Energy Consumption in Housing

John C. Bean

Outline

Our homes consume over 1/5th of U.S. energy

90% of which involves producing and moving heat

How that heat is moved:

CONDUCTION = Transfer of vibrational energy between atoms/molecules

CONVECTION = Movement of hot atoms/molecules to cooler places

RADIATION = Flow of energy via electromagnetic waves (e.g., as infrared heat)

Detailed analysis of how each of these mechanisms affect our homes

And the often simple & cheap things we can do to decrease their impact

Long term energy-saving strategies, including passive solar and smart(er) homes

Versus big savings available NOW via things like "condensing furnaces" and "heat pumps"
Energy Consumption in Housing

Every one of my (many) energy/environmental textbooks has a chapter on autos

Of course: they're one of the biggest ways we, as individuals, use energy!

But, strangely, only one textbook has a whole chapter devoted to housing

Despite it being the other big way that we, as individuals, use energy!

To be fair, most of those textbooks DO have chapters on heating and cooling

Which DO turn out to be the major contributors to household power use

But heating & cooling power diminish hugely in a well built & well maintained home

So today I am also going to discuss our homes, themselves

Because, with a little DIY'ing (do-it-yourself 'ing),

your home offers you your #1 way of saving energy
Where the U.S. Energy Information Administration says we use energy:

From which I generated this U.S. power consumption pie-chart:

Exports (fuels): 12.01%
Commerce: 17.93%
Residential: 21.13%
Transportation: 27.01%
Industrial: 31.48%

Source: EIA 2014 - http://www.eia.gov/todayinenergy/detail.cfm?id=16511&src=Total-b1
Where do we use that "residential" 21.13% of U.S. Energy?

Also from the U.S. Energy Information Administration (EIA):

OLD HOMES:
40% space heating / 17% water heating / 7% air cooling / 30% appliances

NEW HOMES:
30% space heating / 17% water heating / 10% air cooling / 35% appliances

http://www.eia.gov/consumption/residential/
So, yes:

*Our home energy use is mostly about heat - or its removal!*  

Old Homes: Heating + Cooling = 64% of their energy consumption  
Suggesting: 21.13% x 64% => 13.5% of TOTAL U.S. energy consumption!

New Homes: Heating + Cooling = 57% of their energy consumption  
Suggesting: 21.13% x 57% => 12% of TOTAL U.S. energy consumption!

For MIX of OLD and NEW HOMES, let's take Heating + Cooling average ~ 60%  
Accounting for 21.13% x 60% = 12.7% of TOTAL U.S. energy consumption!

Or is it in fact even more?

We need to look more closely at the ~ 1/3 "appliances" contribution:
## U.S. Department of Energy data on power of appliances

Which I’ve converted to **energy** use based on approximate time used per day:

<table>
<thead>
<tr>
<th>Device</th>
<th>Power</th>
<th>Use/day</th>
<th>Energy/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Conditioner</td>
<td>0.6 kW</td>
<td>12 h</td>
<td>7 kW-h/d</td>
</tr>
<tr>
<td>Coffee Maker</td>
<td>1 kW ½</td>
<td>1 h</td>
<td>0.5 kW</td>
</tr>
<tr>
<td>Clothes Washer</td>
<td>0.4 kW *</td>
<td>1 h</td>
<td>0.21 kW-h/d</td>
</tr>
<tr>
<td>Clothes Dryer</td>
<td>4 kW *</td>
<td>1 h</td>
<td>4 kW-h/d</td>
</tr>
<tr>
<td>Cooktop range</td>
<td>3.3 kW</td>
<td>½ h</td>
<td>1.6 kW-h/d</td>
</tr>
<tr>
<td>Dishwasher</td>
<td>2 kW</td>
<td>1 h</td>
<td>2 kW-h/d</td>
</tr>
<tr>
<td>Microwave Oven</td>
<td>1 kW</td>
<td>1/3 h</td>
<td>0.3 kW-h/d</td>
</tr>
<tr>
<td>Oven</td>
<td>3 kW</td>
<td>½ h</td>
<td>1.5 kW-h/d</td>
</tr>
<tr>
<td>Refrigerator</td>
<td>0.7 kW</td>
<td>24 h</td>
<td>1.75 kW-h/d</td>
</tr>
</tbody>
</table>

* vs. implausible MacKay statement (p. 51) that **Clothes Washer = Clothes Dryer = 2.5 kW**

Re-sorting these in energy consumption order:

<table>
<thead>
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<td>4 kW</td>
<td>1 h</td>
<td>4 kW-h/d</td>
</tr>
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<td>2 kW</td>
<td>1 h</td>
<td>2 kW-h/d</td>
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<td>3 kW</td>
<td>½ h</td>
<td>1.5 kW-h/d</td>
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<td>½ h</td>
<td>0.5 kW</td>
</tr>
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<td>1/3 h</td>
<td>0.3 kW-h/d</td>
</tr>
<tr>
<td>Clothes Washer</td>
<td>0.4 kW</td>
<td>1 h</td>
<td>0.21 kW-h/d</td>
</tr>
</tbody>
</table>

RED = All/mostly about heat
Pink = Partially about heat
Assuming my usage times are ballpark correct:

And that:
- Each home has ~ one of the above appliances
- That the RED appliances are ~ 100% about heat
- The PINK appliances are ~ 50% about heat

Fraction of the "appliance" energy consumption due to heating (or moving heat) is:

\[
\frac{7 + 4 + \frac{2}{2} + 1.75 + 1.6 + 1.5 + 0.5 + 0.3}{7 + 4 + 2 + 1.75 + 1.6 + 1.5 + 0.5 + 0.3 + 0.21} = 93.6\%
\]

Multiplying this by earlier appliance energy fractions, we then get:

Heating + Cooling + Appliance Heat => ~ 90% of home energy

~ 19% of TOTAL U.S. energy consumption!
Did I leave some things out?

Sure! Huge TV’s and HiFi systems can be big hitters, as can personal computers

Especially as these combine high power with high use times

But the energy that goes into these things must be conserved

And in our homes, almost no energy is being added to chemical bonds

Nor is very much energy being put into sound, light, radio waves

Which means that almost all of the input power ultimately ends up as HEAT

For almost all appliances & electronics: Power input ~ HEAT output

So to our textbook's rant that:

"It's NOT about every little thing, it's about every big thing!"

Let me add my rant that:

"If it isn't producing (or moving) HEAT, don't worry about it!"
So where/how *does* heat flow into and out of our homes?

On this topic, the U.S. Department of Energy maintains its almost unbroken record of offering minimally useful/detailed educational or consumer information!

But I **did** find this figure used on all sorts of British websites:

With has the unfortunate shortcoming that:

1) UK homes are built differently than in U.S.

   With thermally conductive brick & tile

2) Figure shows WHERE heat exits, but not HOW

   By heat conduction?

   By air air leakage?

   By something else?

http://www.newcastle-staffs.gov.uk/housing_content.asp?id=SXBC10-A780DDF0&cat=1403
So let's dig into heat transfer mechanisms on our own:

From high school physics: Heat energy can be transferred in one of three ways

1) **Conduction** = Transfer of vibrational energy between atoms/molecules

2) **Convection** = Movement of hot atoms/molecules to cooler places

   That is, by gravity pushing cooler (denser) gases below hotter gasses

3) **Radiation** = Flow of energy via electromagnetic waves (e.g., infrared light)

   With that radiation **emitted from** vibrating atoms & molecules

   More intense the vibration (=hotter) => More intense the radiation

   As dictated by "Black Body Radiation" laws

   (more about this in **Greenhouse Effect** [pptx / pdf / key] notes)
1) **Conductive Heat Transfer:**

"Transfer of vibrational energy between atoms/molecules"

Which transfers heat through the walls, ceilings and floors of our homes

Consider one wall/ceiling/floor: How much heat moves through it?

1) It scales with difference in temperature across it: $\Delta T$

2) It scales with its area: $A$

3) It depends on how wall/ceiling/floor is made

   Its thickness, composition, detailed design . . .

   Which is sometimes lumped into a number, $\kappa$

Yielding an equation for **Heat flow** = $\kappa A \Delta T$

Higher $\kappa$, larger area, greater temperature difference: All $\Rightarrow$ Greater heat flow
It's rewritten a bit differently when applied to buildings & housing:

1) In Europe and in engineering textbooks:

\[ \text{Heat flow} = U \ A \ \Delta T \] where \( U \) is obviously the same as \( \kappa \)

Lower \( U \) values => Lower heat loss!

**The units of \( U \)?** Inverting the equation, \( U = \frac{\text{Heat Flow}}{A \ \Delta T} = \frac{\text{Power}}{A \ \Delta T} \)

\[ = \frac{\text{Watts}}{\text{Area} \ (\text{Temperature difference})} = \text{Watts} / \text{m}^2 - \degree C \]

2) Or in the U.S. where, in housing, we're still cursed with antiquated British units:

\[ \text{Heat flow} = \frac{A \ \Delta T}{R} \] where the "\( R \) value" must just equal \( 1 / \kappa \)

Higher \( R \) value => Lower heat loss!

**The units of \( R \) value?** \( R = \frac{A \ \Delta T}{\text{Heat Flow}} = \frac{\text{ft}^2 - \degree F}{(\text{Btu} / \text{hr})} \)

\[ = \frac{\text{ft}^2 - \text{hr} - \degree F}{\text{Btu}} \] where Btu = a "British Thermal Unit" = 1055 Joules

**To convert:** Metric "\( U \) value" = \( 0.176 / (\text{U.S. } "R \) value")
Some R and U values for housing (plus their cross conversions):

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness</th>
<th>R (ft²·hr·°F/Btu)</th>
<th>U (W/m²·°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid wood door</td>
<td>2&quot;</td>
<td>0.067</td>
<td>2.6</td>
</tr>
<tr>
<td>Wood</td>
<td>1&quot;</td>
<td>0.063</td>
<td>2.8</td>
</tr>
<tr>
<td>Hard/Soft woods</td>
<td>1&quot;</td>
<td>0.9 – 1.25</td>
<td>(1.95-0.14)</td>
</tr>
<tr>
<td>Plywood</td>
<td>½&quot;</td>
<td>0.62</td>
<td>(0.28)</td>
</tr>
<tr>
<td>Sheetrock (Gypsum)</td>
<td>½&quot;</td>
<td>0.45</td>
<td>(0.39)</td>
</tr>
<tr>
<td>Fiberglass insulation</td>
<td>3 1/2&quot; / 6&quot;</td>
<td>10.9 / 19</td>
<td>(0.016 / 0.0093)</td>
</tr>
<tr>
<td>Polyurethane foam</td>
<td>1&quot;</td>
<td>6.3</td>
<td>(0.028)</td>
</tr>
<tr>
<td>Cellulose insulation</td>
<td>1&quot;</td>
<td>3.7</td>
<td>(0.047)</td>
</tr>
<tr>
<td>Single pane glass</td>
<td></td>
<td>(0.0347)</td>
<td>4.7</td>
</tr>
<tr>
<td>Single pane glass</td>
<td></td>
<td>(0.035)</td>
<td>5.0</td>
</tr>
<tr>
<td>Double pane glass</td>
<td></td>
<td>(0.0628)</td>
<td>2.8</td>
</tr>
<tr>
<td>Double Pane glass</td>
<td>20 mm gap</td>
<td>(0.10)</td>
<td>1.7</td>
</tr>
<tr>
<td>Solid brick wall</td>
<td>10&quot;</td>
<td>(0.088)</td>
<td>2</td>
</tr>
<tr>
<td>Solid brick wall</td>
<td>9&quot;</td>
<td>(0.08)</td>
<td>2.2</td>
</tr>
<tr>
<td>Insulated brick wall</td>
<td>11&quot;</td>
<td>(0.29)</td>
<td>0.6</td>
</tr>
<tr>
<td>Timber framed floor</td>
<td></td>
<td>(0.25)</td>
<td>0.7</td>
</tr>
<tr>
<td>Solid concrete floor</td>
<td></td>
<td>0.22)</td>
<td>0.8</td>
</tr>
</tbody>
</table>

1: [http://www.engineeringtoolbox.com/heat-loss-transmission-d_748.html](http://www.engineeringtoolbox.com/heat-loss-transmission-d_748.html)
3: "Sustainable Energy without the Hot Air," McKay, Chapter E, Table E.2, page 290 (UIT Cambridge 2009)
Warning / Disclaimer:

The preceding table took me hours to compile!

Not because I could not find data sources

But because they so often disagreed . . . even radically!

I ended up gathering data from three or more sources, for virtually all materials

And then tossing the outliers

Nevertheless:

Seek out additional verification before relying upon any of those data!
But how would you then use such (verified) data?

You'd add all the heat flows, as calculated from \( \text{Heat flow} = U \cdot A \cdot \Delta T = A \cdot \Delta T / R \)

So for each wall, ceiling or floor, you'd need its R (or U) value.

What if you couldn't find U/R data for your particular wall/ceiling/floor?

If you knew it consisted of \( \frac{1}{2} \)" sheetrock + 3.5" fiberglass insulation + 1" plywood

You'd ADD the R values for each of its layers (e.g., from table above):

\[
R_{\text{total}} = R_{\text{sheetrock}} + R_{3.5\text{" insulation}} + R_{0.5\text{" plywood}} = 0.45 + 10.9 + 0.62 = \textbf{11.98}
\]

U's are a bit harder to use because:

\[
U_{\text{total}} = 1 / \text{Sum} \left( 1/U_{1\text{st layer}} + 1/U_{2\text{nd layer}} + \ldots + 1/U_{\text{last layer}} \right)
\]

Above would be a "timber frame" wall built to minimal current U.S. standards.

Which is still \textbf{hugely} better than traditional British \( R_{\text{solid brick wall}} = 0.08 \)!
Next you'd need areas through which the heat is flowing

Which you'd get by measuring the areas of the exterior walls/ceiling/floors

Subtracting out the area of any doors or windows

(and later calculating their heat flows separately)

FINALLY, you'd need the temperature difference across those barriers

Which you could measure at a particular time . . . or much better:

To heat flow for a whole season, use a "degree day map"

Which integrates following quantity over a whole season:

(average inside temp. - outside temp.) x (net time spent at that difference)

With a "heating season" defined as part of year when it's colder outside

And a "cooling season" defined as part of year when it's hotter outside
Yielding degree-day maps such as this:

A heating season degree day map:

<table>
<thead>
<tr>
<th>Zone</th>
<th>Degree-days (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100 – 2000</td>
</tr>
<tr>
<td>2</td>
<td>2000 – 3000</td>
</tr>
<tr>
<td>3</td>
<td>3000 – 4000</td>
</tr>
<tr>
<td>4</td>
<td>4000 – 5000</td>
</tr>
<tr>
<td>5</td>
<td>5000 – 6000</td>
</tr>
<tr>
<td>6</td>
<td>6000 – 7000</td>
</tr>
<tr>
<td>7</td>
<td>7000 – 8000</td>
</tr>
<tr>
<td>8</td>
<td>8000 – 9000</td>
</tr>
<tr>
<td>9</td>
<td>9000 – 10,000</td>
</tr>
</tbody>
</table>

So for central Virginia, a house's total cool season **conductive** heat loss would be

For ONLY walls/ceilings/floors/doors/windows exposed to outside temperature:

\[
= \text{Sum} \left[ \frac{A_{\text{wall } i}}{R_{\text{wall } i}} + \ldots + \frac{A_{\text{floor } j}}{R_{\text{wall } j}} + \ldots + \frac{A_{\text{door } k}}{R_{\text{door } k}} + \ldots + \frac{A_{\text{window } l}}{R_{\text{window } l}} \right] \\
\times [4500 \, ^\circ\text{F days}]
\]

*Figure: "Energy – Its Use and the Environment," Hinrichs & Kleinbach, page 135 (Brooks/Cole 2013)*
How big a deal *is* such **conductive heat loss / gain**?

As noted above, I found little information on housing energy in textbooks and online. But we can look back to that **British** figure to make an estimate:

They make much heavier use of bricks and ceramic roof tiles, which makes their walls & attic/roofs MUCH more thermally conductive.

In their homes, these surfaces account for 60% of the total home heat loss.

But I'd be surprised if U.S. homes cut this below 20%.

Leaving another ~ 80% of energy loss to account for.

Thus, moving on to our next candidate:

http://www.newcastle-staffs.gov.uk/housing_content.asp?id=SXBC10-A780DDF0&cat=1403
Convective Heat Transfer

"Movement of hot atoms/molecules to cooler places as driven by gravity pushing cool/dense air below hotter/less-dense air OR by winds"

The MANY, MANY paths by which outside air can be driven into our homes

But how important can these tiny cracks/holes be?

It is estimated that a typical U.S. home experiences

1 complete home air exchange PER HOUR

In other words, every hour your furnace must:

Heat, from outside to inside temperature,

the air volume of your entire house

=> ~ 1/3 of U.S. home heating energy

Which can double when outside wind speed rises to just 20 mph!
But don't we need some fresh air?

Won't we suffocate otherwise? Or be poisoned by household chemicals?

Amer. Soc. of Heating, Refrigerating & AC Engineers (ASHRAE) had a standard of:

7 cfm/person + 1 cfm/(100 ft$^2$ of floor space)  

("cfm" = cubic foot / min)

Assume 4 people living in a 2000 ft$^2$ home (with typical 8' ceilings):

Required air exchange:  7 x 4 cfm + 1 x 20 cfm = 48 ft$^3$/min

Air volume of home: 2000 x 8 ft$^3$ = 16,000 ft$^3$

Required home air changes/hour = 60 x (48/16,000) = 0.18

In 2013, the standard was changed to 7 cfm/person + 3 cfm/(100 ft$^2$ of floor space)

New required air exchange:  7 x 4 cfm + 3 x 20 cfm = 88 ft$^3$/min

New required home air changes/hour = 0.33

Both are a lot less then the 1 full exchange/hour you're likely getting now!

My (confirming) experience with leaky American homes

Our incredibly poorly designed U.S. doors / door frames:

Our doors DO have slender rubber weather-sealing gaskets for which:

~ 0 mm squeeze => Crack for air to funnel in

~ 3 mm squeeze => Medium Compression / Good air seal

~ 6 mm squeeze => Strong Compression requiring **slamming** of door

What determines the squeeze of these gaskets? The **door striker plate**:

Which determines the point at which the door latches

So this plate should be positioned with ~ 2 mm accuracy, right?

U.S. doors are mostly factory built, complete with hinges, in a frame

But the striker plates are NOT installed, nor are holes cut for them

**Why? So that we can choose our favorite style of door latch ("lockset")**
I've owned 3 homes and built ~ 40 Habitat for Humanity homes:

It is **almost impossible** to chisel out the recess required for the striker plate.

And then drill the necessary screw holes.

With the required ~ 2 mm accuracy.

(particularly if you're **also** installing a deadbolt lockset)

Further, because buyers **DO** immediately notice the need to **slam** a door closed.

Builders err on the side of more loosely positioned striker plates.

Meaning that door gaskets range from 0 to proper compression.

**You don't believe me?**

On a windy day, run your hand down the edge of a door.

Or at dawn/dusk look at the **sunlight** coming in at edges of some doors!
My response as a DIY homeowner?

I first tried chiseling new recesses + new screw holes for the striker plates

But a NEW screw hole must be ~ 4 mm away from OLD screw hole

Meaning that new hole often => Over-compression / Need to slam door

I DID eventually find online ONE adjustable striker plate

That, in my already chewed up doorframes only sort of worked

I finally enlarged the old screw holes, and glued in replacement wood plugs

(which required buying a special "dowel/plug" cutting drill set)

And then tried to drill new properly positioned holes in the plugs

The ALTERNATIVE, RATIONAL, but still STILL CHEAP ($5 to $20) solutions?!

i) Factory-installed latches/striker-plates (you could still choose doorknobs!)

ii) Adjustable or pull-tight types of latches

(As already used in Scandinavia and other parts of northern Europe)
A further energy lesson taught to me by stink bugs:

After going through all of the above door repair/modifications

In a fairly new, fairly well built house, we were still plagued by winter drafts

Then I noticed a trail of stink bugs crawling in at a door's corner

On hands and knees I figured out HOW they were getting past the door's seal:

Proper door seals: My door seals:

To save the (miniscule) cost of miter cutting the gasket corners (i.e. "picture framing")

They just cut the pieces ~ 1" short

Leaving breezeways & bugways

At all four door corners
These weren't cheap doors (and I've seen same problem on other not-cheap doors)

My solution for this problem?

I spent an hour on the Internet identifying replacement gaskets, then

For $35 I bought enough to REGASKET every exterior door on my house

But I measured carefully AND made 45° razor blade cuts at their ends

Which took me a grand total of about 1 hour for six doors

(And would have taken door manufacturers trivial time & money!)

RESULT: My previously drafty house is no longer drafty

=> Same winter comfort at 1-2°C cooler heating temperature

Why do we Americans put up with this pennywise / pound foolishness!
Cutting **convective heat loss** is thus all about little things:

Which, in its own way, is good news

Because for **conductive heat loss**, only thing a DIY homeowner can easily do is:

- Install insulating sheets of fiberglass in attic or under crawlspace floors

Whereas for **convective heat loss** that same homeowner can:

- Caulk cracks (anywhere and everywhere!)
- Install rubber gaskets in electrical outlets located on exterior walls
- Replace door and window seals
- Or, if you are more ambitious, replace/repair door and window latches

=> Saving VASTLY more in heating costs than these DIY repairs cost you

Even saving money if you have to pay someone to do repairs for you!
Bringing us to: **Radiative Heat Transfer**

"Flow of energy via electromagnetic waves (e.g. infrared light)"

With radiation **emitted from** vibrating atoms & molecules

More intense the vibration (= hotter) => More intense the radiation

From the physics of "Black Bodies," materials naturally radiate an amount of energy:

\[ \varepsilon \sigma T^4 \]

where \( T \) is their absolute temperature,

\( \sigma \) is the "Stefan-Boltzmann Constant" = \(5.670 \times 10^{-8} \) W/m\(^2\)-K\(^4\)

and \( \varepsilon \) is the material's "emissivity"

Which for most organics, including wood & paints, is about 0.95

For an **opaque** material, the relevant temperature is its **surface temperature**

But convective heat transfer (preceding) cools **outside** surface temperature of a well insulated wall to **almost the surrounding air temperature**
Yielding infrared images like this for well-insulated homes:

Wall surfaces are at almost the surrounding temperature (above, $\Delta T \sim 1-2^\circ\text{C}$), thus:

Radiation FROM walls TO environment $(\varepsilon \sigma T_{\text{wall\_surface}}^4)$ is only a bit higher

than radiation FROM environment TO walls $(\varepsilon \sigma T_{\text{environment}}^4)$

So there's little NET radiative heat transfer from a well insulated wall

But apparent window temperatures are right off the top of the scale!

Image: http://www.nicolascretton.ch/Astronomy/Spitzer_IR_space_telescope/Spitzer.html
"Apparent window temperatures" because:

The outside surface temperature of the window glass itself is also $\sim T_{\text{environment}}$

But because glass is transparent, it passes radiative heat out from the hotter interior

Let's run some numbers from temperatures given in preceding image:

$T_{\text{environment}} \sim 14^\circ\text{C}$, $T_{\text{wall surface}} \sim 15.5^\circ\text{C}$, $T_{\text{interior}} \sim 21^\circ\text{C}$ translating to °K:

$T_{\text{environment}} \sim 287.1^\circ\text{K}$, $T_{\text{wall surface}} \sim 288.6^\circ\text{K}$, $T_{\text{interior}} \sim 294.1^\circ\text{K}$

Net heat loss per square meter (assuming all emissivities $\sim 0.95$):

Heat thru wall to environment: $\varepsilon \sigma (288.6^4 - 287.1^4) \ W = 7.7 \ W / \text{m}^2$

Heat thru window to environment: $\varepsilon \sigma (294.1^4 - 287.1^4) \ W = 37 \ W / \text{m}^2$

**5X more radiative heat (per area) from windows than walls!**

So radiative heat transfer is almost all about windows!
Windows are **intended** to pass visible light:

But most **radiative heat transfer** occurs at invisible infrared (IR) wavelengths.

Do normal plate glass windows transmit infrared light? **Yes!**

Some glasses do **absorb** IR: Summer sun would then heat outer glass, which would help if you still had cooler inner pane(s) of glass.

http://www.shimadzu.com/an/industry/ceramicsmetalsmining/chem0501005.htm
But you can also **reflect** part of **all** light colors:

By making your windows into partial mirrors (that are, for instance 25% reflective)

During the day you'd hardly notice if light from the outside was 25% dimmer

And if you did notice, you'd probably end up appreciating it

A night, from outside, your inside lights would appear 25% dimmer

Optical tricks can **ALSO** produce **stronger** reflection in **only** the infrared:

Done by setting up destructive or constructive interference of light waves

from surfaces of additional, very thin, **metal coating-layers**

Sum of all 3 tricks (absorption + all color reflection + enhanced IR reflection)

=> **“Low E” Glass & Windows**

Where "E" again stands for **emissivity** = surface's efficiency at emitting light
Transmission of Low E glass / windows:

Now based more on changes in reflection, rather than absorption:
Energy savings with low-E windows?

Here I (finally) found some semi-useful info from the U.S. Department of Energy: 1

"On average, low-e storm windows can save you 12%–33% in heating and cooling costs. This Equates to $120–$330 in annual savings, assuming a $1,000 annual heating/cooling bill."

Then working a bit with the Home Depot purchasing app:

- Home Depot brand double-hung NON Low-E windows ran ~ $200 each
- Anderson brand double-hung windows, all Low-E, started at ~ $400 each
- I doubt that simple low-E process cost more than $50 of the added $200 per window

IF Department of Energy's "typical" U.S. house had 15 such windows:

- To replace with Low-E windows => 15 x $400 = $6000 => 20-40 year payback
- To build with Low-E windows (assuming my $50 ΔP is correct) = $750 cost

Which would mean an energy savings payback in as little two years

So that's how normal homes loose/gain heat

But what about abnormal PASSIVE SOLAR HOMES?

These attack home heating and cooling losses point by point:

To deal with CONDUCTIVE Heat Transfer:

WALLS: Go from 2x4 wood-framed walls to 2x6 or 2x8 framed walls

Space for insulation goes up by ~ 50-100%, as does R value

Cutting wall heat loss by 33-50%

CEILINGS and FLOORS: Just pile on more fiberglass insulation blankets

WINDOWS: Move from double to triple pane glass
To deal with **CONVECTIVE** Heat Transfer:

**Passive solar homes:**
- Use ultra-tight-latching doors and windows
- Seal all remaining cracks and holes
- Wrap whole house in wind impermeable "house wrap" (e.g., "Tyvek")

**Potential Problem:** House’s air changes may fall below desirable 1/3 per hour

In which case you add an **"air-to-air heat exchanger"**

Which pushes inside air out, and outside air in:
- Forcing them to pass closely, ~ averaging temperatures
- So incoming air gets ~ **halfway** to inside air temperature

Thus ~ halving load to furnace/AC/heat pump
Finally, to deal with **RADIATIVE** Heat Transfer:

Passive solar homes reduce heat absorbed from sun by painting walls light colors.
And similarly reduce heat to roof by abandoning black shingles for lighter shingles.

**But then passive solar homes make bigger changes:**

Add passive water heater on south facing roof, saving most of the 17% of residential power now used by water heaters.

But don't use low-E windows - instead size and locate windows to:

**Capture** solar heat in the winter, but **avoid** it in the summer.

How? Some new type of selectively mirroring window? No (at least not yet).

**Instead, just redesign window overhangs and re-orient house:**

The “five elements of passive solar design:”

1) Vast majority of window **APERTURES** should be on south face (for U.S. homes)

2) Then **CONTROL** entry of solar radiation into windows via roof overhangs

   Allowing only low winter sun to reach window, but not higher summer sun

   (And **don’t** use Low-E glass to block infrared heat from that winter sun!)

3) Inside those windows install dark **ABSORBER** surfaces to collect that winter IR
The “five elements of passive solar design” (continued)

4) Beneath those absorbing surfaces install **THERMAL MASS**

   Things like stone or concrete that **absorb a lot of energy** as they heat up

5) Then provide for **HEAT DISTRIBUTION** from those thermal masses

   So that when sun sets, heat from thermal mass is distributed throughout home
An early example of U.S. passive solar homes:

The “Betatakin Cliff Dwelling” I photographed on a late May afternoon in Arizona:

Built by the Anasazi’s ~1000 years ago (all across Arizona & New Mexico)

Not generally in the cliff (as for defense), but at the base of an overhanging cliff

Facing to the south (or sometimes southwest)

Where houses would ONLY get DIRECT sunshine in the winter

Which would then heat the houses AND the surrounding stone

In other words, they nailed the whole idea of passive solar design!
So why can’t **WE** now “nail” the use of passive solar design?

**You DO need to aim most of your windows southward:**

Which, if you didn’t want to be staring at the side of your neighbor’s house

Means that houses should probably lie on ~ east to west streets

So south would be out toward either front yard or back yard

**But the rest is really easy (simple and cheap):**

- Overhanging roof on south face of house
  
  - Dark light-absorbing stone or concrete floors in south facing rooms
    
    - Air circulation to share stored heat with other rooms

- Plus well insulated and light-colored roof and W/N/E walls to shed summer heat

**Which could give many/most of us low to no heating & cooling houses**

**Saving 2/3 of the residential 21.13% of total U.S. power consumption!**
But back to the more normal homes most of us now live in:

Where we must still use energy to generate winter heat, and get rid of summer heat.

Recall the governmental data I cited at beginning of this talk:

Winter heating alone => 30-40% of U.S. residential power consumption

And how do we typically produce such heat?

By passing electricity through "resistor" heating elements

OR by burning hydrocarbon fuels in furnaces

How efficient are these processes (and how might they be improved)?

Resistive heating elements already convert electricity to heat VERY efficiently

But then the problem is at our still dominant fossil-fuel power plants

Which can convert fuel energy to electrical energy at only ~ 33% efficiency
What furnaces burning fossil-fuels right in our home?

They are now much more efficient than fossil-fuel power plants!

Types of furnaces (and percentage of such models) vs. heat delivery efficiency:

So what IS a condensing furnace, and why are they ~ 15% more efficient?
Non-condensing (conventional) vs. condensing furnaces:

Both have a central chamber where fuel burns with incoming house air (white)

Producing "exhaust" = very hot air + water vapor + byproducts = Orange

Beside which, other house air passes, picking up some of this heat

Producing warm air to be returned to house = Pink (warm) / Red (warmer)
But in condensing furnace, **exhaust loops back** to pass by incoming air:

That exhaust contains water vapor

Cooled by incoming house air, its water vapor **condenses** into liquid water

Water vapor then gives up its "heat of vaporization"

Which is partially absorbed by incoming house air

**Pre-heating** house air, before it passes burn chamber

This **also** cools the exhaust enough that a brick chimney is no longer required

It is replaced by small blower + PVC plastic pipe

Elimination of chimney = Big cost reduction AND

PVC pipe allows furnaces to be placed in more efficient locations
But there is an even newer and radically more efficient heating alternative!
Heat Pumps:

A LOOP of copper piping, with a very narrow segment at one point (capillary/valve)

Plus "heat exchanger" zig-zags inside house (left), and outside house (right)

Filled with "coolant" that normally boils at around room temperature

Purpose:

Pump pressurizes "coolant" gas entering house, causing it to condense into liquid

Losing heat TO inside air

Leaving house, liquid sprays thru restriction

Droplets gain heat FROM outside air

Converting coolant back to gas

(and process repeats over and over)
But wait, doesn't that sound a lot like **Air Conditioners**:

A LOOP of copper piping, with a very narrow segment at one point (capillary/valve)

Plus "heat exchanger" zig-zags inside house (left), and outside house (right)

Filled with "coolant" that normally boils at around room temperature

**Purpose:**

Pump pressurizes "coolant" gas leaving house, causing it to condense into liquid

**Losing heat TO outside air**

Entering house liquid sprays thru restriction

Droplets **gain heat FROM inside air**

Converting coolant back to gas

(and process repeats over and over)
Yes, they are the same with just the pumping direction reversed!

So you "kill two birds with one stone" saving on equipment

But it's even better when you look at the heating cycle:

With fuel-burning heater, you get 0.8-0.95 Watts of heat per 1 Watt of fuel energy

With heat pump, ~ only energy used is to power coolant pump

That pump delivers 3-4 Watts of heat per every 1 Watt it uses =>

80-95% furnace efficiency vs. 300-400% heat pump efficiency

Hold it! How can anything be 300-400% efficient?

Energy going into the pump is not producing the heat, it's just moving it

So think of a heat pump as a "heat transportation system"

And, with optimized design, transportation systems can be quite efficient

Shortcomings?

Heat pump heating efficiencies fall as outside temperature decreases

Because it's harder to pick up heat from that colder outside air

Note: Here a "ton" is antiquated U.S. way of rating heating/cooling capacities

Defined by cooling power once provided by melting 1 ton of ice

Figure: http://www.watkinsheating.com/blog/heat_pump_operation_102/
Leading to heat pump usage maps like this:

Which recommended adding electric heating elements in colder climates despite low efficiency of those elements (due to ~33% efficient power plants).

But more modern fix is to add back in a fuel burner

This produces what is called a "hybrid" heat pump in which:

For outside temperatures below ~ 45°F, heat pump shuts down

And fuel burner takes back over the heating

Remember: Burners = 80-95% efficient (vs. overall electric heat figure of < 33%)

My hybrid heat pump also has an inside heat exchanger that was carefully optimized to condense out more water from humid summer air

This made that air much more comfortable

and led us to increase summer inside home temperatures by 2-3°F

When I replaced my Furnace + AC with a Hybrid heat pump:

My heating/cooling bills dropped by more than 1/3

A level of savings also cited on official / governmental websites
Other potential energy saving "big hitters?"

What about all of our appliances?

Which government figures say account for ~ 1/3 of residential power use?

Motors: They can be big energy users, but they are already highly efficient

So only alternative here is to settle for lower powered appliance motors

As Europe did in recent ban on high power vacuum cleaners

But most home motors are just not used enough to matter very much

"Vampire Chargers" as decried by our textbook's cited UK politicians?

McKay: "It's NOT about every little thing, it's about every big thing!"

Chargers ARE now "little things" wasting very little power

Because, as explained in my Renewable Distributed Grid note set:

Cool semiconductor AC/DC conversion circuits replaced hot transformers
Instead identifying heat-seeking targets based on my rant that:

"If it isn't producing (or moving) HEAT, don't worry about it!"

Eliminate hot incandescent light bulbs:

Wonder of wonders, the U.S. Congress has already banned them!

Buy "Euro" style front loading clothes washing machines:

Hold it! Earlier DOE data said these used only 400W, for short periods

Yes, but they are followed by dryers consuming 4000W, for longer

But to save water, new washers don't just drown clothes in volumes of rinse water

They add a little water, then spin like crazy to remove that water

As a result, clothes leave the washing machine MUCH less wet

Thus requiring ~½ the time in the energy hogging dryer!

In another of their almost useless, never more than one page long postings, the U.S. Department of Energy cites a 70% energy savings for new washing machines.

But it's typically vague as to if this is for washers alone, or washers plus dryers

1) http://en.wikipedia.org/wiki/Induction_cooking
Continuing on our heat-seeking mission:

**Induction cook top ranges:**

For normal ranges, hot air quickly passes by pots/pans, then moves into the room. According to tests, the fraction of heat transferred to pots/pans is **44%** for gas burners.

**Induction ranges** substitute "coils" (see [Magnetic Induction](http://en.wikipedia.org/wiki/Magnetic_induction) notes) which create pulsed magnetic fields that only excite electrical currents (and thus heat) in nearby metals. So their heat transfer efficiencies test at up to **74%** (with manufacturers claiming up to **84%**).

**BUT NOTE** (as in this carefully composed advertising photo):

You can put your hand on an induction cook top, but you better not be wearing any metal rings!

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Less dramatic, but nevertheless high impact:

Incrementally improved but particularly high use/energy appliances:

For instance, Water heaters, refrigerators, and air conditioners

As improved via better burners, insulation, coolant cycles, etc.

These are used so heavily (most of them almost constantly) that result is:

Water heaters alone now account for 17% of our U.S. residential power

Air Conditioner's topped my estimated household energy list at 7 kW-h/day

Followed by clothes dryers (which I've already discussed above)

And below that, refrigerators at 1.75 kW-h/day

Dramatic energy and money savings can thus be achieved by replacing an old unit with a newer "Energy Star" design that is only 10-20% more efficient

1) http://en.wikipedia.org/wiki/Induction_cooking
Figuring out appliance by appliance savings impact is difficult

But here is what California has achieved with incentives / regulations:

http://berc.berkeley.edu/californias-classic-chart-really-caused-energy-savings/
Federal government has also gotten into appliance improvement:

In the form of "Energy Star" labeling

Telling you how many $ you can save by buying a better appliance

AND in **new homes** builder's are required retain such labeling

So READ (and pay serious attention to) THESE LABELS!

However, did YOU know washing machine choice could save big dryer expense?

That still came as a surprise to me!

Suggesting HUGE energy saving opportunities via public education

Knock, knock, knock: U.S. Department of Energy, wake up (damn it)!
Even more could be done via state-mandated home building codes

Because:

1) We consumers seldom know enough to make such home construction decisions

   Didn't parts of my long home-owning experience surprise you?

2) OR we lack the leverage over builder's choices to ensure that they choose well

   Builder's often ignore single purchaser's requests or overcharge for them!

So despite prevailing anti-big-government / don't tread-on-me sentiments

I strongly suggest following the lead of states such as California:

Incorporating more energy saving requirements into home building codes

We could also require landlords to separately bill for an apartment's energy use

   Also requiring them to divulge recent charges to be would-be renters

   Which would incentivize construction of energy-efficient apartments
Independent of saving energy, what about saving the planet?

For even the SAME energy use,

we could significantly reduce our CARBON FOOTPRINT

by shifting energy usage AWAY from peak evening hours

HOW/WHY?

Evening "peak power" requires special "peaking power plants"

Which, because they only produce power for a couple of hours a day,

must be both very fast-starting and very cheap ("low capital cost")

Today that means that they likely burn natural gas, and do so in the dirtiest way:

Via lower efficiency single cycle gas turbines ("OCGT")

(for more info, see The Grid (pptx / pdf / key) & Fossil Fuels (pptx / pdf / key) notes)
Motivating & Facilitating such a Shift in Energy Consumption:

MOTIVATION can be provided just by forcing us to pay more for evening power

Which IS in fact considerably more expensive for power plants to produce

FACILITATION is commonly suggested via either:

1) Using **Smart Appliances** + **Internet of Things**

   to *INFORM* us of costly evening power use (hopefully leading us to curtail it!)

   OR:

2) Using **Smart Grid** + **Internet of Things**

   to give *power companies* the ability to *CONTROL* our evening power use

But these raise serious efficacy, security, and privacy concerns

Leading me, in **Smart Grid** (*pptx* / *pdf* / *key*) notes, to make some alternative suggestions
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This set of notes was authored by John C. Bean who also created all figures not explicitly credited above.

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