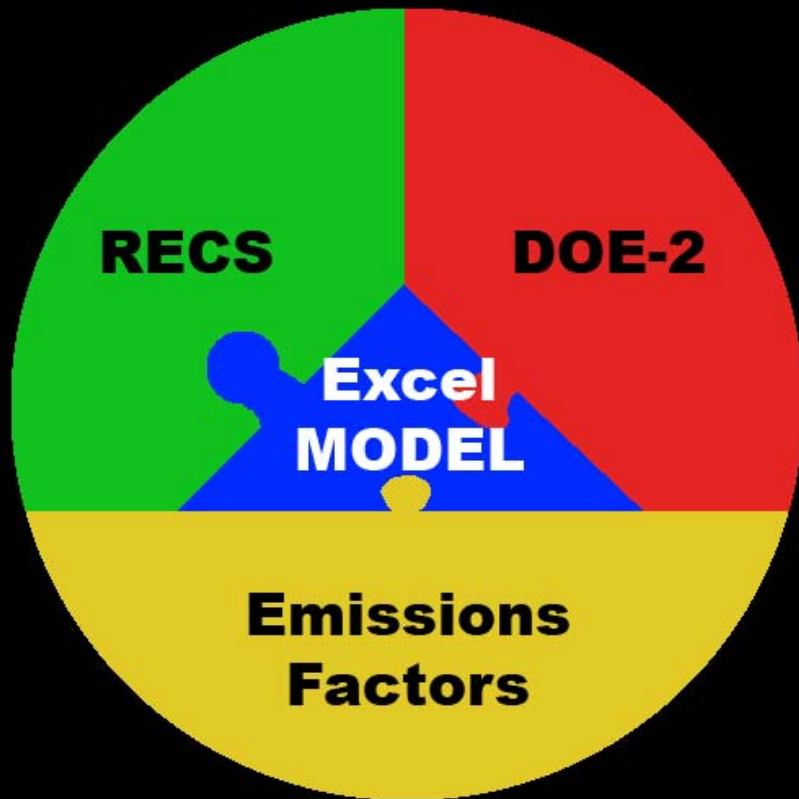
From DOE-2 to RECS

- How do we combine the data?

Energy Consumption
 \times Window Percentage

\times Emissions Factor

= Aggregate Emissions



Excel Model

Theoretically: For any home type:

Heating and Cooling Consumption \times

% of Consumption due to Windows \times

Carbon Emissions per unit of Fuel

= Total Carbon Emissions due to windows for particular home type

Do this for all home types, and weight types by their importance \rightarrow **National Total**

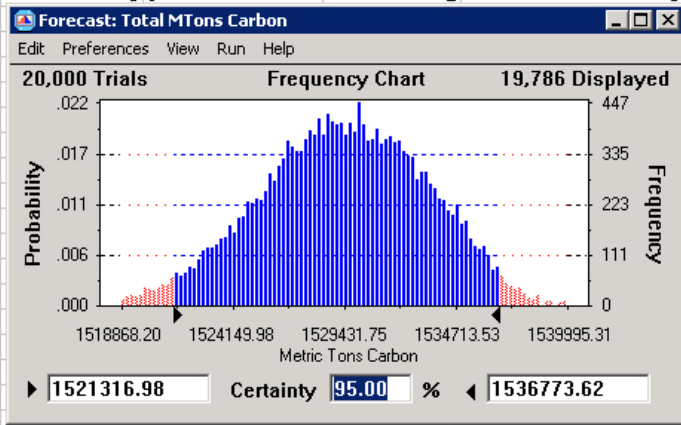
- Regional Spreadsheets

Uncertainties and Limitations of the model

Roof Imputer		Wall Imputer	
1	93%	1	85%
0	7%	0	15%

Assumptions Control Panel	
Window Replacements make a difference	0
Window Type	Dynamic
Thermal Breaks	Manual

Roof Wall Insl	A Retrofit	B Retrofit	Retrofit	Assigned Home	Main Panes	Replacement Panes	Number of Panes	Storms	T
1	1	1	1	1 b1q	2	0	2	0	1
0	1	0	0	0 b	2	0	2	0	0
1	1	1	1	0 c	2	0	2	0	0
0	0	0	0				2	0	0
1	1	1	1				1	1	1
1	1	1	1				2	0	0
1	1	1	1				2	0	0
1	1	1	1				1	0	0
1	1	1	1				2	0	0
1	1	1	1				1	1	1
1	1	1	1				1	1	1
1	1	1	1				2	0	0
1	1	1	1				1	1	1
1	1	1	1				1	1	1
1	1	1	1				2	0	0
0	0	0	0				1	0	0
1	1	1	1				1	1	1
0	0	0	0				1	1	1
1	1	1	1	1 b1	2	0	2	1	1
1	1	1	1	0 dq	2	0	2	0	0
1	1	1	1	1 b1	2	0	2	0	0
1	1	1	1	0 d	2	0	2	0	0
1	1	1	1	1 a1	1	0	1	1	1
1	1	1	1	1 b1	1	0	1	0	0
1	1	1	1	0 dq	1	0	1	0	0
1	1	1	1	1 b1	1	2	1	1	1
1	1	1	1	1 b1	1	0	1	0	0
0	0	0	0	0 b	1	0	1	1	1
1	1	1	1	1 b1	2	0	2	0	0

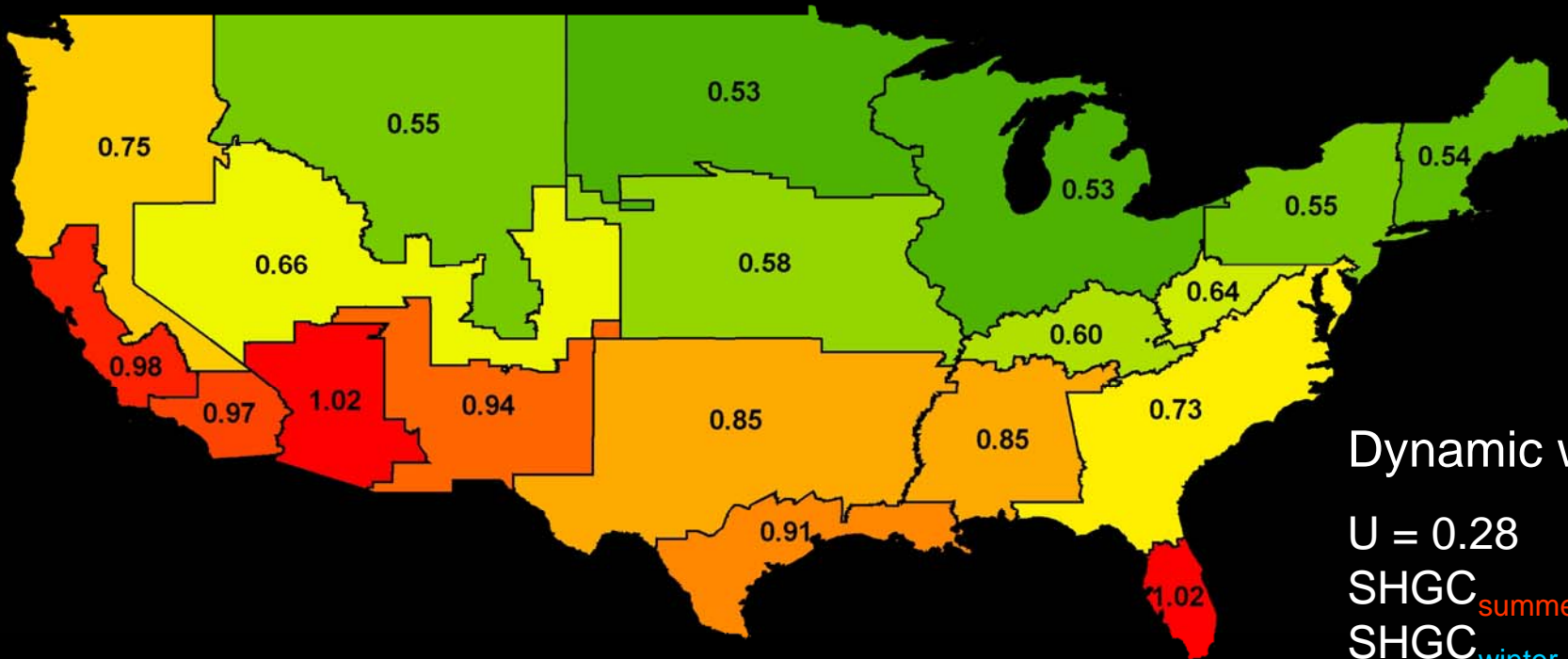


Calculating Savings

- Uncertainty higher for absolute values than relative changes.
- Calculate savings in carbon emissions
- My goals:
 - Examine potential emissions reductions from Dynamic and Ultra Windows.
- How is this done?
 - “Technical Potential”
 - “How much carbon emissions would be avoided if we replaced all windows with?”

Why are there savings?

Mean U – Factor by Climate Region



- Do improvements in SHGC or U - Factor drive energy savings?

Future tasks: Savings

- Update stock from 1993 – 2000
- More closely examine weak points in stock.
- Dynamic or Ultra? Determine benefits on regional basis.
- Create scenarios for carbon emissions reductions.

Absolute Carbon Emissions

- Preliminary result: **18 Tg / yr.**
- What is this comparable to?
 - 8 Million US Autos, driving 137 million miles/yr
 - > 5x total Carbon emissions of Rhode Island

This is smaller than the **32 Tg** I estimated earlier . . .

- Would uncertainties I have identified bring my number closer to this value?

“Emissions Savings” in Context

- Dynamic windows could avoid **7.5 Tg** carbon emissions.
 - Take 3 million cars off the road.
- Cost savings:
 - Avoid **\$11 billion/yr** in energy consumption.
 - Direct savings alone would result in payback of investment in 30 – 60 yrs.
 - Pinpoint priority areas.

Windows in Green Architecture



- Significant environmental benefits from upgrading existing window stock.
- Dynamic windows allow for more flexible design of homes.
- Upgrading of existing housing stock important.

Acknowledgements

Steve Hamburg

Rich Brown and Joe Huang, LBNL

Brian O'Neill

Jeff Albert, Lynn Carlson, Bill Jesdale

Darius Arasteh, Christian Köhler, Robin Mitchell, LBNL

Royce Fellowship Program

My parents

Margaret

CES Community

Mac104 Crew