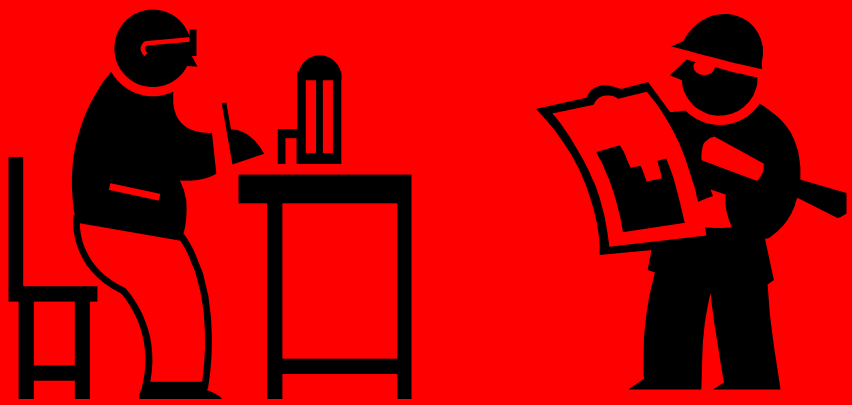
Integrated Design: Because Nothing Persists Longer Than Bad Design

NTAEE
Jul 16, 2015



Paul Westbrook
Sustainable Development Manager, LEED AP
Texas Instruments Facilities
Senior Fellow, US State Department Energy & Climate Partnership for the Americas (ECPA)

Texas Instruments

Outline

- Sustainability
- Integrated design defined
- Residential case
- Commercial/Industrial case

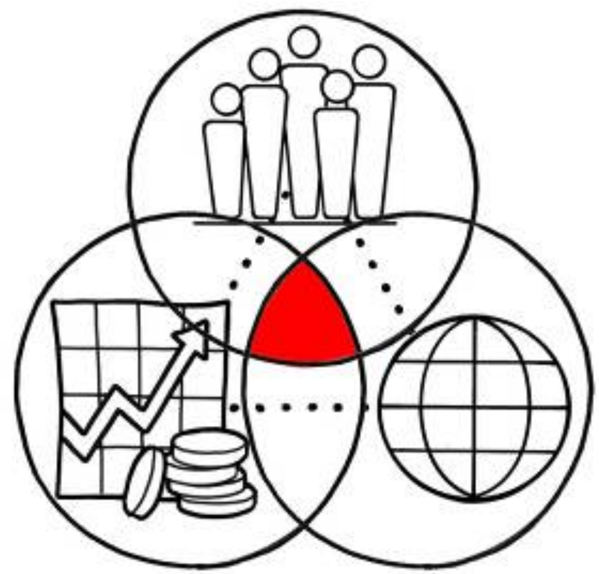
Sustainability Defined

- Official Definition

Brundtland Commission of the United Nations, 1987

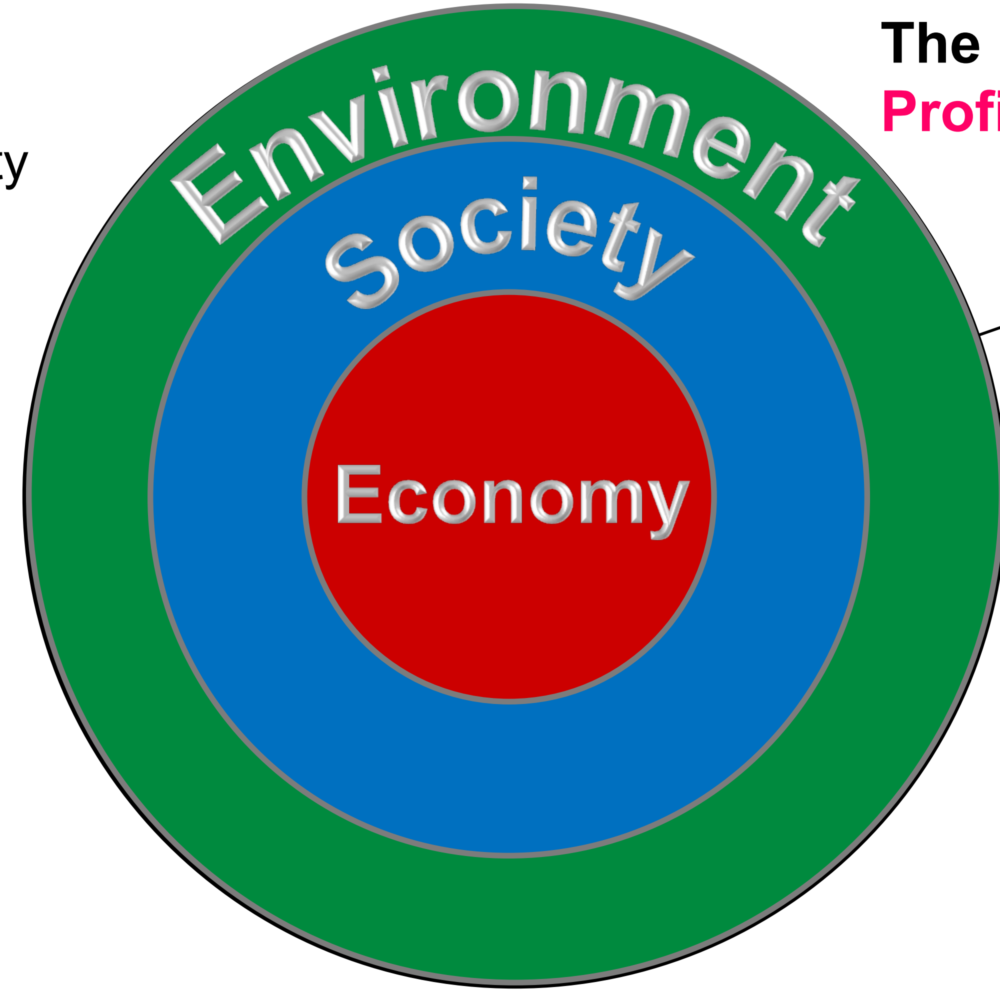
Simply stated . . .

The balance of people, profit, and the planet



Sustainability Diagram

Environmental Sustainability
Ecosystem Integrity
Carrying Capacity
Biodiversity



The balance of People, Profit, and the Planet

Human Well-Being

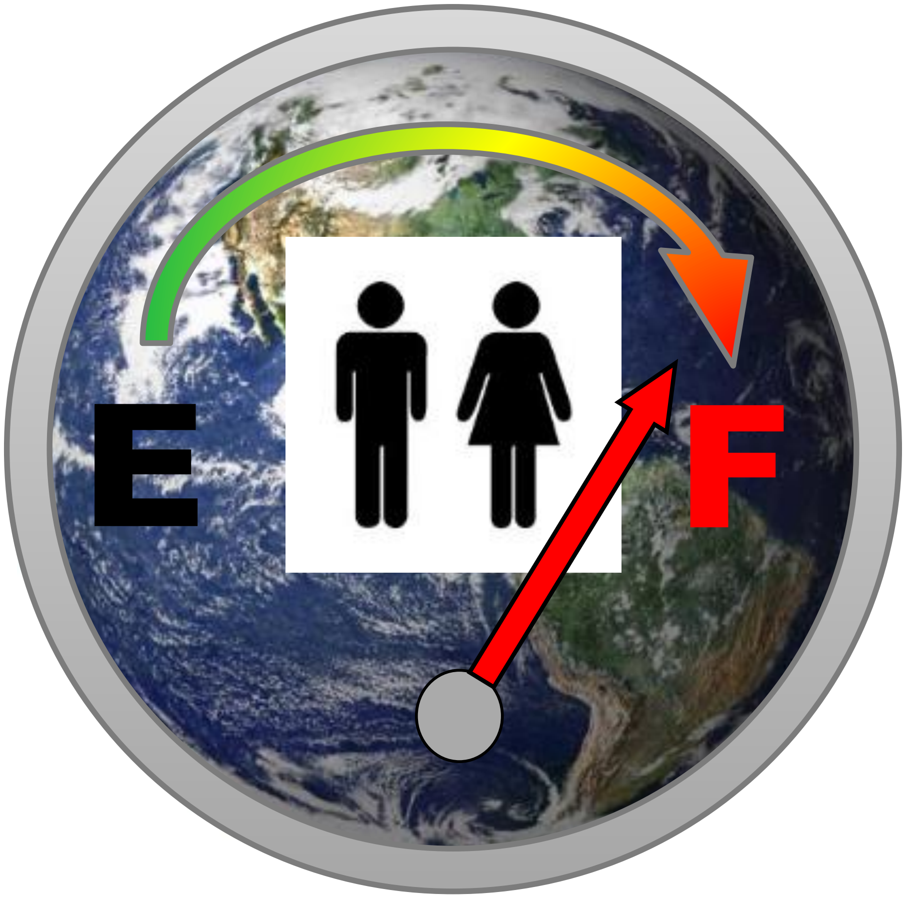
Economic Sustainability
Growth
Development
Productivity

Social Sustainability
Cultural Identity
Empowerment
Accessibility
Stability
Equity

A sustainable system delivers services without exhausting resources. It uses all resources efficiently both in an environmental and economic sense.

Planet Capacity

Human Population



Available Resources

Sustainability Defined

- What does sustainability mean for businesses?

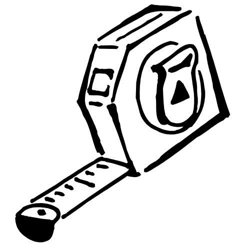
"The promise of business, is to increase the general well-being of humankind through service, a creative invention and ethical philosophy. Making money is, on its own terms, totally meaningless, an insufficient pursuit for the complex and decaying world we live in."

Paul Hawken, The Ecology of Commerce

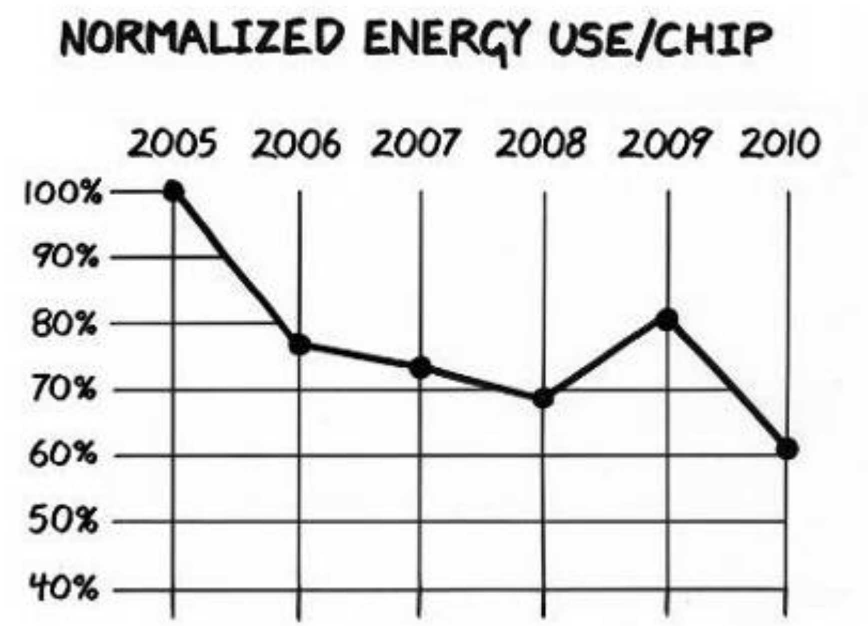
TI Mission Statement: Texas Instruments helps customers solve problems and develop new electronics that make the world smarter, healthier, safer, greener and more fun.

Measurement

- Does anyone have a sustainable measuring device?



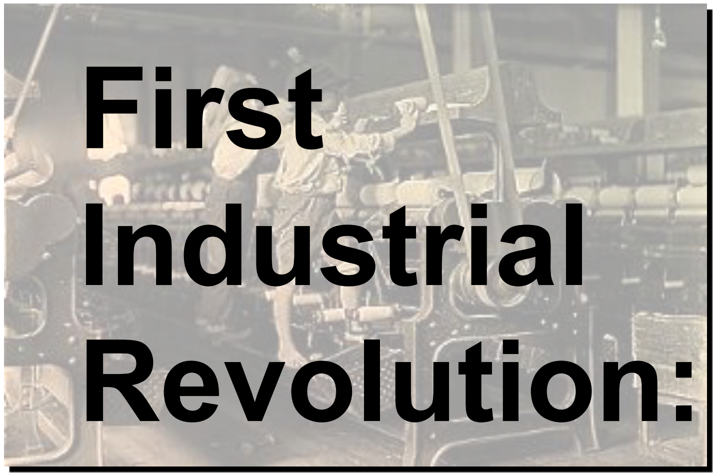
- Measurement is easier when broken into the major components:
  - Planet Factors
    - Energy
    - CO2
    - Emissions
    - Water
    - Materials
    - Waste



- Data can be normalized against square footage, units produced, weather, etc.
- Data is tracked over time and shared with employees to engage their assistance

Revolutionary Idea

Natural Capitalism



First Industrial Revolution:

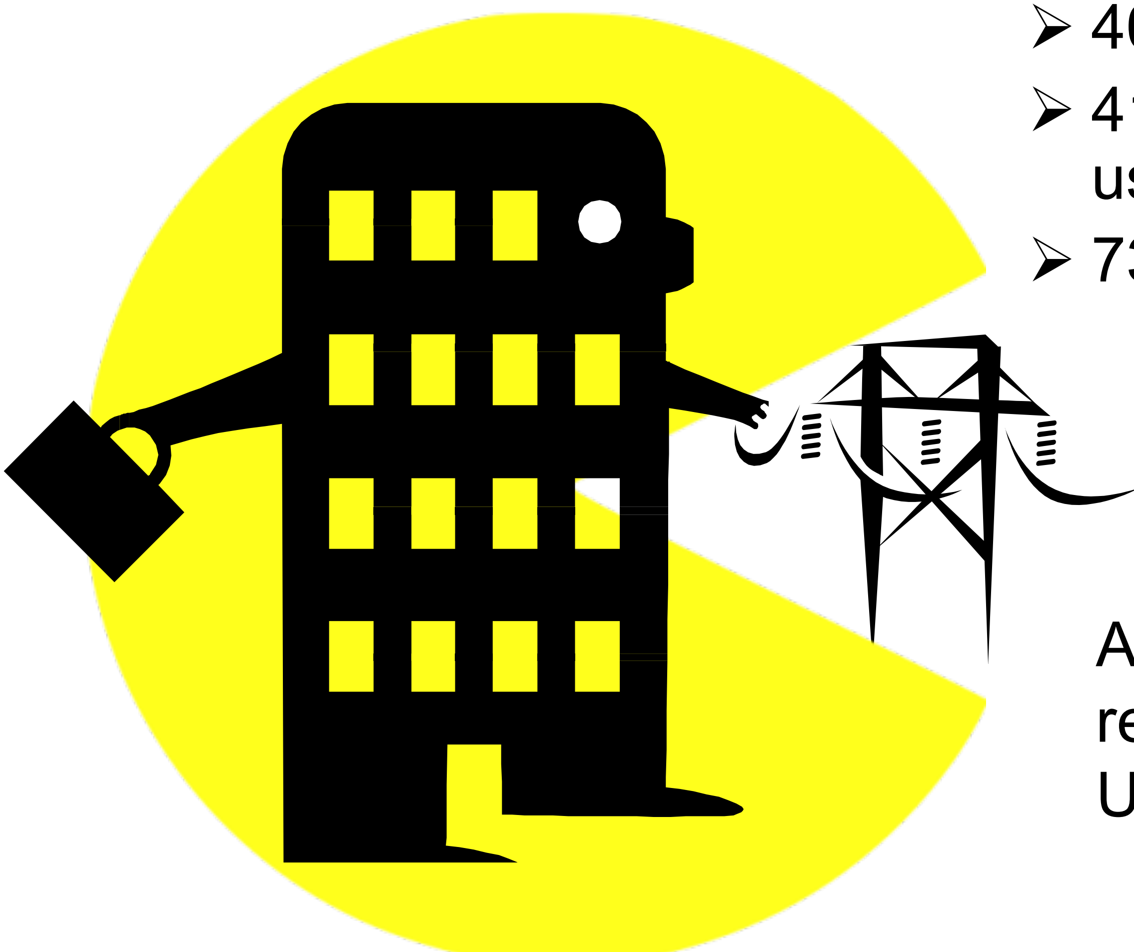
People are scarce and nature is abundant – increase labor productivity

Next Industrial Revolution:

People are abundant and nature is scarce – increase **resource** productivity

REUSE
REDUCE
RECYCLE

Buildings



Buildings consume:

- 14% of the potable water
- 40% of the raw materials
- 41% of all primary energy used in the US
- 73% of all U.S. electricity

And buildings are responsible for 38% of all U.S. carbon emissions

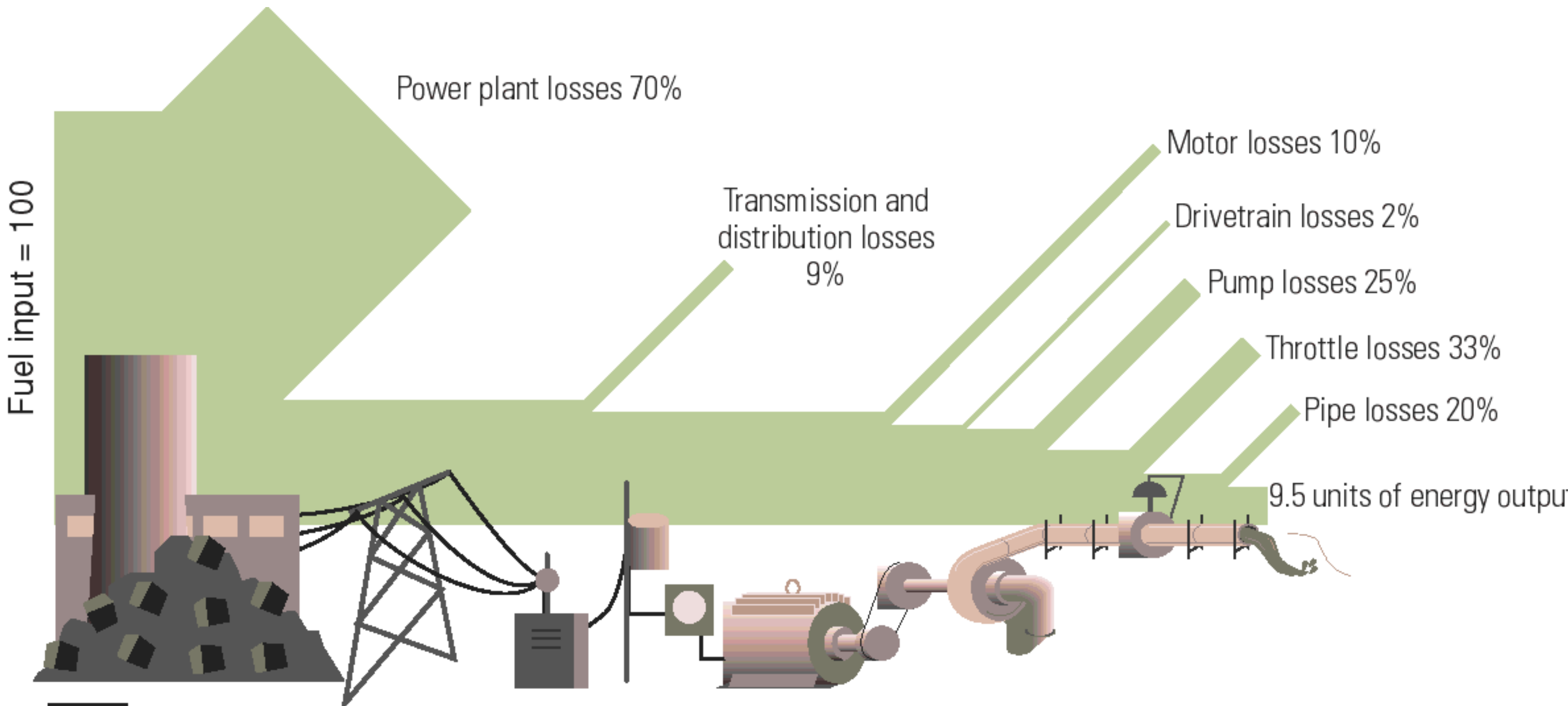
Source: 2012 USGBC

Energy Efficiency

The First Step

Texas Instruments

Losses and Waste



From the *Drivepower Technology Atlas.*
Courtesy of E SOURCE, www.esource.com.

The Negawatt

Negawatt (n) - a measure of energy efficiency; a unit in watts of energy saved

Solar and wind may be sexy . . .





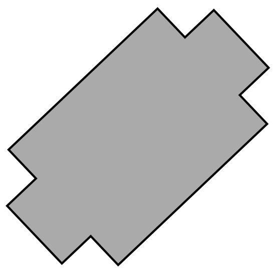
. . . but efficiency yields the best financial and environmental benefits

Integrated Design

An iterative, non-linear process

Typical Linear Design Process

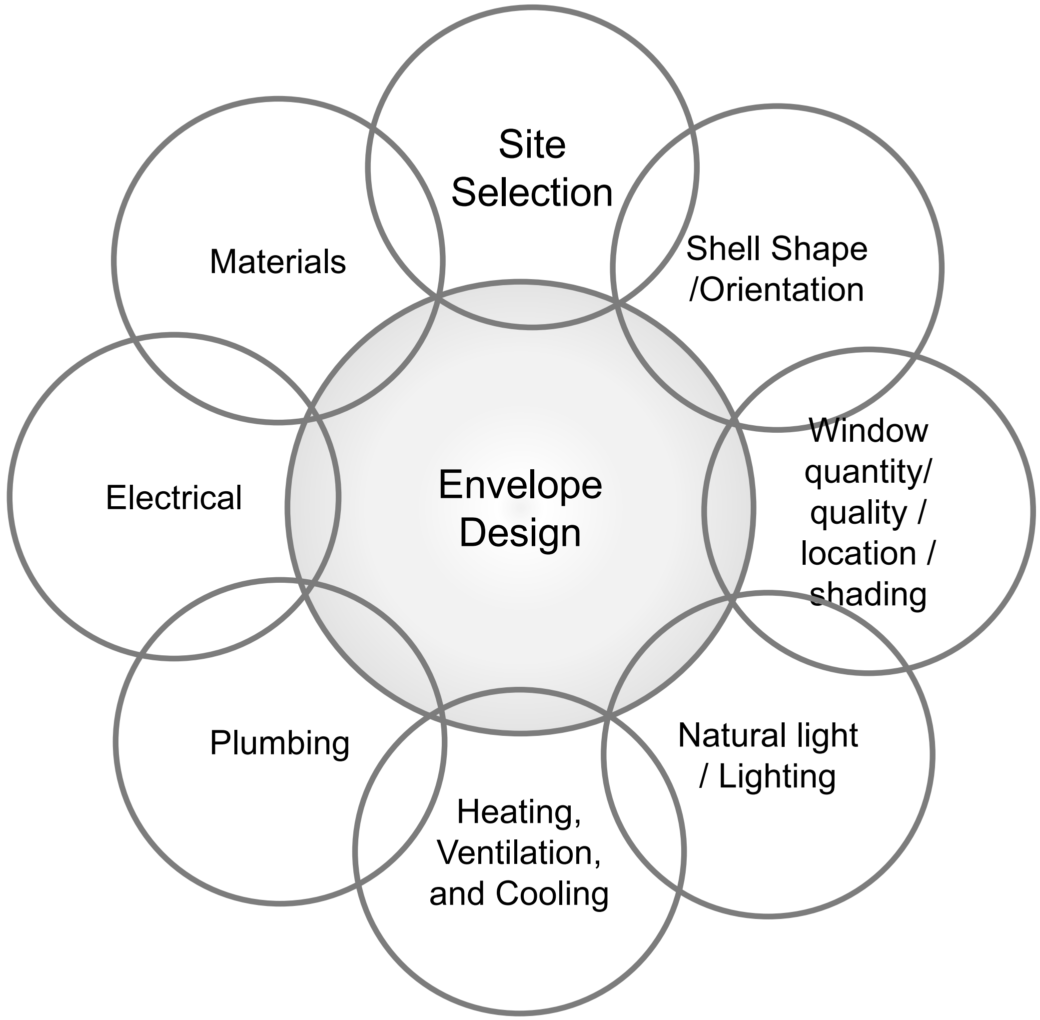
1. Architect draws up design



2. Everyone else makes it work:
- High cooling load window locations
- No room for ductwork
- Excessive materials use / waste
- Poor daylighting

. . . Over budget,
then "value engineering" occurs

Integrated Design Process

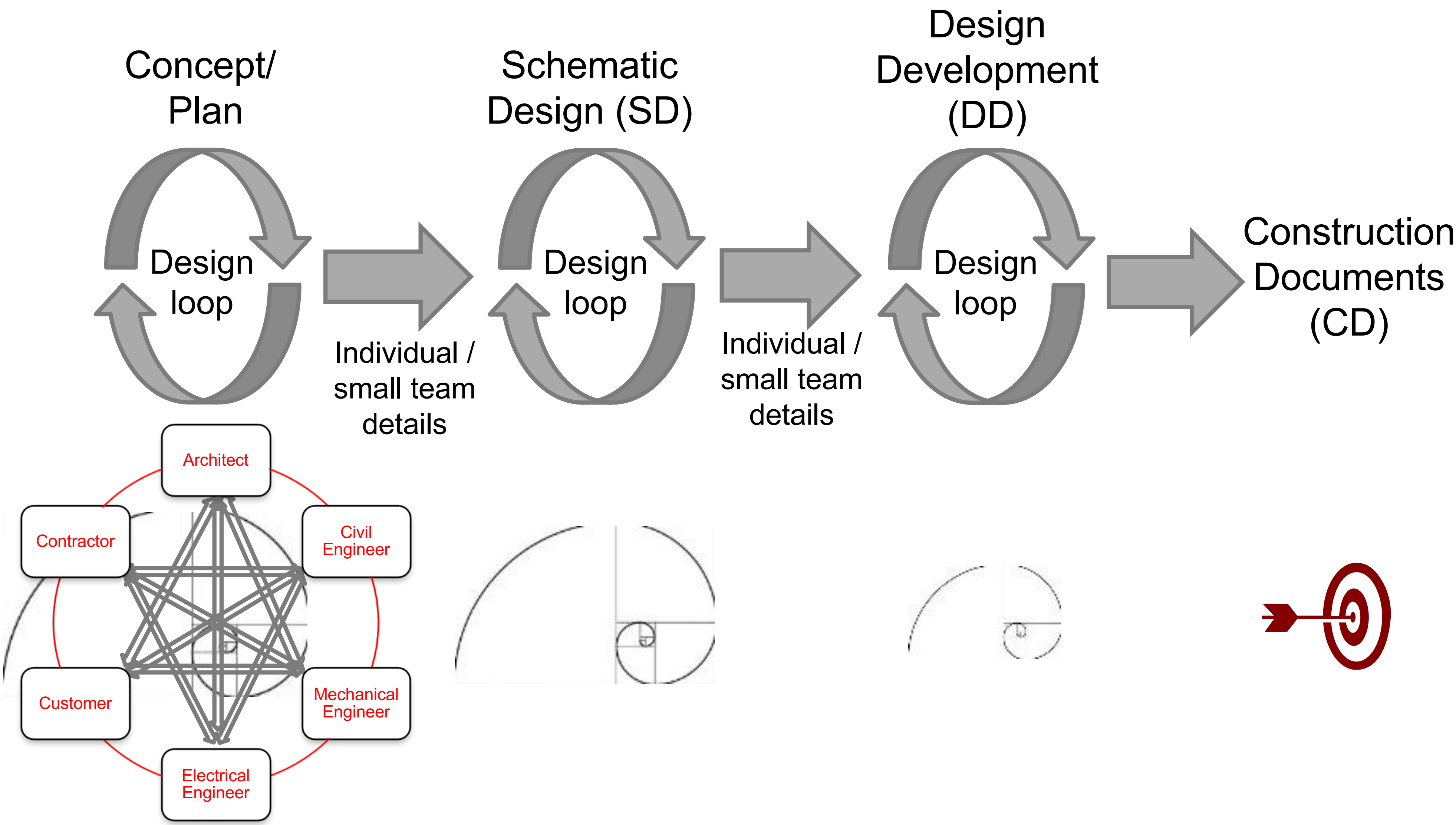


Value Engineering

Value Engineering is Neither

- Amory Lovins, RMI

Integrated Design: Loops



Case One: Personal Experience

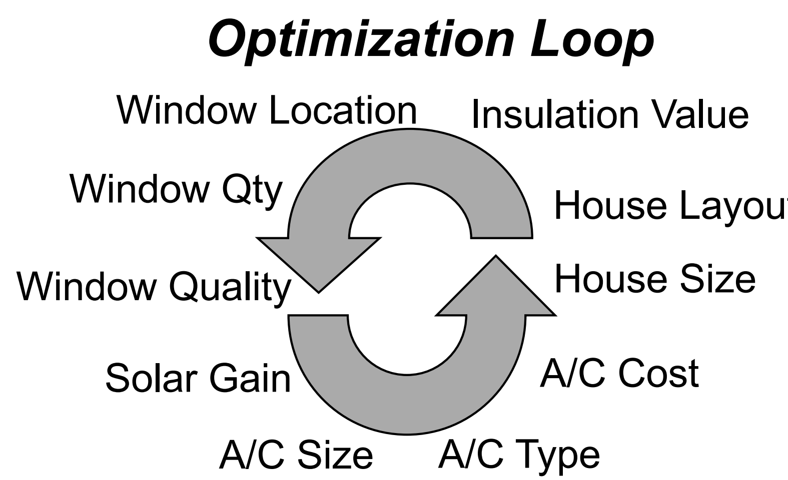
- In the early 90's I designed my own passive solar home
  - I was the architect, engineer, finance department, interior designer, ...
  - I hired a small, local builder and obtained their input during the design phase
  - We asked for input from suppliers during the design

"Quality, Cost, Schedule – Pick Two"

  - We took the time to do make sure the quality was there – from the design, through the construction
  - We managed the budget by estimating and bidding the entire job during the design phase
    - And we did a few iterations as needed

Case One: Integrated Design Example

- These items:
  - Proper orientation with respect to the sun path
  - The best glazing, in the right place, with the correct overhang
  - High levels of insulation and air tightness
  - A reflective metal roof
- Led to:
  - Reduced cooling/heating load
- Which resulted in:
  - A much smaller air conditioning system
- Which allowed me to afford:
  - A highly efficient ground source heat pump



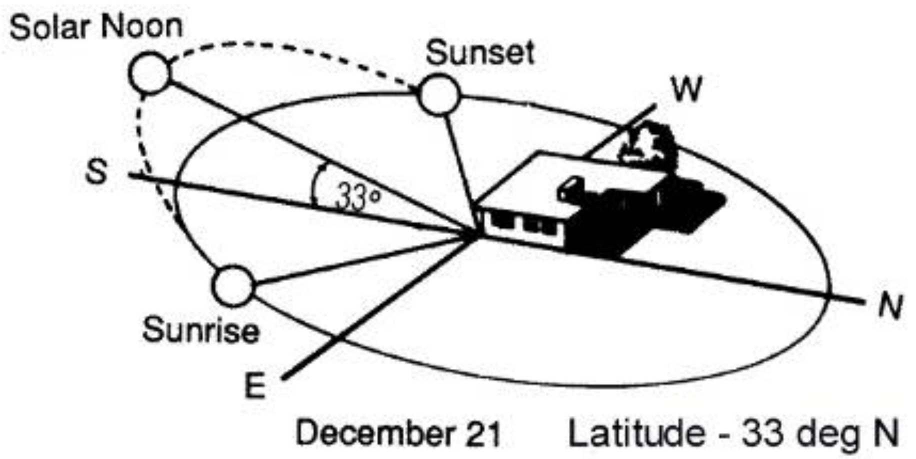
All those items combine for better comfort at lower energy use and cost

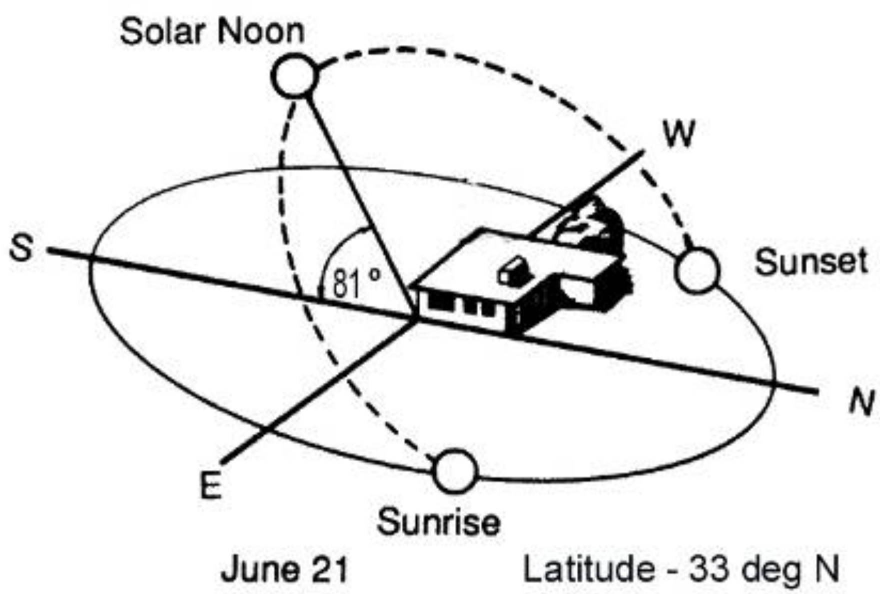
Case One: Features

- Well insulated and sealed house (Structural Insulated Panels – SIPS)
- Good quality windows in the right place – with the right shading
- Efficient air conditioning – ground source heat pump
- Energy recovery ventilator
- Efficient lighting and appliances
- Solar water heating
- Galvalume standing seam metal roof
- Earth-bermed garage

Westbrook House - www.enerjazz.com/house

Passive Solar

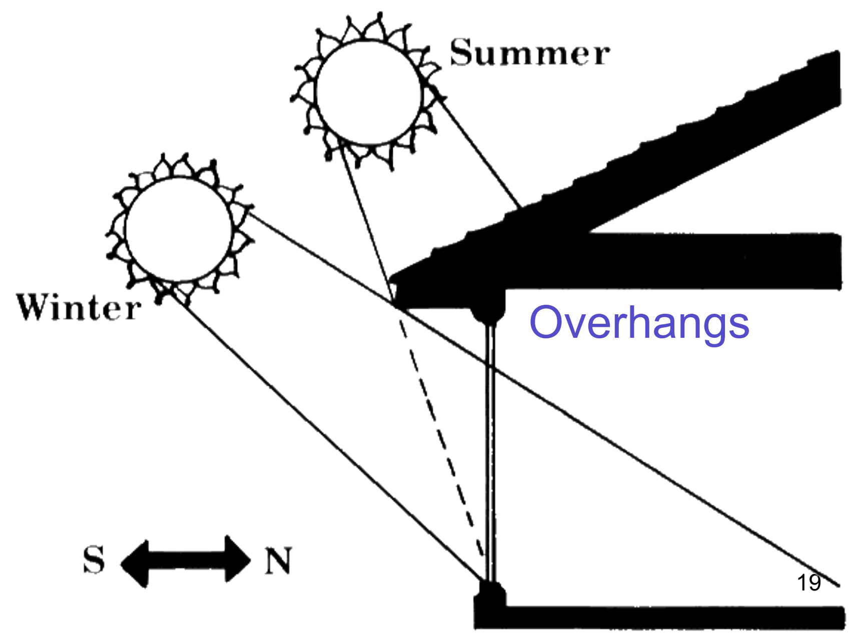




Minimize E & W windows

- Orientation
- Solar Control
- Mass and Insulation

Reflective roof



Northern Hemisphere

Case One: Perspective

Compact, two story stacked

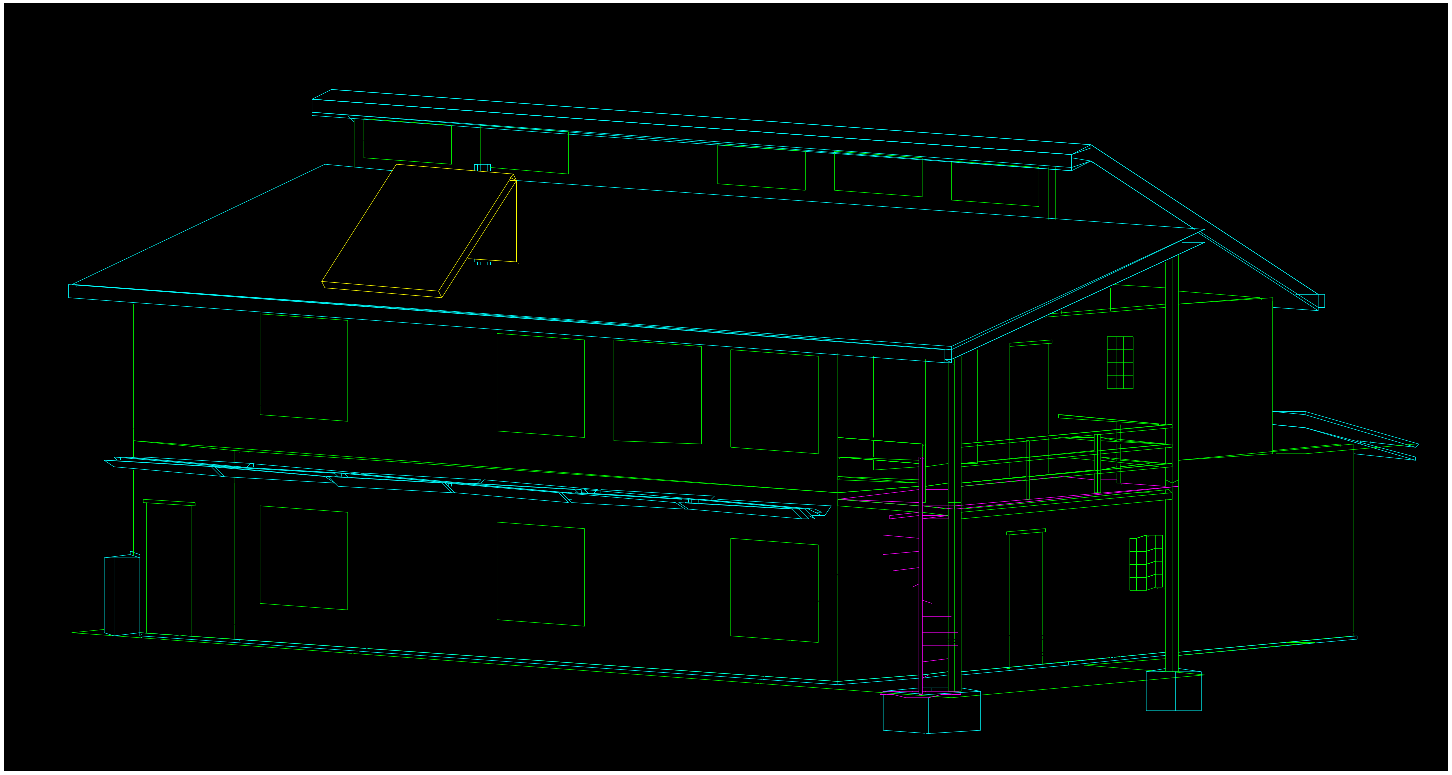
Clerestory windows for light and ventilation

Galvalume metal roof

Solar Water Heating

Deck and shade over east windows

Windows on the south with overhangs



Insulated slab perimeter

Structural Insulated Panels (SIPS)

Westbrook House - www.enerjazz.com/house

Photos at solar noon:

Winter solstice (left)

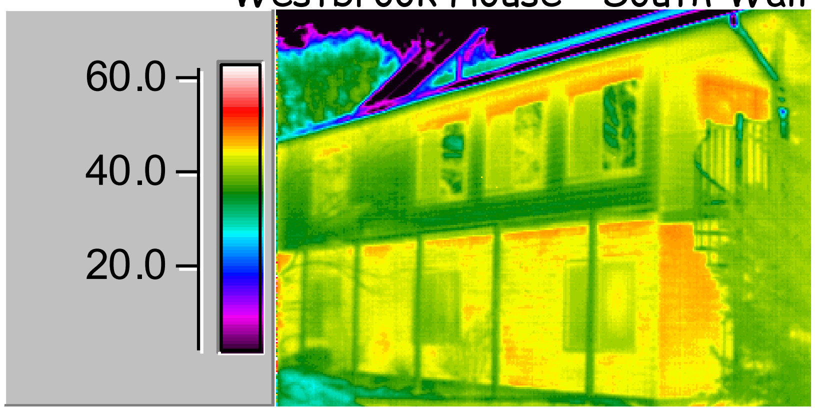
Equinox (lower left)

Summer solstice (below)

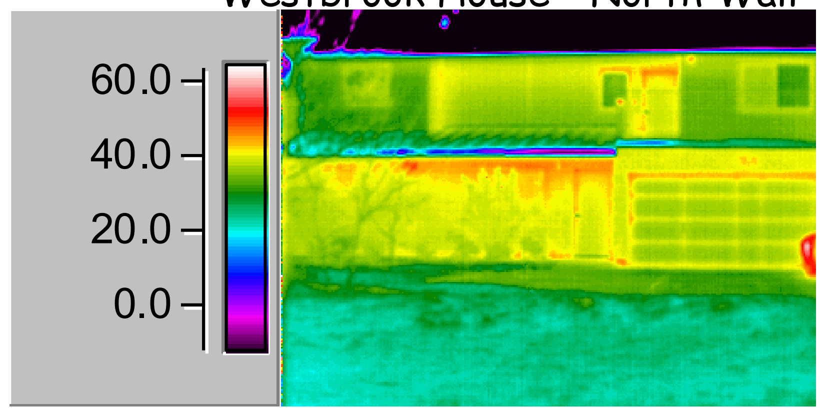
SIP Thermal Performance

These are infrared pictured of a SIP house and a standard construction house

Westbrook House - South Wall

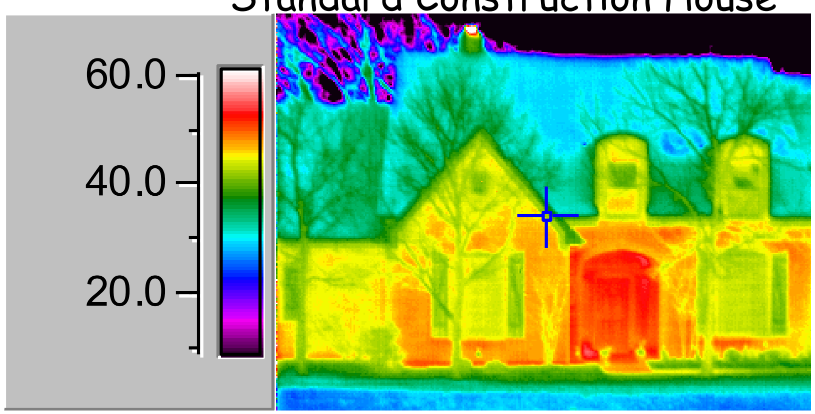


Westbrook House - North Wall

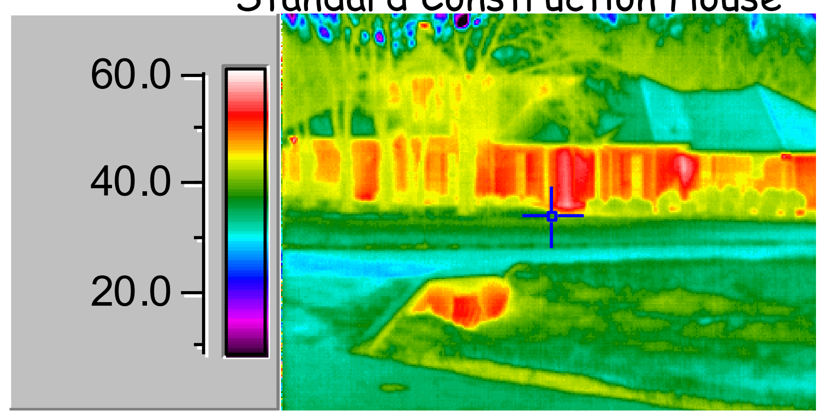


Outside Temp = 43 deg F

Standard Construction House

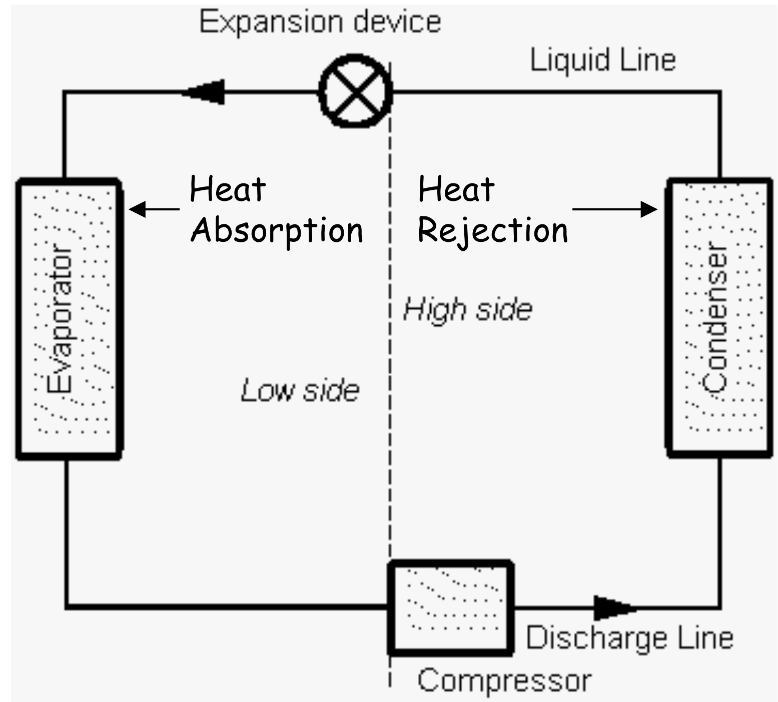


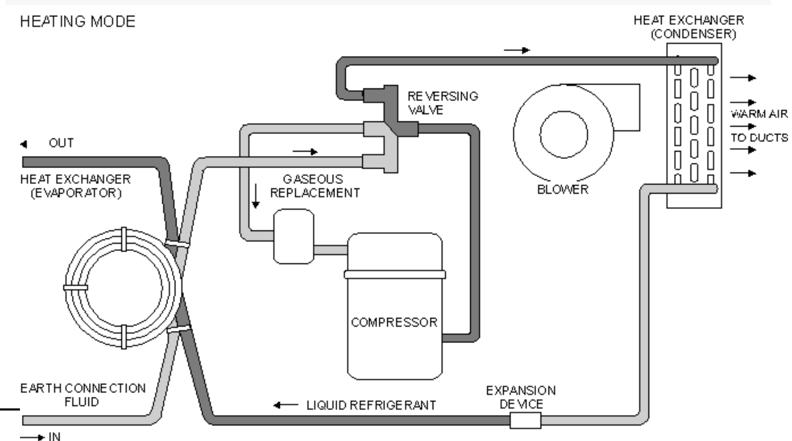
Standard Construction House



Heating / Cooling

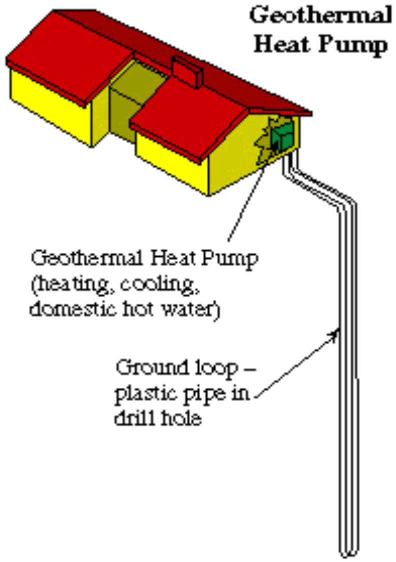
- Oversizing an HVAC system increases the initial cost and decreases the comfort. A short-cycling unit does not fully dehumidify.
- Two-speed units (yr 1996) meet the variable loads more efficiently.
- Zoned duct is helpful in a two story home.
- Good design choices can greatly minimize the HVAC system size. The Westbrook House only needs 2 1/2 tons of cooling (2713 SF).

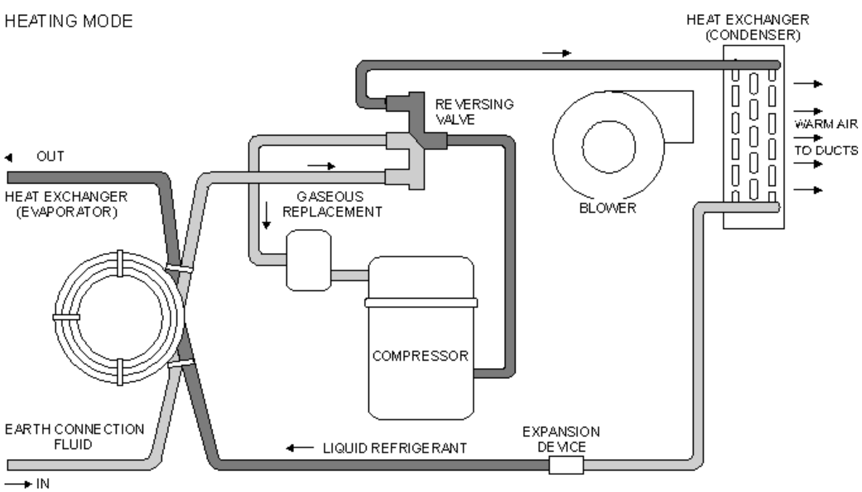




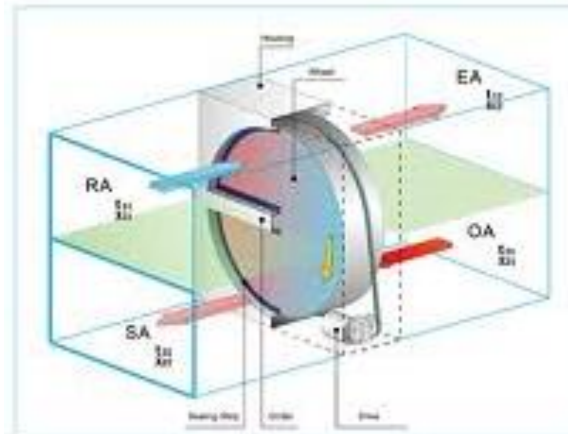
Ground Source Heat Pump (GSHP)

- The GSHP uses the relatively constant temperature of the earth as a heat sink or source.
- A GSHP can also be used as an efficient method of water heating.
- The minimum efficiency allowed is 13 SEER (as of 2006). The Westbrook House GSHP has a SEER of 22.
- There is no noisy outdoor fan unit and we don't reject heat to the already overheated air.



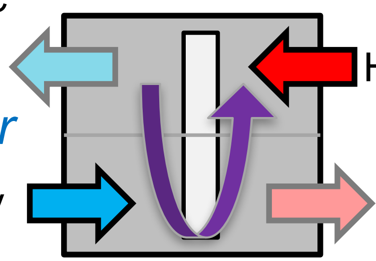


Energy Recovery Ventilator (ERV)

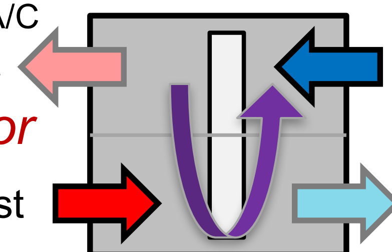


- The house is very air tight
  - GOOD: energy savings, minimal dust
  - BAD: not much fresh air
- An ERV brings in a steady stream of fresh air, but recovers much of the energy from the exhausted air
- Recovers over 70% of the total energy

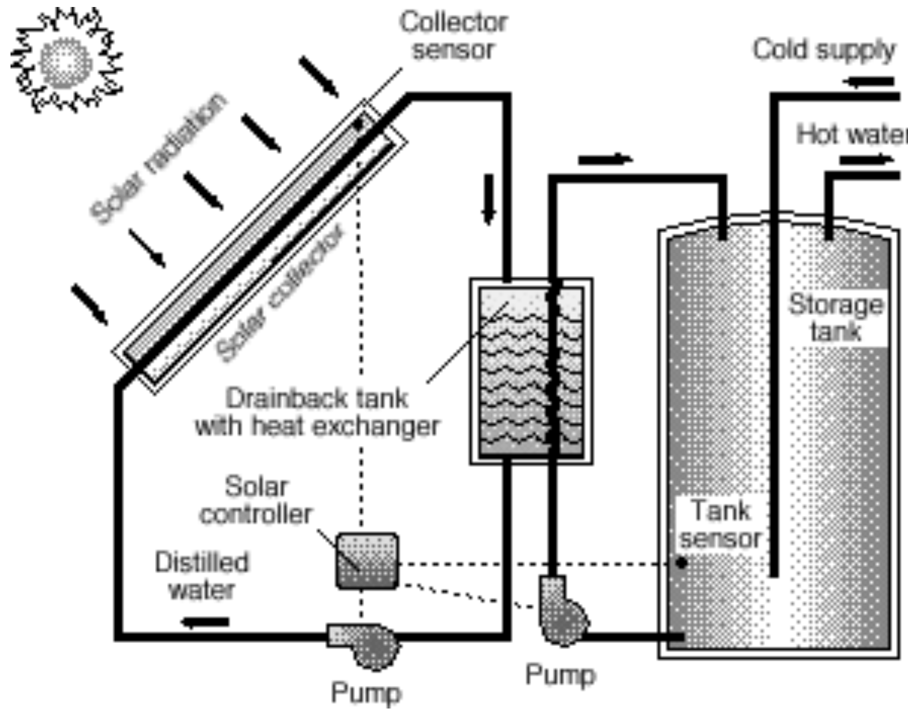
Summer



Winter



Water Heating



- Water heating can account for up to 30% of the electric use in a home.
- Solar Flat Plate water heating can be cost effective.
- A side benefit of ground source heat pumps is a hot water recovery option which provides free hot water during the summer.
- R-25 polybutylene (Marathon) water heater / storage tank provides for long, hot storage – and a lifetime tank warranty
- Heat pump water heaters are improving rapidly.

Case One: Results

- Energy costs of about 1/3rd of my neighbors
- Water costs about 1/6th of my neighbors
- Low maintenance costs
- Won the 1996 NAHB Energy Value Housing Award for Innovative Design
- House was exactly on budget – no late VE required
- The builder and I are still speaking – in fact, we are friends
- Tour of my house by a TI VP sparked an idea to do this process on a very large scale . . . . (Case Two)

Westbrook House - www.enerjazz.com/house

Payback One Month!

- Cash Flow
- Efficiency features added $13,000 to the house cost
  - That adds about $70-$90/month to the mortgage payment
- Utility bill was at least $100/month less than a similar size typical house in our climate
- Pay ~$80/month more to the mortgage company, but save ~$100/month in utilities
  - Net savings of $20/month
    - Also, mortgage interest is tax deductible, energy use is taxed
- When the mortgage is paid off then you get to keep all the utility savings.

Payback Information

Design Goals		
Energy Efficiency		Environmental Sensitivity
Low Maintenance		Cost Effective Design / Construction
Logistics		
Construction Time:	6.5	months
Move In:	Sep-96	
Size (A/C):	2713	SF of A/C space
Size (gross):	3312	SF under roof
Electricity Savings (all electric home)		
Average Electric Bill:	$85.00	avg use: 817 kWh/month
Highest Electric Bill:	$170.71	Aug-06
Westbrook Electric Cost/Yr:	$1,020.00	817kWh/mo * $0.104/kWh over 15 year avg
Average Home Elec. Cost/Yr:	$3,038.78	Avg use south: 10.77 kWh/sf/yr @ .104/kWh
Annual Savings:	$2,018.78	
Monthly Savings:	$168.23	
Payback		
Cost for Energy Efficiency Items:	$ 13,000.00	Total cost of all energy efficiency upgrades
Added to a 15 year mortgage:	$99.22	/mo @ 5.5% int + tax deduct on mortgage
Added to a 30 year mortgage:	$74.94	/mo @ 6% int + tax deduct on mortgage
With a 15 year mortgage, you SAVE:	$69.01	/month - but get full payback faster.
With a 30 year mortgage, you SAVE:	$93.29	/month

After the mortgage is paid, you realize the full savings every month.
Note that mortgage interest is tax deductible.
Energy bills are not deductible. In fact, energy use is taxed.
Payback occurred in the first month when we paid more to the mortgage co. but less to the utility.

Nice Looking and Nature Friendly

Efficiency First…Then Generation

- Since I have reduced the consumption I can power the house with a modest sized renewable energy system
- In 2006 I was selected by Southwest Windpower as a test location for their new Skystream 2.4kW wind generator
  - Developed with the National Renewable Energy Lab (NREL)
  - Designed to be a simple, quiet, efficient, and clean power source for residences

Texas Instruments

Skystream Wind Turbine

Wind Turbine Performance

- I am in a modest wind zone (class 2+)
- I have too many tall trees close to the tower
  - Should have a 300 foot clear radius
- My tower is only 35 feet tall
  - My output is only about 1/8th what it should be
  - Wind power output is the cube of the wind speed
    - Small change in wind speed = large change in power output

Here Comes the Sun

- When solar photovoltaic (PV) prices dropped in 2012 I installed a system
- I installed a 3.3kW array
  - Produces more electricity than I need for 2-3 months a year
  - Produces about 2/3 of my total electrical needs during the year

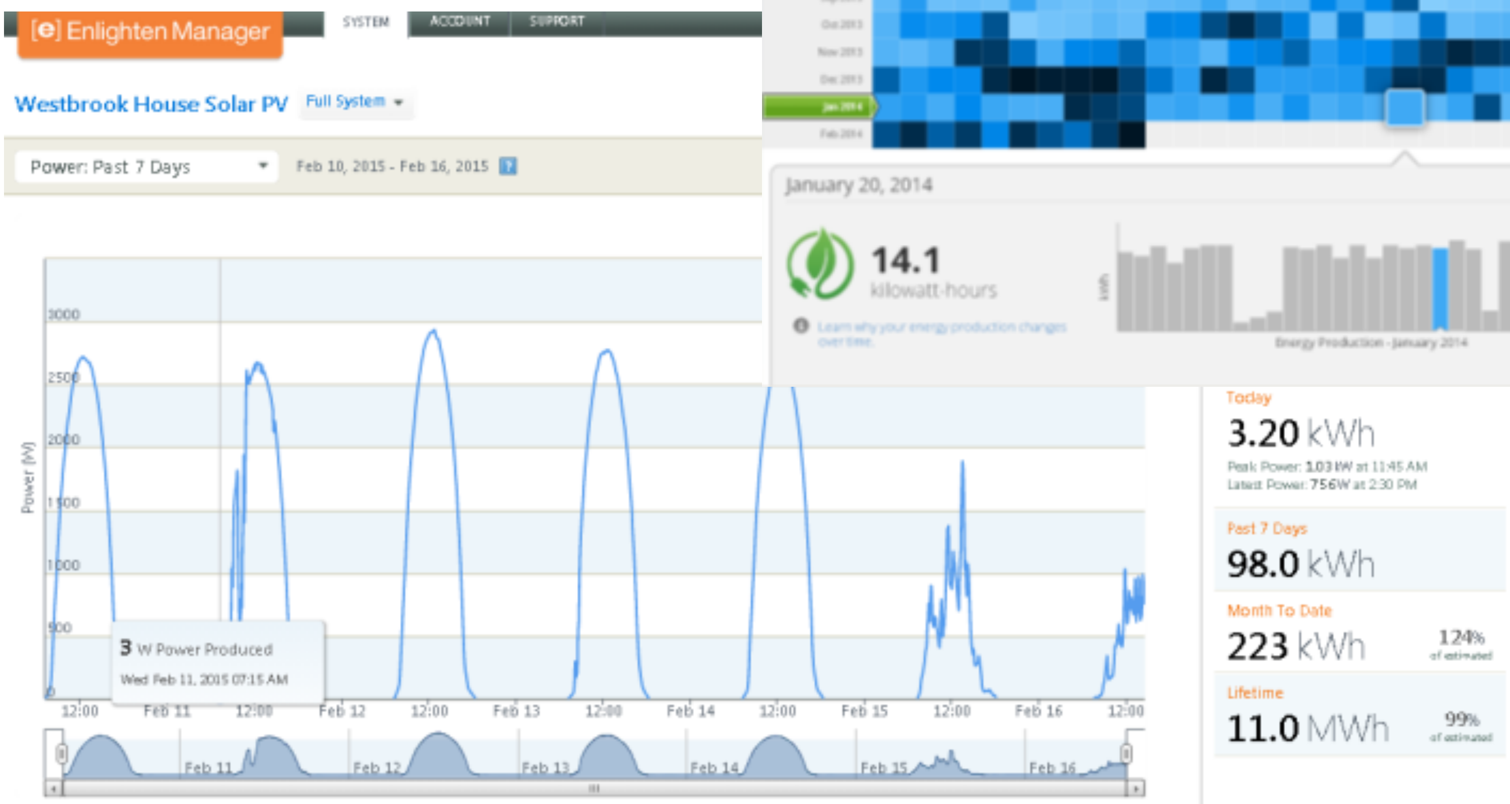
A 5kW system would have made me an annual net zero energy home, but our utility rate structure is poor – no payment for excess energy to the grid and a low-use fee penalty for not using enough energy each month.

More Solar

- In early 2014 I sold the wind turbine and added a couple more solar panels on the turbine pad – up to 3.75kW now.

Real Time Solar Production Monitor

- Solar PV system
- My Monitor Link
- System Info
- Public View



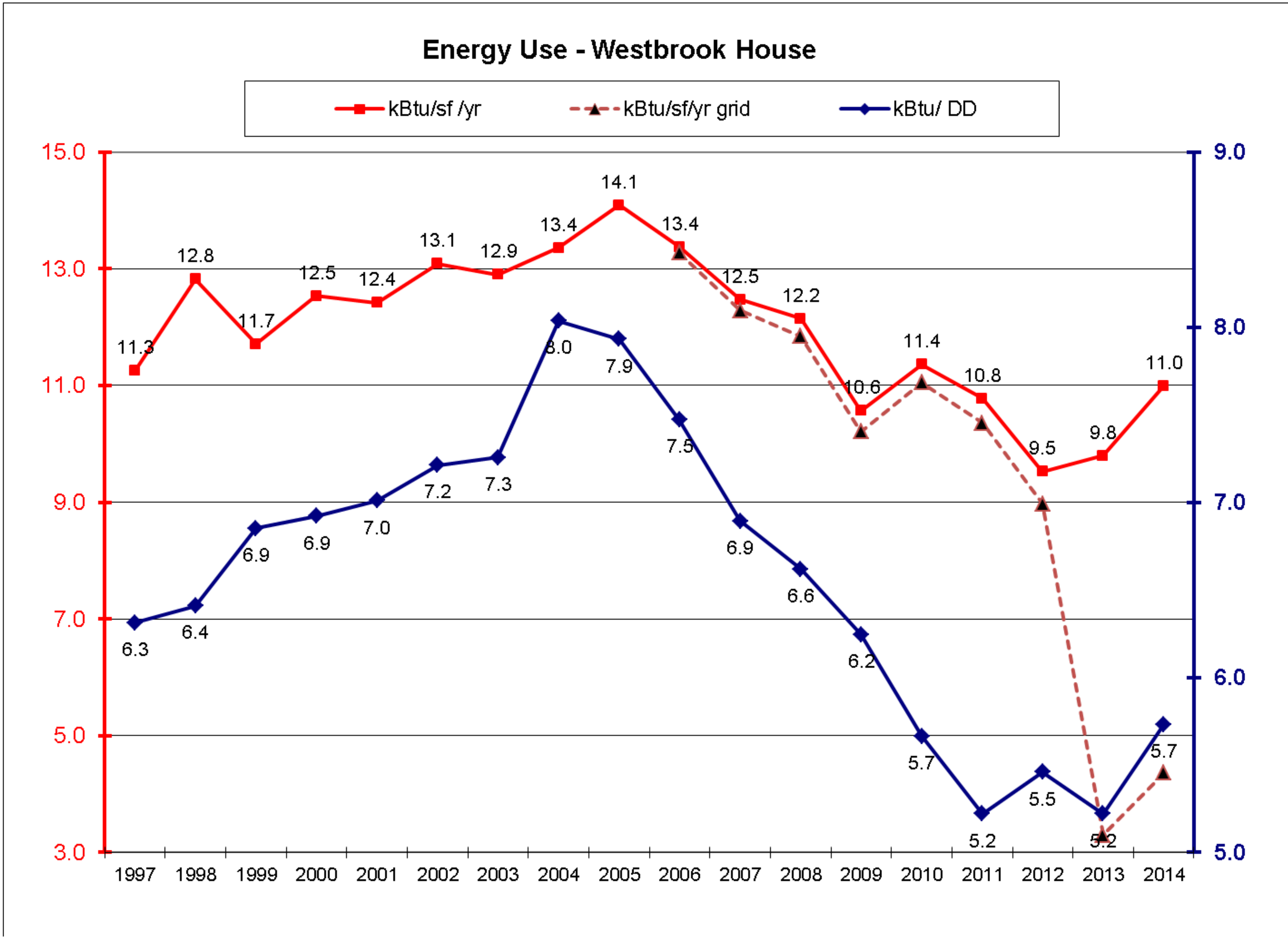
Annual Utility Costs

Texas average = 40kBtu/sf

Westbrook House Annual Utility Data							2,713 sf, 3 people				
Year	kWh sum	kWh util	kWh wind	kWh solar	Cost/Yr	Average Cost/Mo	Effective Elec Rate	kBtu/ sf	kWh/ sf/yr	kWh / DD	Water Use/Yr (gallons)
2005	11,205	11,205	0		$ 1,177	$ 98.08	$ 0.105	14.1	4.1	2.3	37,000
2006	10,633	10,555	78		$ 1,443	$ 120.28	$ 0.137	13.4	3.9	2.2	35,000
2007	9,916	9,770	146		$ 1,305	$ 108.79	$ 0.134	12.5	3.7	2.0	28,000
2008	9,661	9,419	242		$ 1,364	$ 113.65	$ 0.145	12.2	3.6	1.9	38,000
2009	8,403	8,118	285		$ 1,247	$ 103.92	$ 0.154	10.6	3.1	1.8	29,000
2010	9,034	8,788	246		$ 1,222	$ 101.84	$ 0.139	11.4	3.3	1.7	34,000
2011	8,571	8,238	333		$ 1,137	$ 94.73	$ 0.138	10.8	3.2	1.5	42,000
2012	7,573	7,137	228	208	$ 1,000	$ 83.32	$ 0.140	9.5	2.8	1.6	29,000
2013	7,791	2,625	216	4950	$ 575	$ 47.89	$ 0.219	9.8	2.9	1.5	33,000
2014	8,742	3,472	7	5263	$ 673	$ 56.10	$ 0.194	11.0	3.2	1.7	28,000
Sums and Averages	kWh sum	kWh util	kWh wind		Cost		Elec Rate ($/kWh)	kBtu/ sf	kWh/ sf/yr	kWh / DD	Water Use (gallons)
Total>	171,111	158,909	1781	10421	$ 17,560						606,500
Annual>	9,506	8,828			$ 976		$ 0.119	12.0	3.5	1.9	33,694
Monthly>	792	736			$ 81.30						2,808

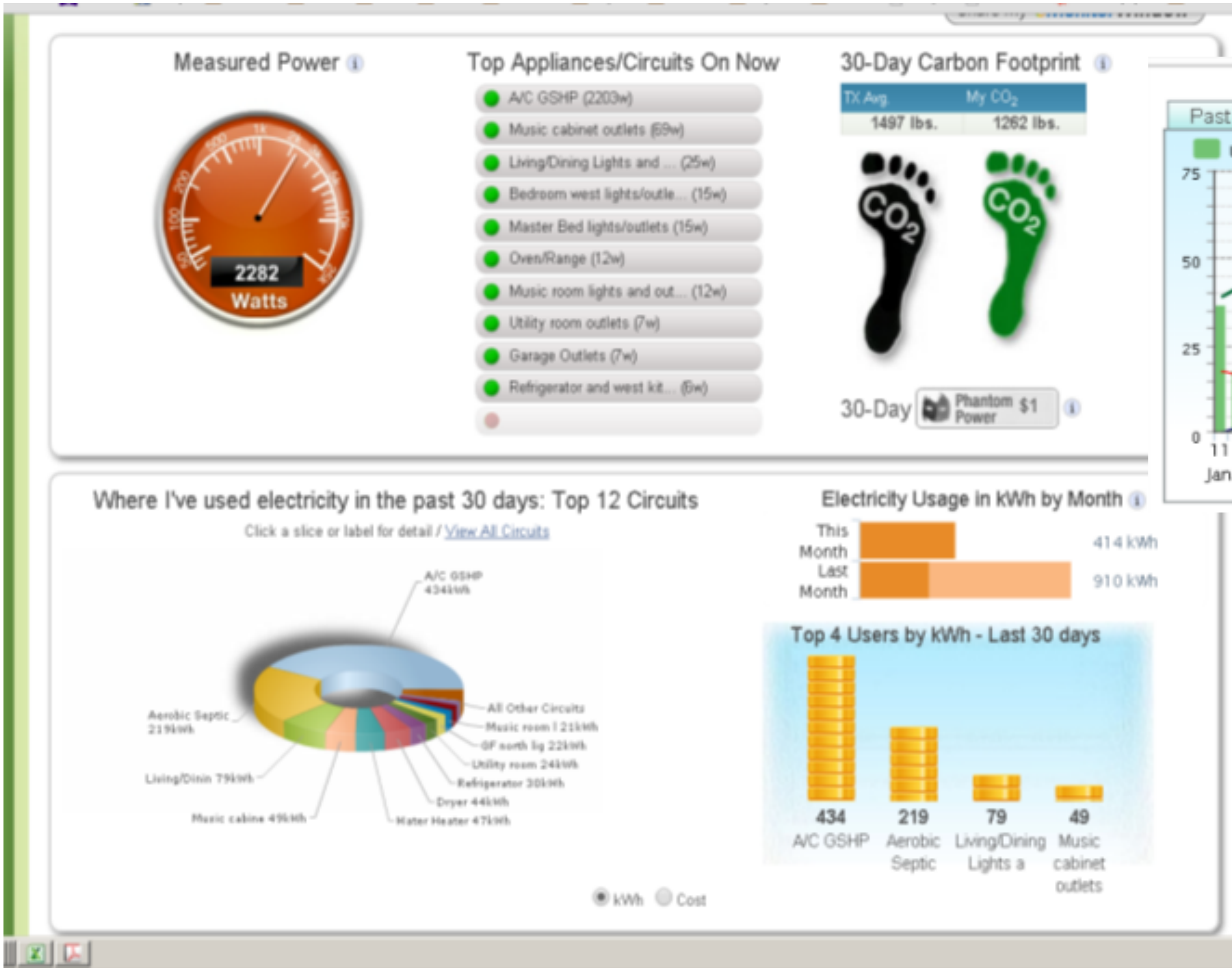
http://www.enerjazz.com/house

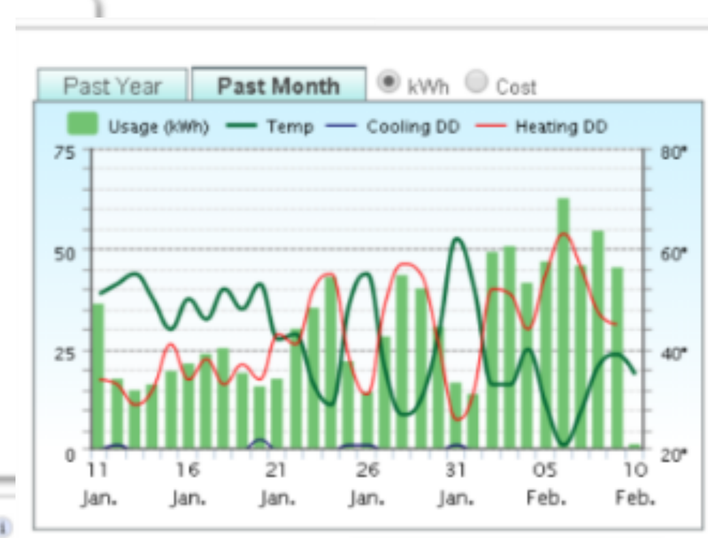
Use Trend



Energy Use - Westbrook House
kBtu/sf /yr
kBtu/sf/yr grid
kBtu/ DD
15.0
13.0
11.0
9.0
7.0
5.0
3.0
9.0
8.0
7.0
6.0
5.0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
11.3
12.8
11.7
12.5
12.4
13.1
12.9
13.4
14.1
13.4
12.5
12.2
10.6
11.4
10.8
9.5
9.8
11.0
6.3
6.4
6.9
6.9
7.0
7.2
7.3
8.0
7.9
7.5
6.9
6.6
6.2
5.7
5.2
5.5
5.2
5.7

Real Time Energy Use Monitor

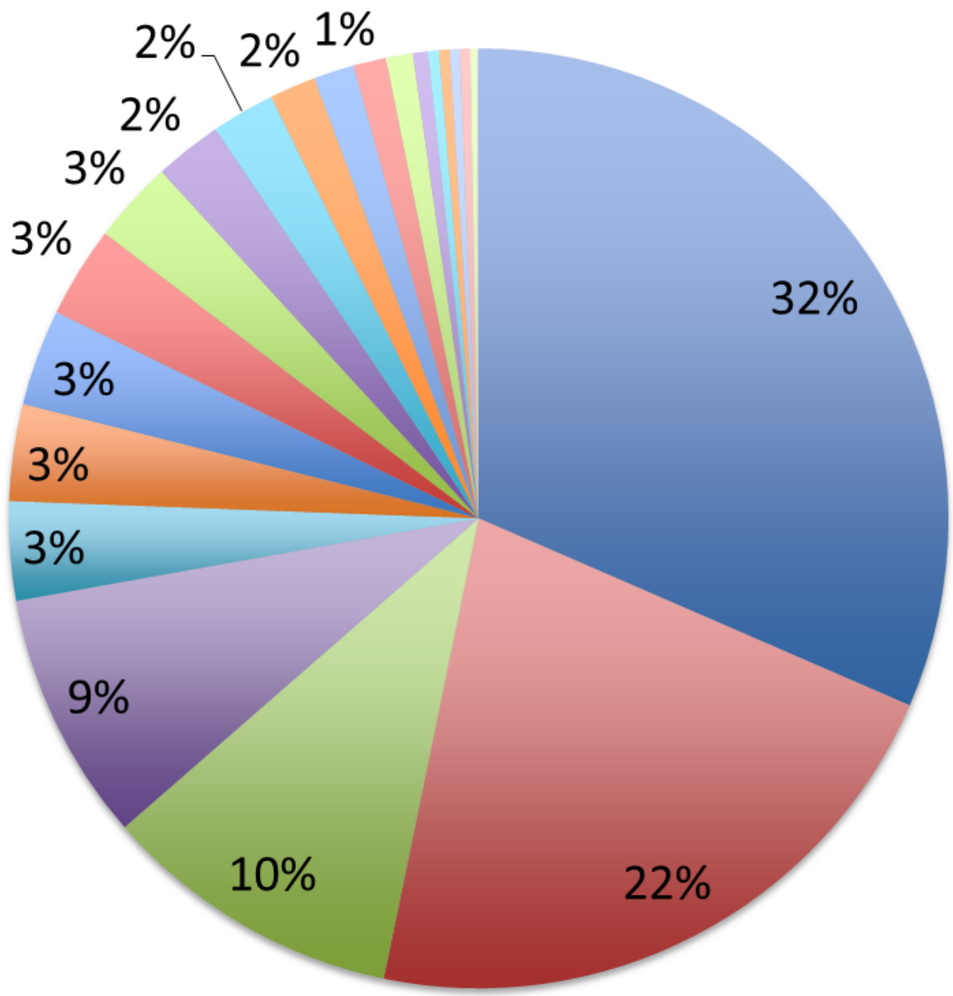




[My Monitor link]

[Public View link]

Annual Energy Consumption



~7,800 kWh/yr, 2,713 sf, 3 people, north Texas

What Would I Do Today?

- Passive House type structure
  - Extremely well insulated and airtight
    - Walls ~R-40, Roof ~R-60
- Higher quality windows (>R-8 available)
- Integrate small A/C unit into energy recovery ventilator (ERV)
- Consider solar PV driven heat pump water heater instead of solar water heater

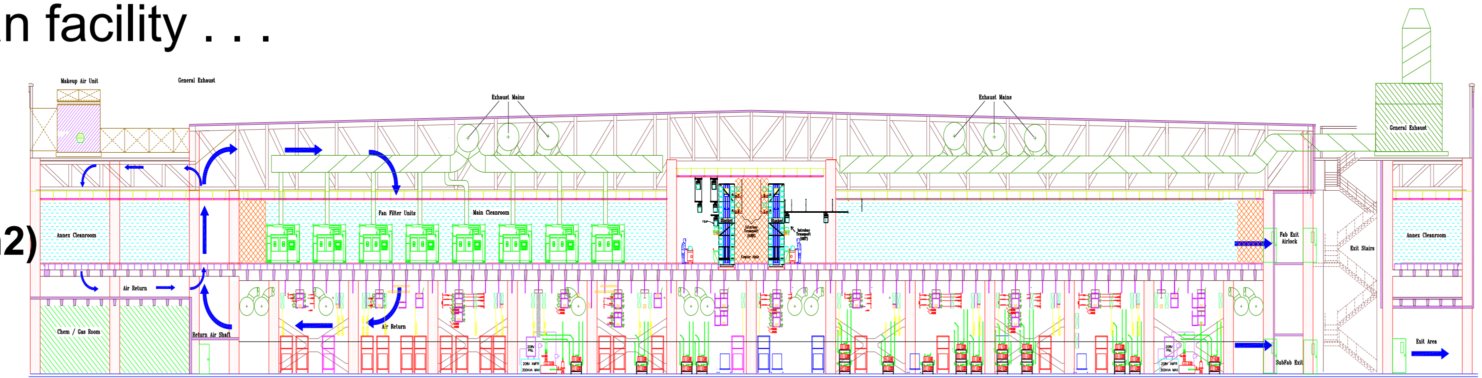
Case Two: Semiconductor Fab

- 92-acre site
- 1.1 million square feet
- 220,000 square feet of cleanroom space
- Capacity for about 1,000 employees
- Main components:
  - Fab building (Fab=fabrication)
  - Support building
  - Central utility plant (CUP) building
  - Administration building

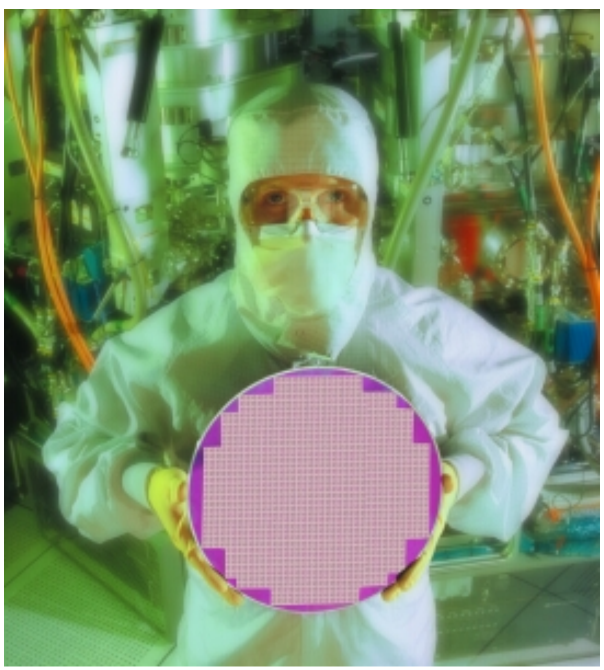
What is a wafer fab?

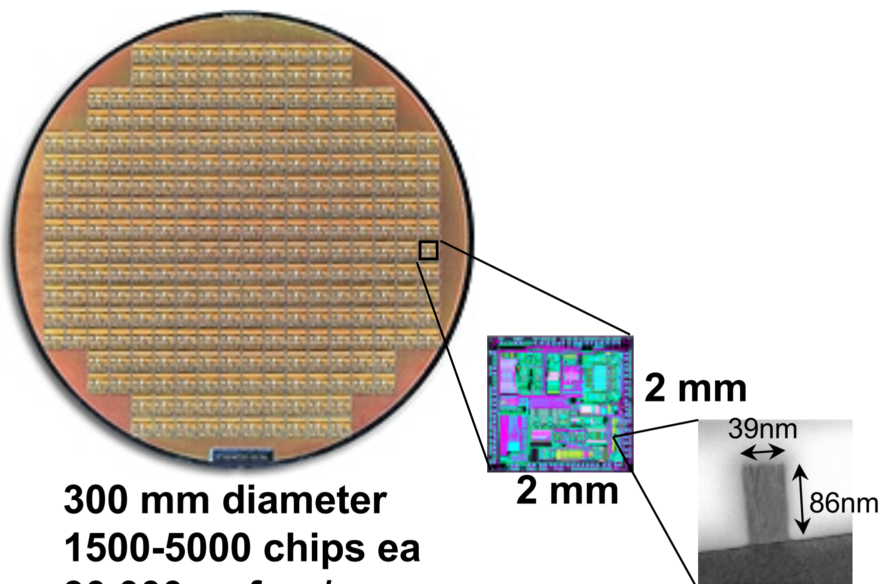
A very big, clean facility . . .

Total space:
1,100,000 gsf (102,000 m2)
Clean room space:
220,000 sf (20,400 m2)



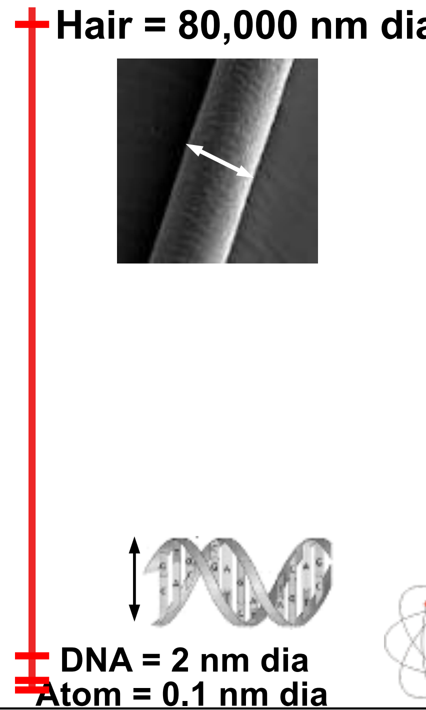
. . . that fabricates very small chips on large silicon wafers





300 mm diameter
1500-5000 chips ea
30,000 wafers/mo
1 billion chips/yr

Gate = 39 nm dia



Case Two: The Opportunity

- Very tight temperature and humidity requirements . . .
  - 70F+/-2 (21C+/-1) and 45% RH +/- 3%
- Combined with a large amount of exhaust and subsequent make up air . . .
  - 650,000 cfm (307 m3/sec) = 2 Macy's Kermit balloons per second
- Combined with the need to recirculate a large volume of air through the filters for cleanliness . . .
  - 4,400,000 cfm (2077 m3/sec) = 22 Goodyear blimps a minute
- Combined with hundreds of process tools with vacuum pumps, RF generators, and support equipment . . .
- Combined with extensive use of deionized (DI) water to rinse the wafers during processing . . .

Could lead to annual power consumption of 300,000 mWh (21,000 TX homes worth) and water consumption of 2 million gallons/day (5,500 TX homes worth). Annual utility bills could total $20M - $25M.

Case Two: Strategy

- Strategy Team - Fabscape
  - 4 strategy teams were formed in advance of project
  - Request made to add a 5th team - sustainability
  - Generated early white papers on a number of ideas

- Tour My House
  - Invited 3 TI VP's to tour active/passive solar home
  - Low utility bills for "normal" house spurred interest

- Design Workshop
  - Teamed up with Rocky Mountain Institute (RMI)
  - Held 3-day design charrette to brainstorm ideas
  - Generated 15 "Big Honkin' Ideas" to carry forward along with a large list of other good ideas
  - Made a first pass at LEED score sheet

Rocky Mountain Institute
abundance by design™

Case Two: Project Management

- Sustainable Development Manager role assigned
  - Chief integrator of ideas and systems
  - The building was the system to be optimized
- Project Manager was fully supportive
  - Safety, Cost, Schedule, and Sustainability were front page
- Construction Contractor was the general contractor with the design firm working under them
  - Everyone on board from the start

Don’t optimize the parts and pessimize the system

Cost Reduction – Friend or Foe?

- Challenge:
  - –Reduce project costs per square foot by 30 percent from the previous semiconductor fab
- Response:
  - –A LEED building does not have to cost more
  - –Forced space efficiency
  - –Forced us to question everything
  - –Couldn't just copy previous design – had to innovate
  - –All of this led to . . . . Engineering!

Integrated Design

You know you are on the right track when your solution for one problem accidentally solves several others.

- Amory Lovins, RMI

Integrated Design Example

Office Lighting

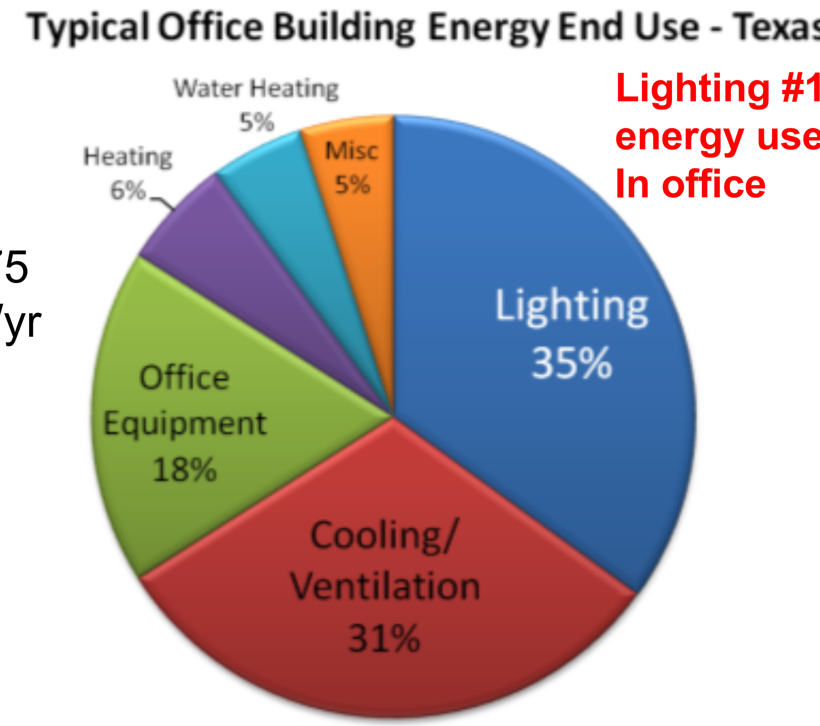
Standard cost = $125
op cost = $40/yr

Ergolight cost = $375
op cost = $25/yr

Simple payback = 16.7 years

However, we need 30% fewer Ergolight fixtures. Simple payback down to 6.7 years.

Efficient lighting also saves cooling energy. Simple payback down to 6.0 years.



Lighting #1 energy user In office

Add the contribution from dozens of similar projects (lighting, reflective roof, light shelves, sun shades, quality windows, extra insulation, better vacuum pumps, . .)

Enough cooling load disappears to avoid buying a $1M chiller . . . and the cooling tower, pumps, pipes, and even the space needed to install it.

Simple payback is now 0.0 years. The total net capital cost is the same, or even less, and the operating costs are lowered forever.

Integrated Design Example

But wait, it gets even better . . .

Ergolights are individually controllable by each employee
Natural daylighting has been shown to increase productivity

Cost of operation over 30 years for an office building

People costs account for 92% of all costs over a 30 year period.

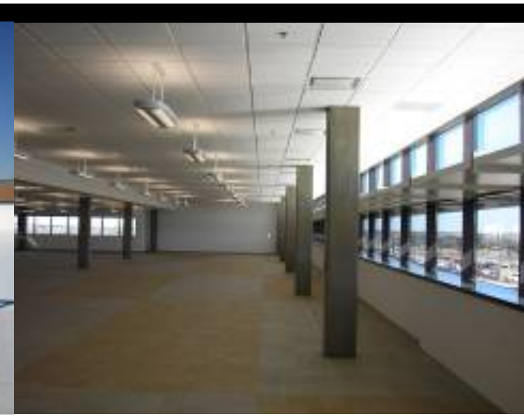
If natural daylighting, self-control of lighting, improved indoor air quality, and all the other green building factors improved productivity by just 1% that would save the company >$1M/year for a large office complex.

Plus, if people like the building and control over their space it can give companies a recruiting advantage for top talent.

Office Efficiency

- Passive solar orientation with exterior shading
- Optimized glazing (high VLT, low SHGC, low U value)
- Reflective roof
- Natural daylighting with light shelves
- High-efficiency lighting (motion and daylight sensors)
- Demand-controlled ventilation
- Attention to detail on insulation and infiltration
- Solar water heating






More Integration

< Areas were restored to native prairie grass to minimize irrigation and provide biodiversity.

Pond collects runoff from most of the 92 acres. 2.7 million gallon (10.2 million liters) base + 2 million gallon buffer. The pond meters runoff and settles sediment. Pond water is used for all site irrigation.

Windmill drives an air compressor to aerate the pond.

Sustainability at RFAB


Native Meadow Restoration


Rain Water Reuse Pond


Reflective Roof


Dark Skies Friendly Lighting


Exterior Shades


Day lighting


Efficient Lights

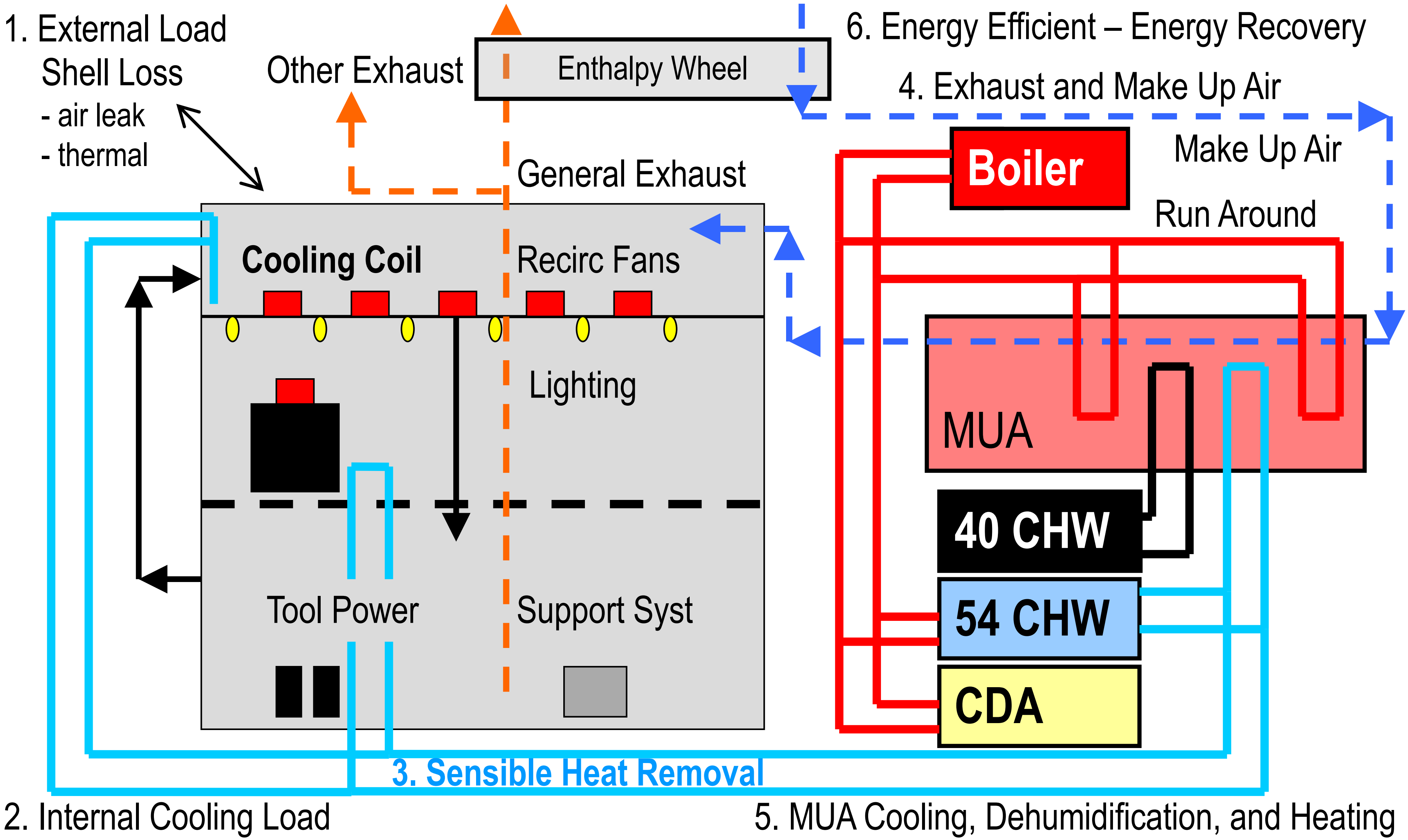

Solar Water Heating


Water Turbine Powered Faucet


Bicycle Parking


Efficient cooling system with waste heat recovery

Fab Energy Flow

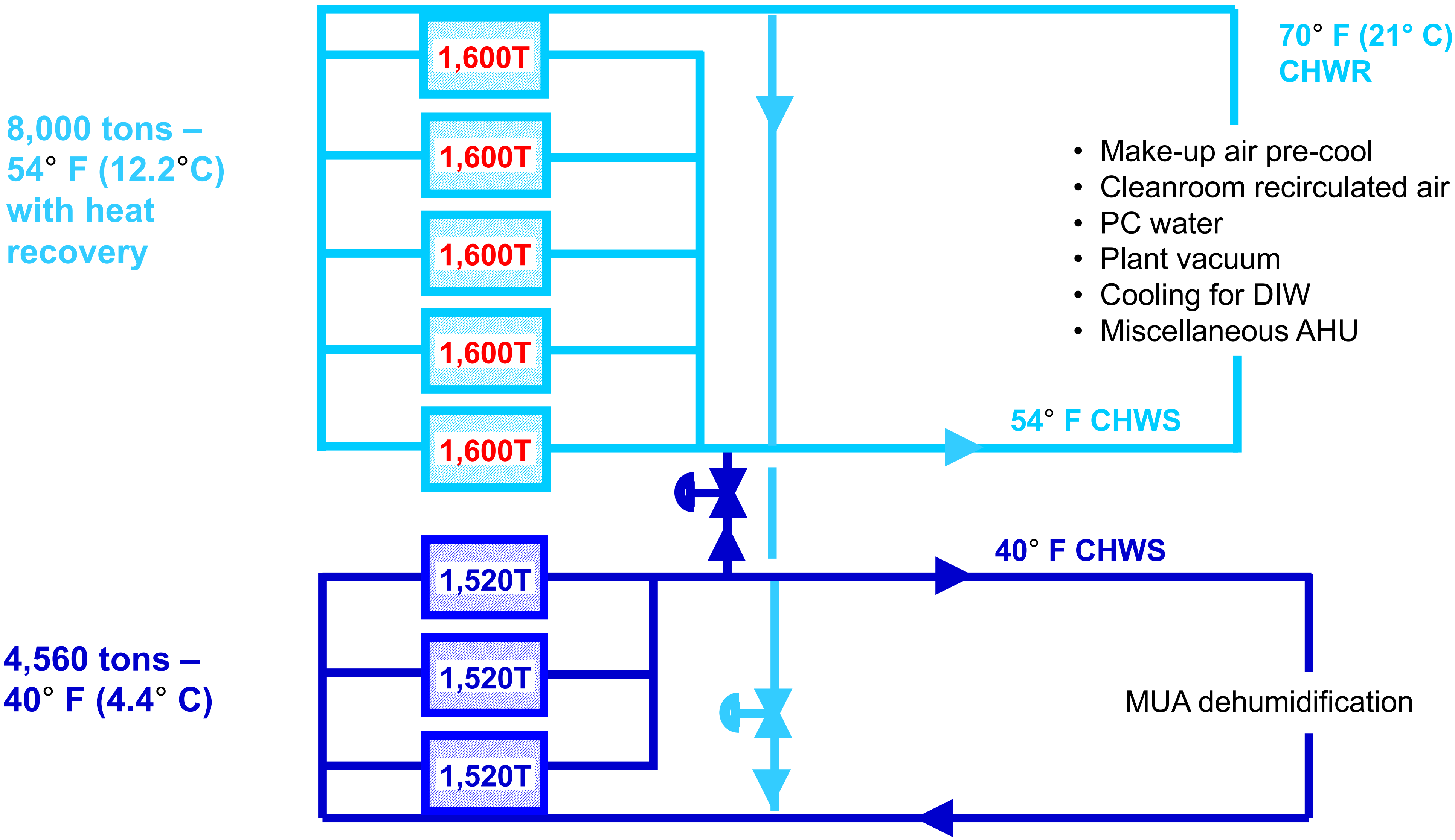


Energy Savings – Facilities Efficiency

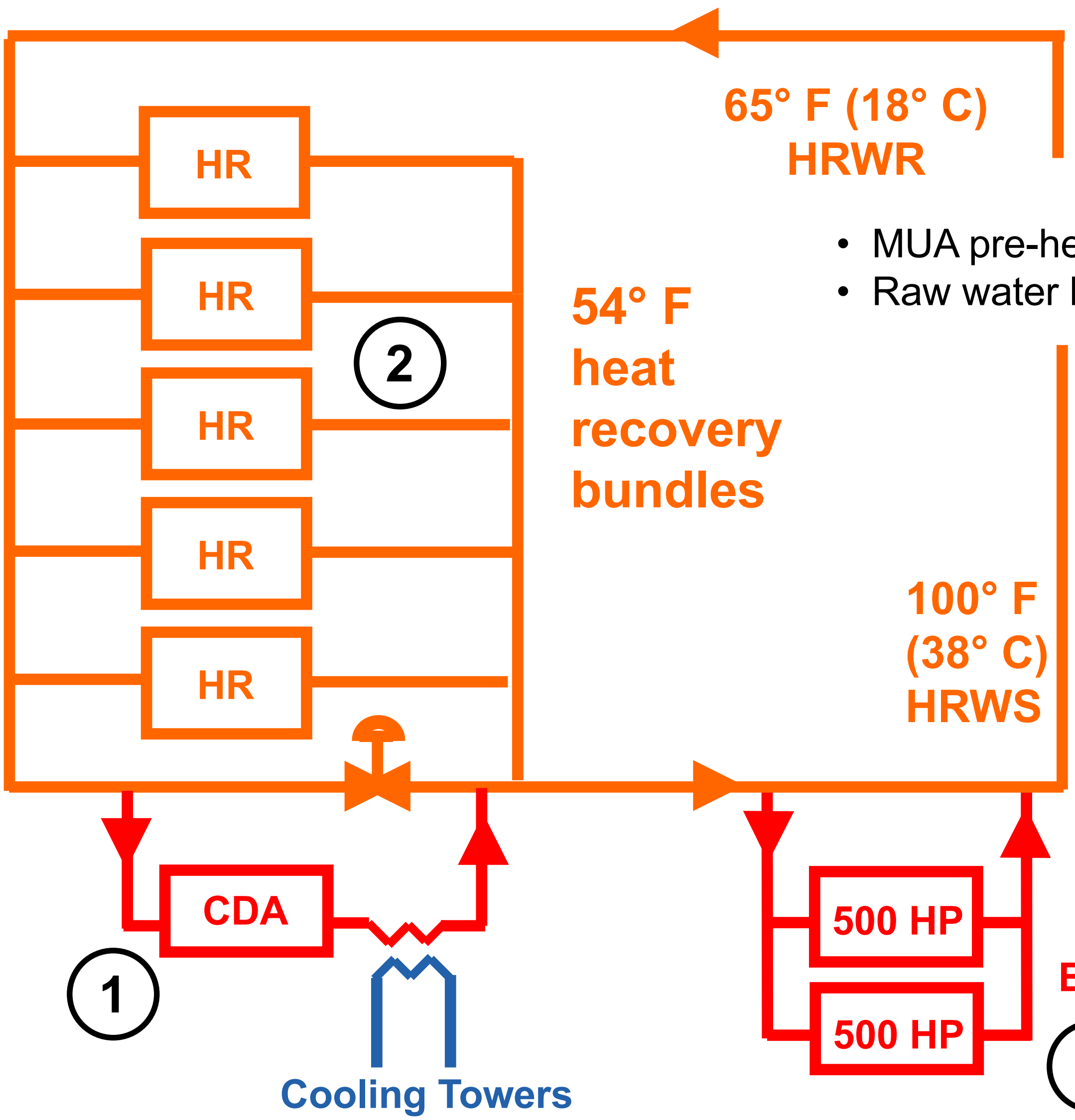
Central Utilities Plant – Chiller Plant (25% of fab load)

- Split plant to match needs to capacity:
  - 40° F (4.4° C) for dehumidification (.44 - .51 kW/ton)
  - 54° F (12.2° C) for all other loads (.32 - .50 kW/ton)
- Heat recovery on 54° F plant (75% of CHW load)
  - More constant load year-round
  - Minimal energy penalty for free hot water
  - Reduced boilers from 6 to 2 (500HP each) – haven't run in 3 yrs
- Utilize variable primary distribution – only one set of pumps that vary their speed with the demand
- Redundancy is 1 x 40° F chiller for both 40° F and 54° F (blending for 54° F)

Energy Savings – Chiller Plant

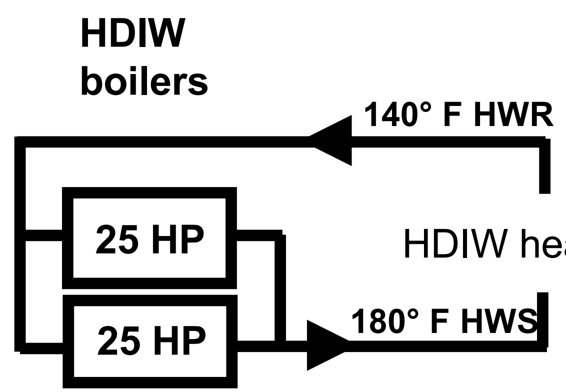


Energy Savings – Hot Water



- MUA pre-heat/re-heat
- Raw water heating for DIW

1. Primary source – waste heat from air compressors;
2. Secondary source waste heat from chillers;
3. Coldest days require boilers to be used. (haven't used in over 3 years)



Energy Savings – Facilities Efficiency

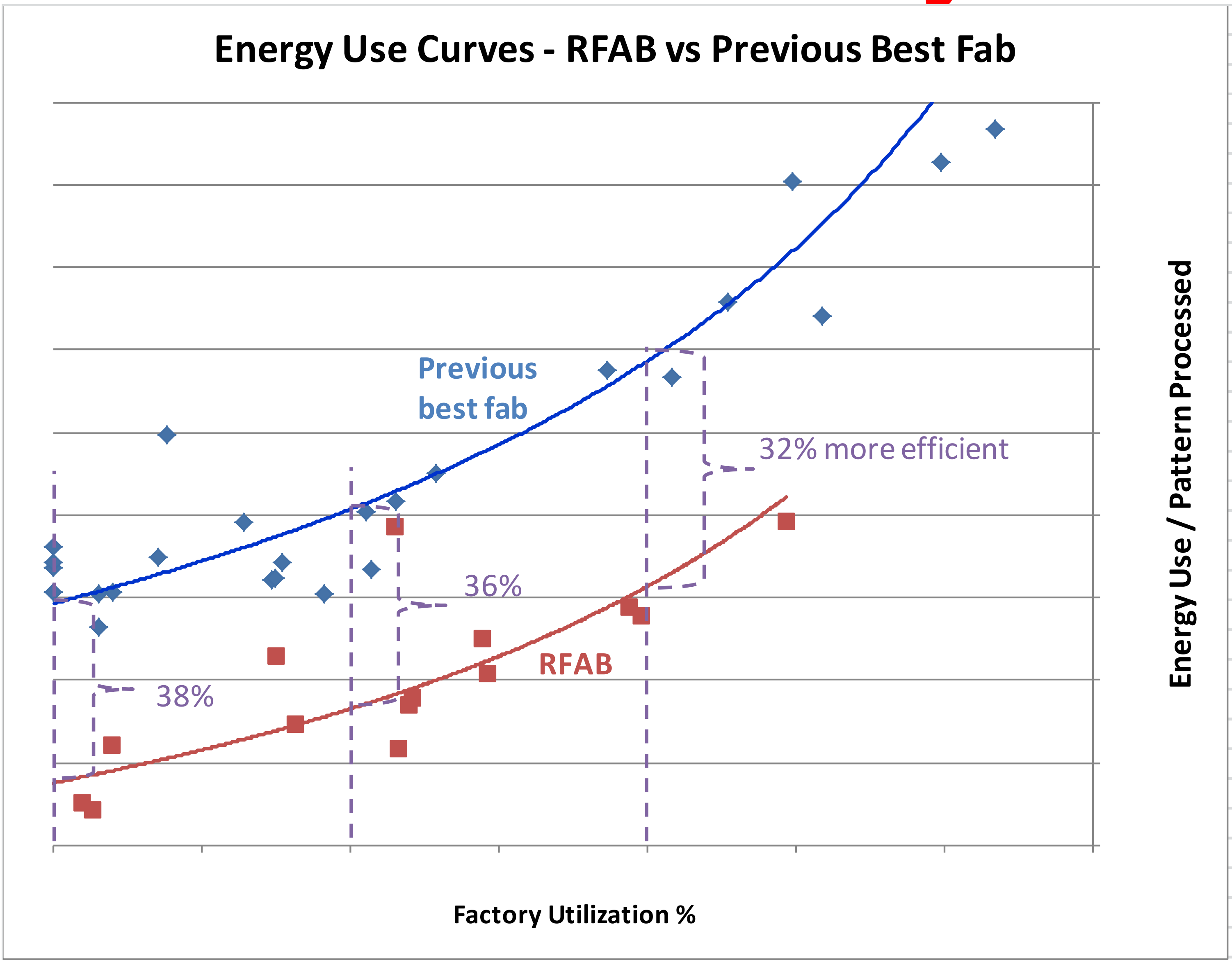
- Make-Up Air
  - Runaround coils for free reheat
  - Lowered face velocity (<400fpm) to reduce fan HP
  - Used high-pressure spray humidification instead of steam
  - Planned for the space to add enthalpy recovery wheels to recapture up to 70% of the exhaust energy
- Recirculating Air
  - 25 percent cleanroom filter coverage (300 ton load reduction vs. 50%)
    - Reduced filter pressure drop and minimized velocity
    - Achieved >10,000 cfm/kW at 70 feet per minute velocity

Results

- We invested less than 1 percent of the project cost ($1.5M/$320M) in LEED-related items:
  - Predominately efficiency improvements that we would have considered regardless of LEED
- Overall project cost was 30 percent less per square foot than our previous fab just 6 miles away
- In the first year, we saved >$1 million in operating costs
- At full build out, we will save more than $4 million per year:
  - Running 38% more efficient than it's local sister fab
  - 50 percent on site emissions reduction
- LEED Gold Certified Office and Fab (first LEED Gold fab in the world)

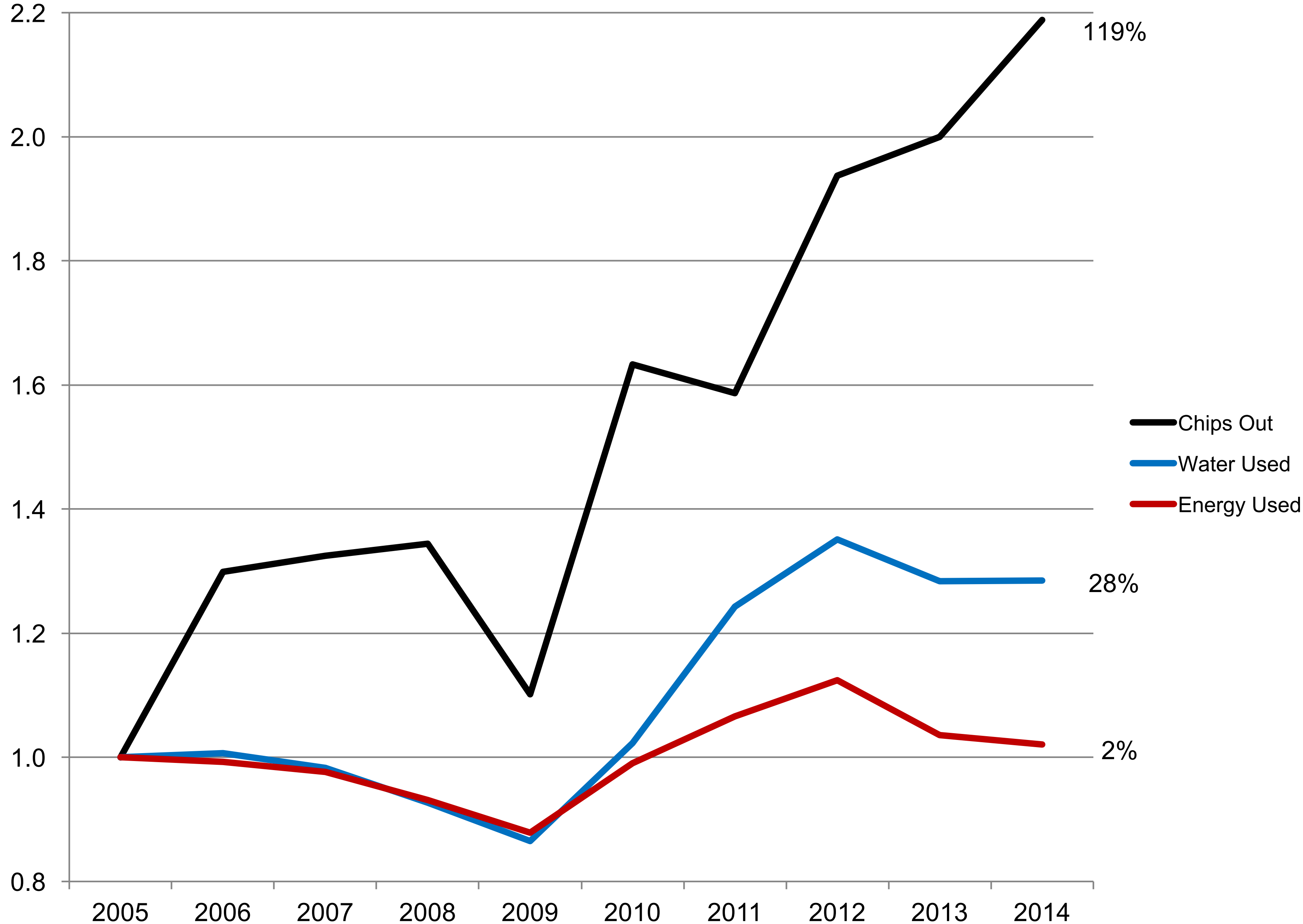
www.ti.com/rfab

TI RFAB Efficiency



- **RFAB**
  - RFAB uses 38% less energy to process a wafer pattern than other local fab
  - The other TI 300mm factory is located 6 miles away (same climate) and was built 10 years before RFAB.

TI Trends



Texas Instruments

Don't Wait . . . Integrate

$$\int_{\text{Start}}^{\text{Finish}} \text{Design} = \text{Better Results}$$

Texas Instruments

Thank You

- Links
  - Westbrook House – www.enerjazz.com/house
  - TI RFAB – www.ti.com/rfab
  - Paul's Prius (10.8 years of data) – www.enerjazz.com/prius