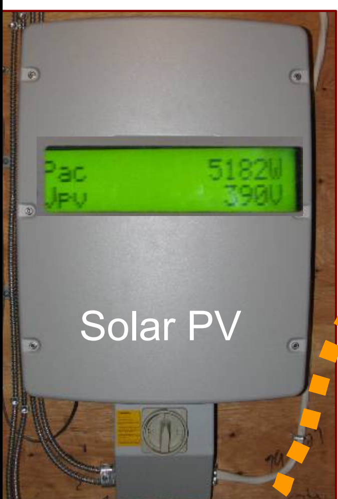
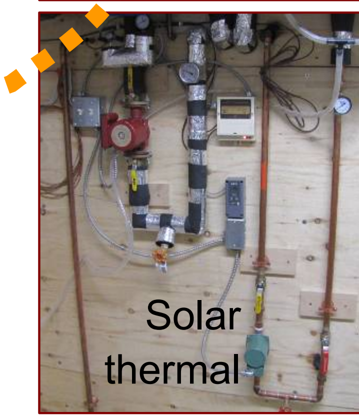
Renewable Energy Systems in Net Zero Energy Houses … what we've learned

Riverdale NZE



Alaska Centre for Appropriate Technology

Mill Creek NZE



Juneau, Fairbanks, Wasilla, Anchorage

2011 April 11-15

Gordon Howell, P.Eng.

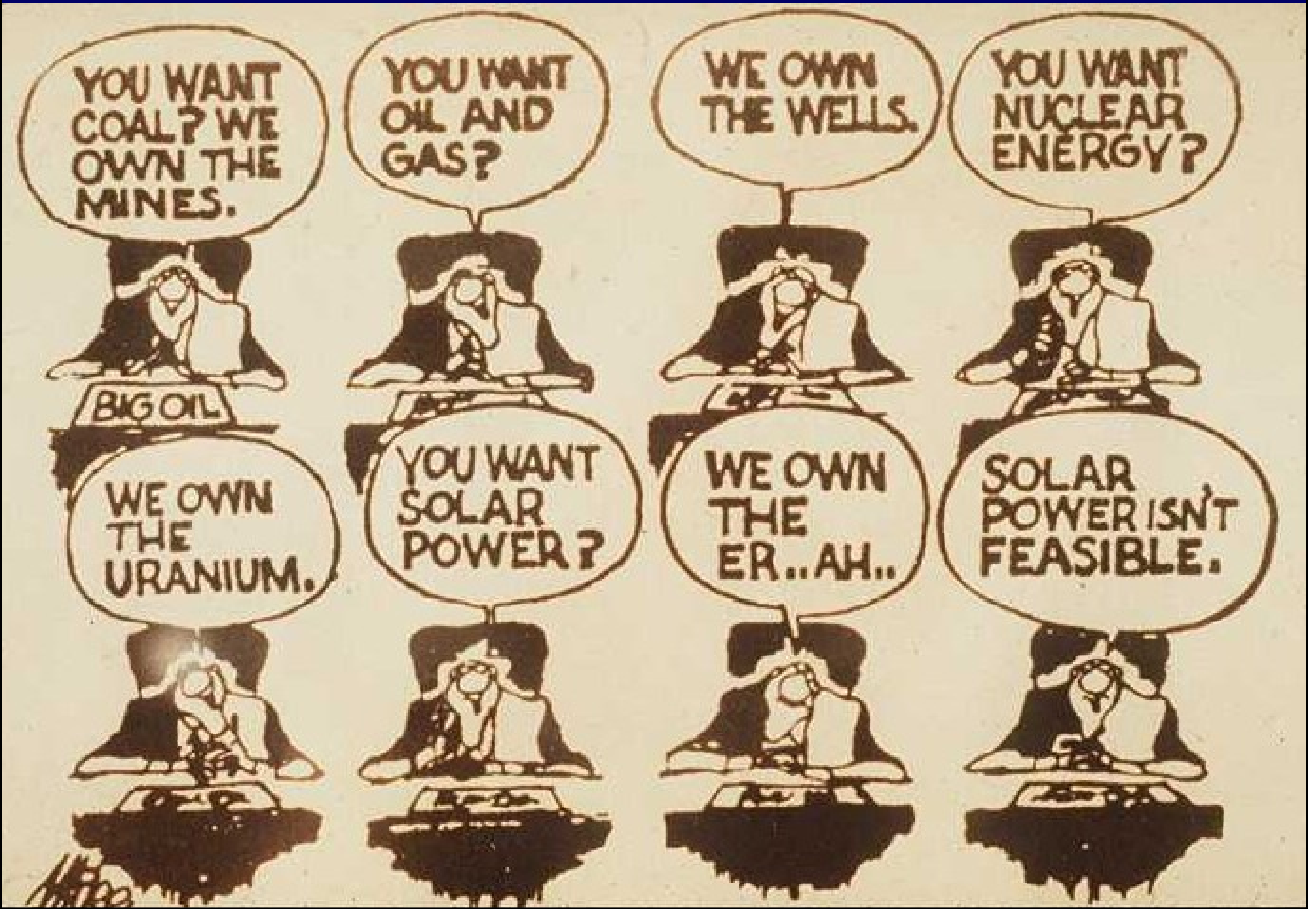
howell-mayhew engineering, inc.

Peter Amerongen

Habitat Studio & Workshop Ltd

Edmonton, Canada

Cartoon from 1979… Has anything changed?



Community Engagement

- We've been fascinated at how people have responded to our invitations to tour the Riverdale house.
- We kept a detailed log of our engagement with the community throughout the building and the demonstration period.

	# of	# of people
– tours:	147	8,800 from 16 countries (max. 1400 on one day)
– presentations:	73	6,300
– articles:	33	700,000
– TV:	41	1,500,000
– radio:	23	140,000
– newspaper:	15	400,000

Canada
Germany
Russia
Australia
Japan
China
America
Britain
South Africa
Uganda
India
France
Philippines
Korea
Spain
Nicaragua

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Presentation Outline

- Goal:
  - For you to be empowered to take your own steps in building a net-zero energy house.
- Process:
  - For you to see what we did;
  - What we've learned;
  - What we'd recommend;
  - How we've modelled a house in Juneau, Fairbanks, Wasilla, Anchorage.

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Energy Supply Choices…

– how do we decide???

- Electrical fixtures and appliances – electrical
- Water fixtures and appliances – water
- Building envelope – heating

} **Ultra-high efficiency <u>technologies</u>**

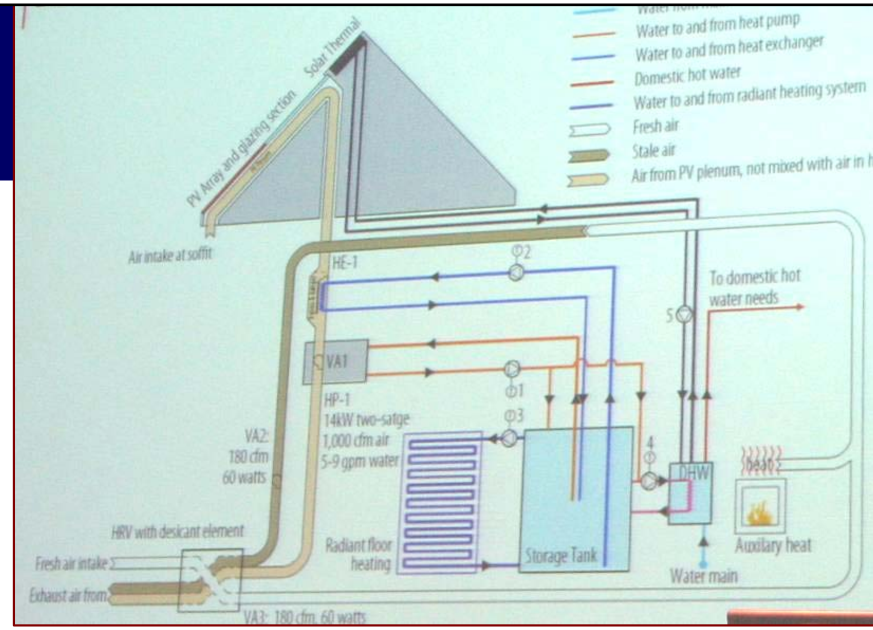
- Passive solar space heating…???
- Active solar liquid for domestic water heating…???
- Active solar liquid for space heating…???
- Active solar air for space heating…???
- Wood heating…???
- Heat pump: ground, air, water, solar…???
- Solar-electric heating: air circulation, electricity…???

} **Heating <u>technologies</u>**

- Solar photovoltaics…???
- Microwind…??? (likely not in urban settings)
- Microhydro…??? (likely in rural settings)

} **Electricity <u>technologies</u>**

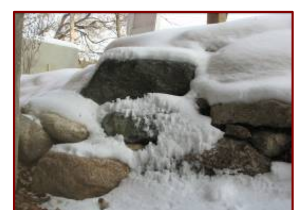
Design Guides…



- ***Keep it simple…***

- ***Complexity*** of systems ***is a concern*** with their:
  - Designing; Controls; Maintaining;
  - Modelling; Commissioning; Documenting; and
  - Installing; Operating; Homeowner training.

- ***Reduce # of House Energy Systems***:
  - Homeowners likely not familiar with most of the new energy systems in the house
  - Reduce the number of systems people have to deal with.
  - What are the heating options? Are they are really needed?…



Keep These Energy Functions Separate…

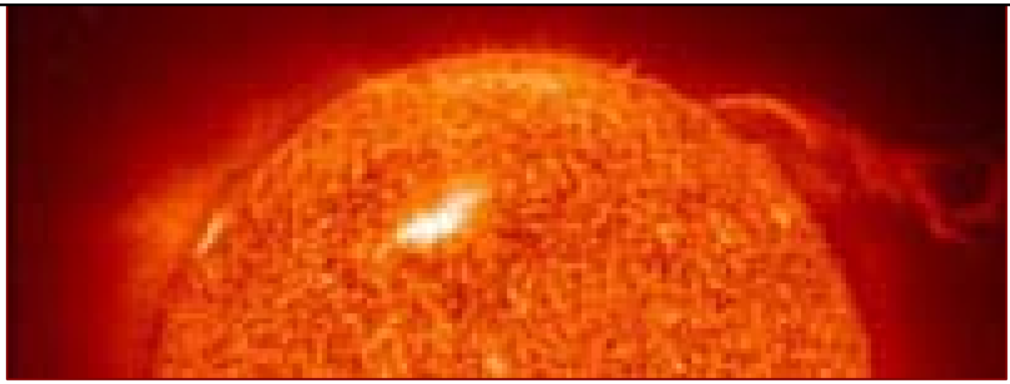
- **Heat energy**
  - **Space heating**
  - **Domestic water heating**

- **Electrical energy**
  - **Appliances, motors, lights, controls**

- Heat energy and electrical energy
  can be converted from one to another, of course

  I find it particularly valuable
  to consider heat and electricity separately
  because of their different supply technologies.






Energy, Power and Electricity

People's misunderstanding about them causes much confusion

– They are NOT the same –

(OK, so what are they…)



What Is Electricity?

- Electricity is **NOT** power
- Electricity is **NOT** energy
- Electricity **IS** electronic charges
- Electricity **CONTAINS** energy (not power) and we know how to extract it

just like

- Gasoline is **NOT** power
- Gasoline is **NOT** energy
- Gasoline **IS** a fuel
- Gasoline **CONTAINS** energy (not power) and we know how to extract it

Energy *vs.* Power – they are NOT the same

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Energy *vs.* Power – they are NOT the same

- **Energy** = power x time
  - the ability to do work
  - the ability to move an object over a distance

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Energy *vs.* Power – they are NOT the same

Analogy

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- **Power** = energy / time

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  - is a rate, is the flow of energy (the amount of energy used at any moment in time)

Analogy

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  - joules per second = watts (W) J / s → measured in m / s ft / s

Like speed:
- is not distance
- is the "flow" of distance

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Analogy

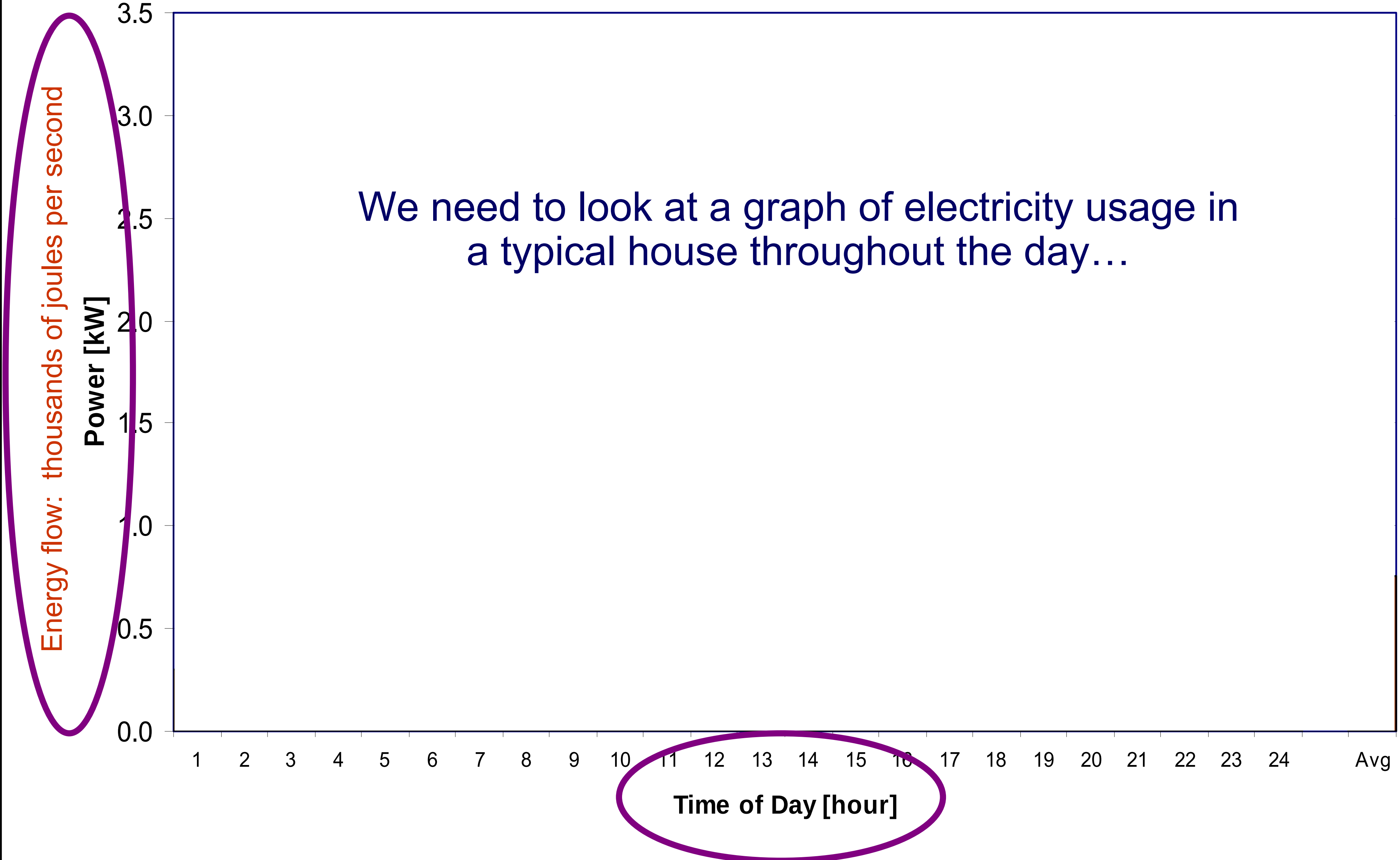
- **Energy** = power x time → Like **distance**
  - the ability to do work
  - the ability to move an object over a distance
- It is measured in
  - joules (J) → measured in metres (m) feet (ft)
  - kilowatt-hours (kWh) = power x time (kWh means "thousand x watts x hours")

- **Power** = energy / time → Like **speed**
  - is a rate, is the flow of energy (the amount of energy used at any moment in time)
    - is not distance
    - is the "flow" of distance
- It is measured in
  - joules per second = watts (W) J / s → measured in m / s ft / s

Electricity – what do we buy?

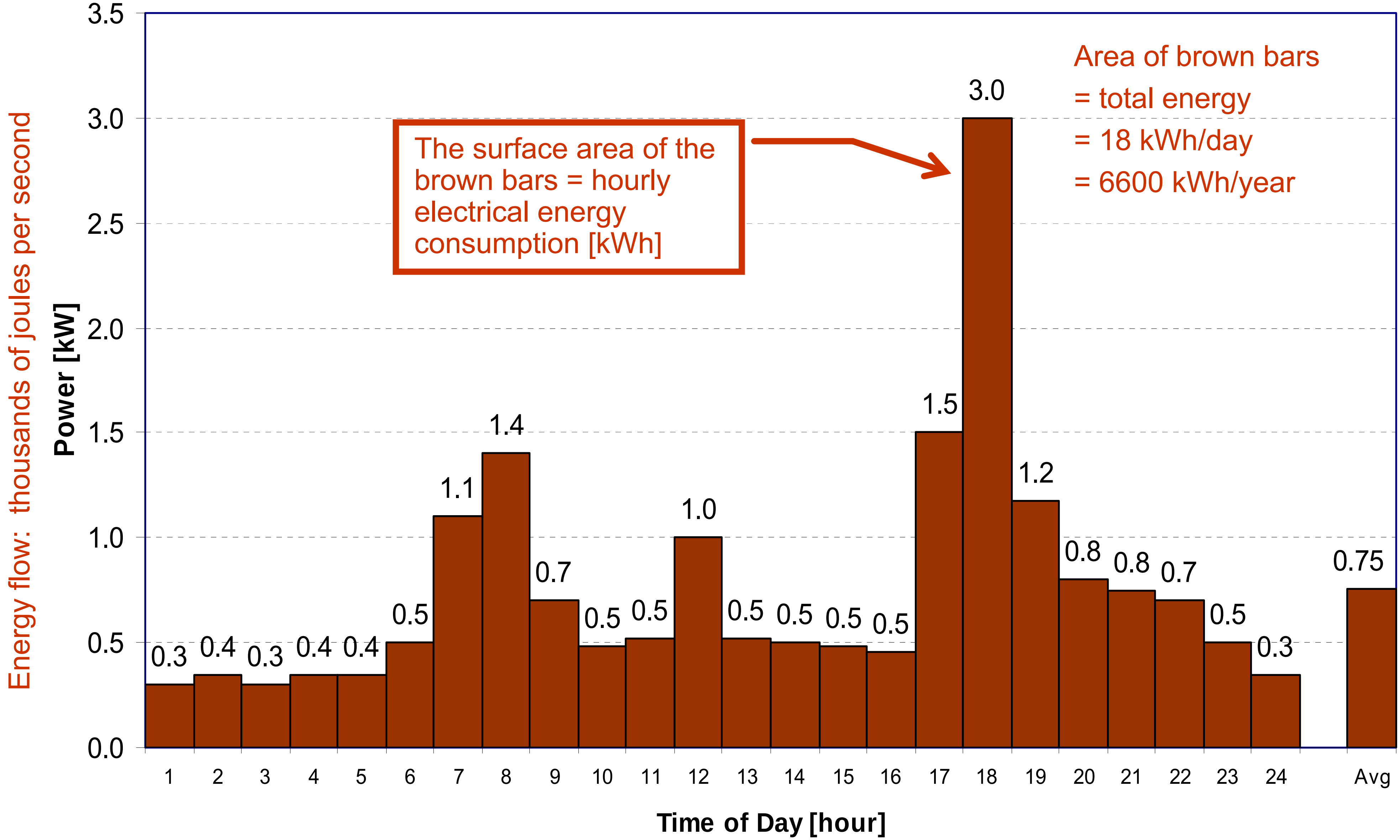
- When we buy electricity,
  we buy electrical **energy** (which is measured in kWh).
- We do **not** buy electrical power (which is measured in kW).
- Look at our electricity bills and our electricity prices
  and we will see kWh, not kW.
- kWh means "thousand x watts x hours"…
  - Forgetting the little "h" in kWh is **NOT** good and leads to mass confusion.
  - **Energy is NOT "kW / h", it is "kW x h"**
  - **Power is NOT "kW / h", it is "kW"** (= thousands of joules per second)

Power (of any sort) and Time



We need to look at a graph of electricity usage in a typical house throughout the day…

Electrical Energy



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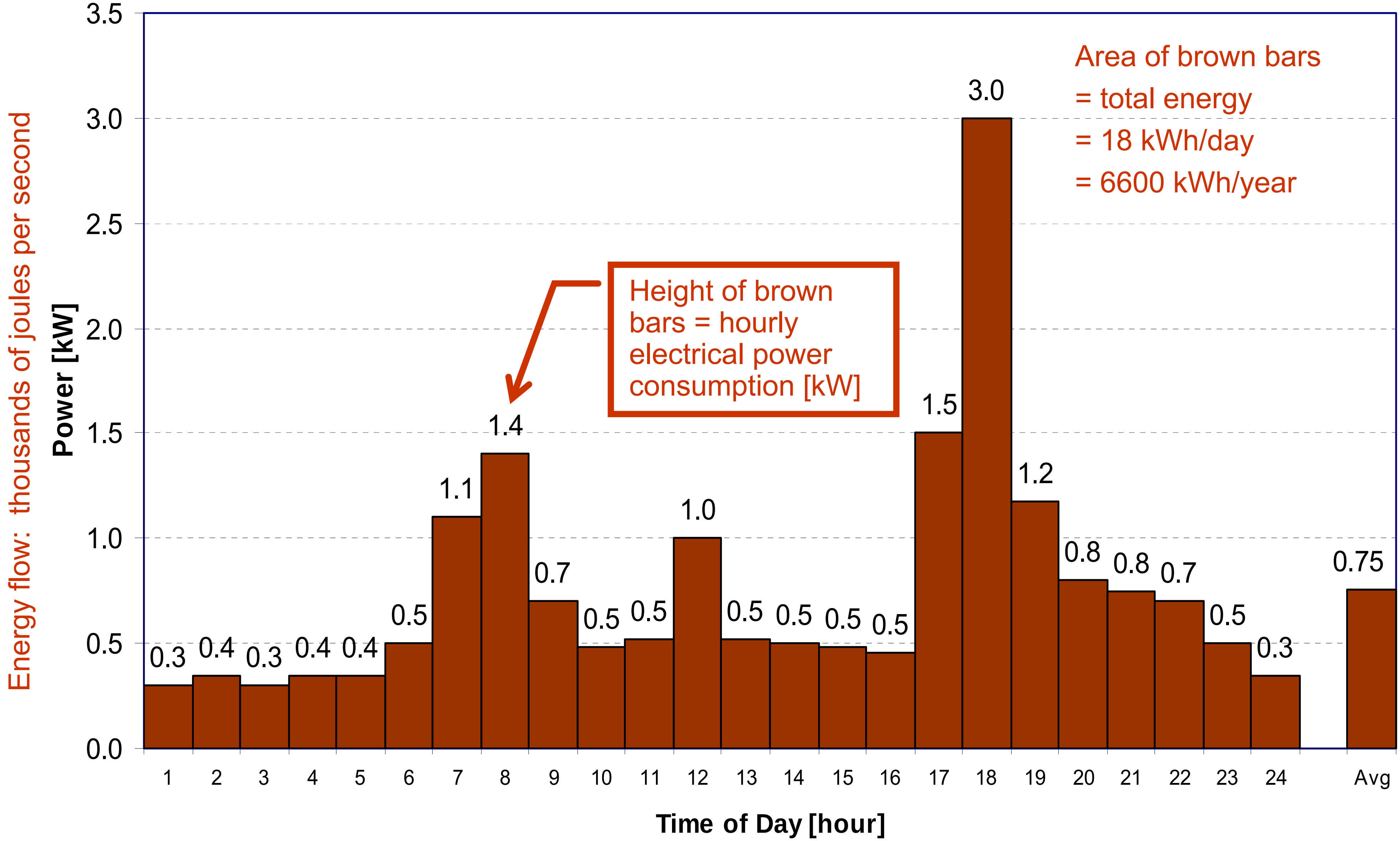
Electrical Power



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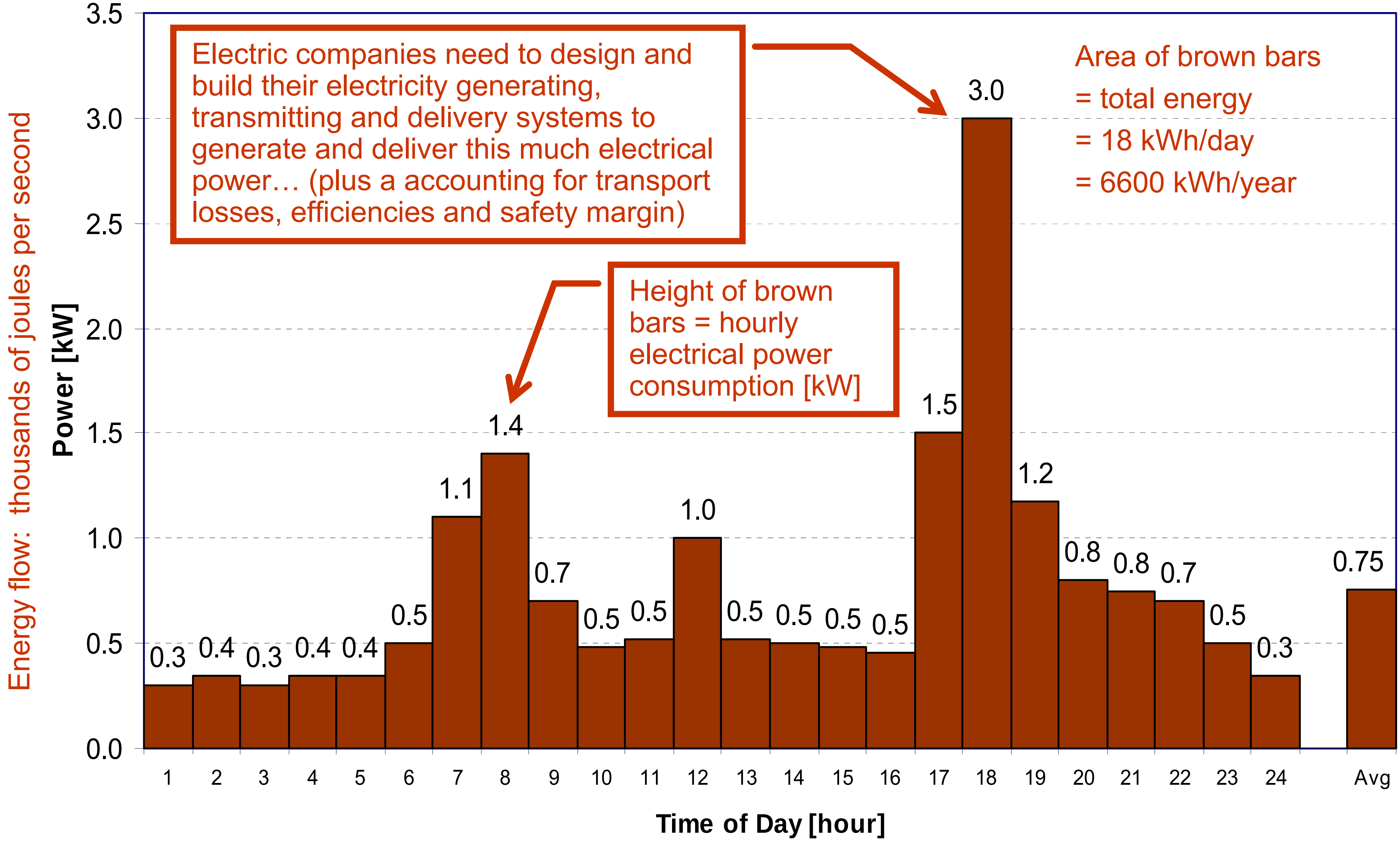
Electrical Power Capacity



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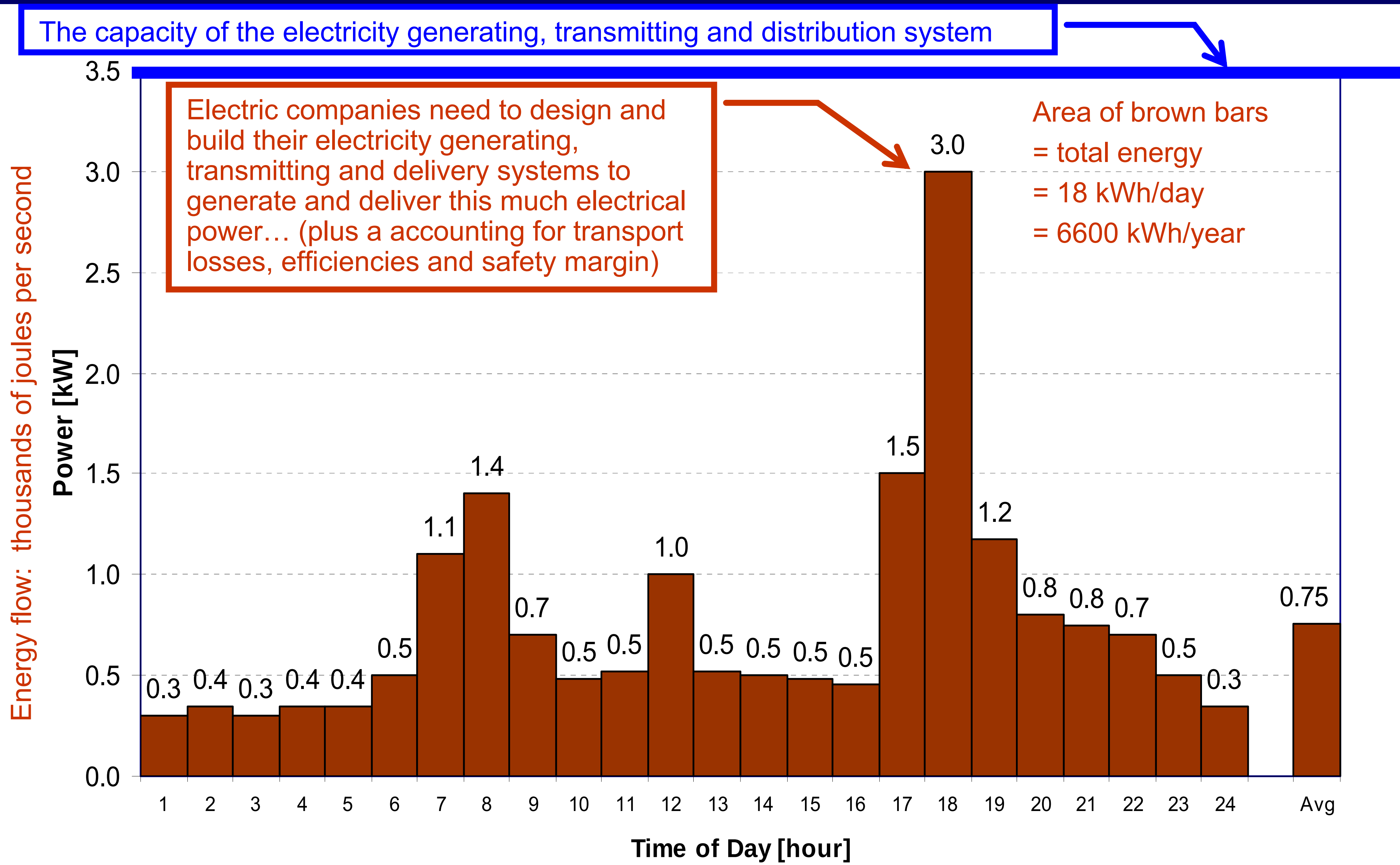
Electrical Power Capacity



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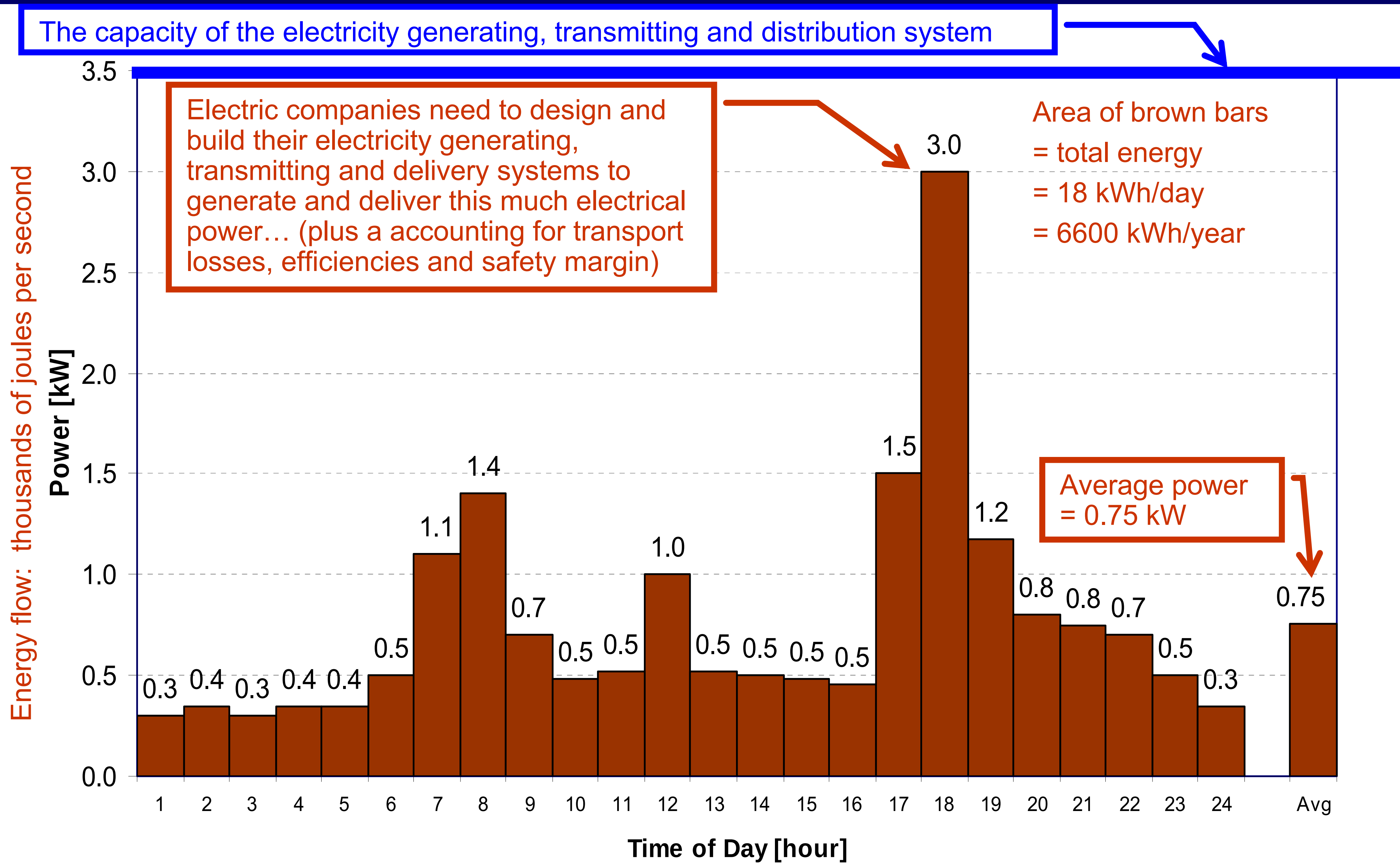
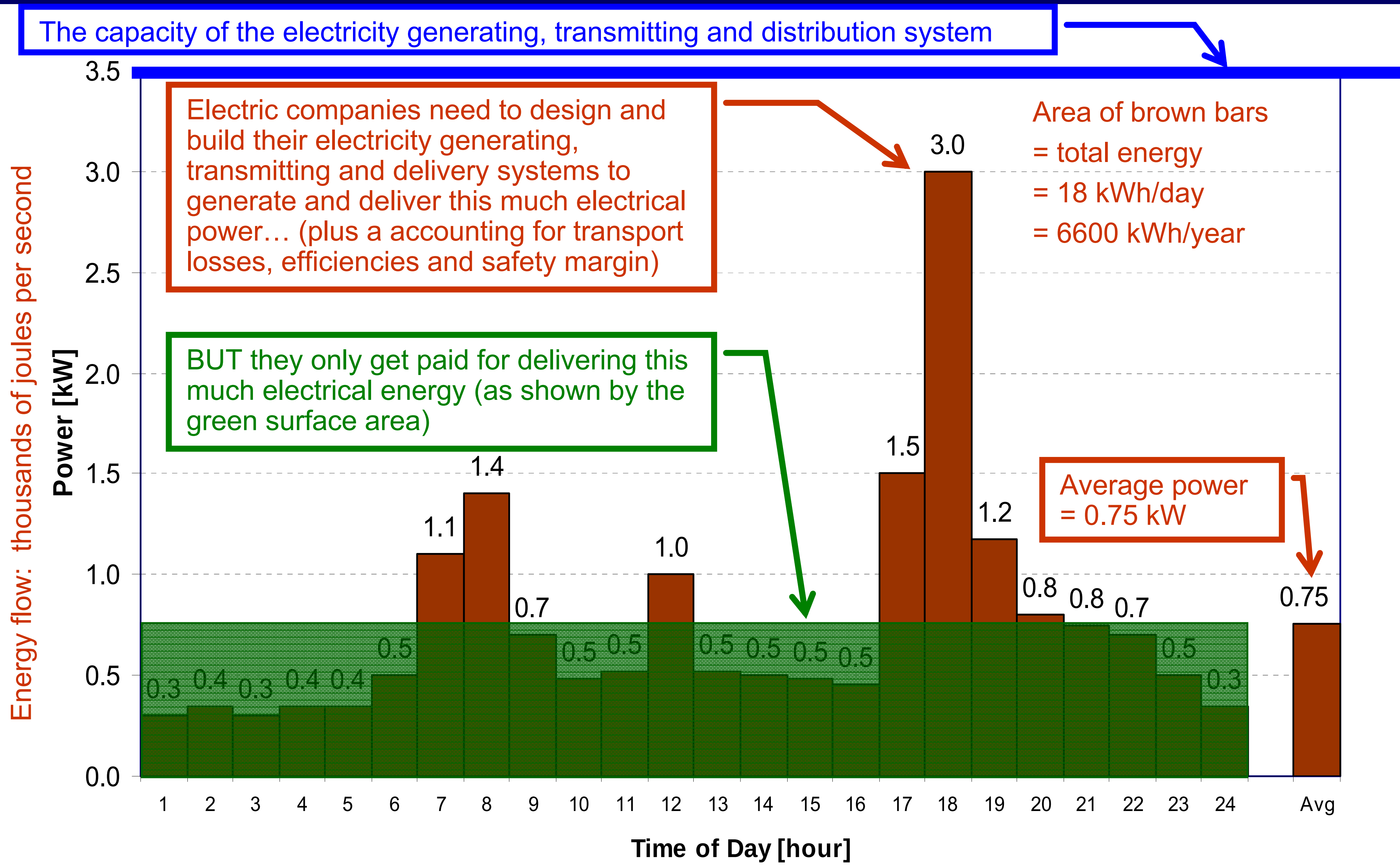
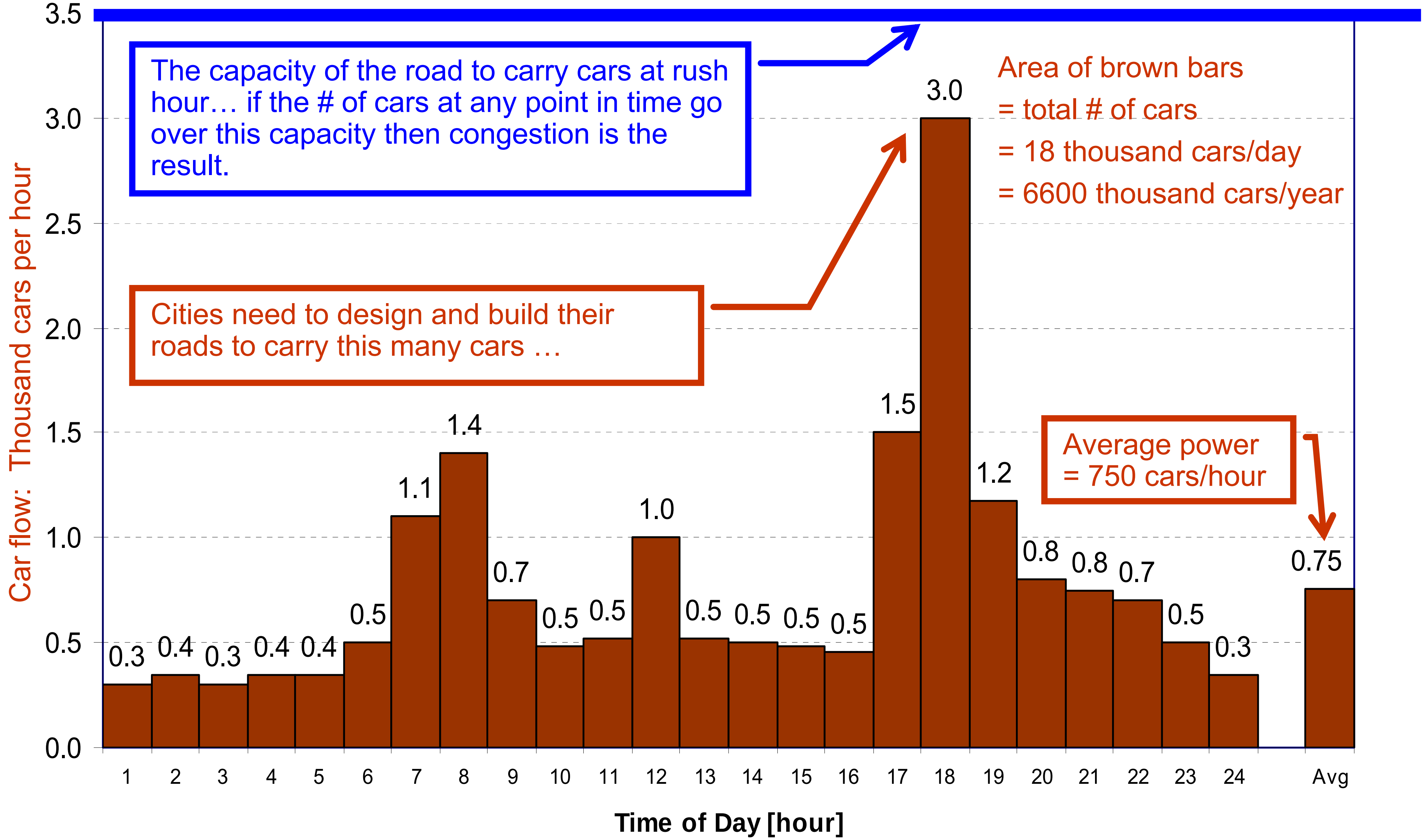
Electrical Power Capacity



Electrical Energy Revenue



Analogy to Roads…



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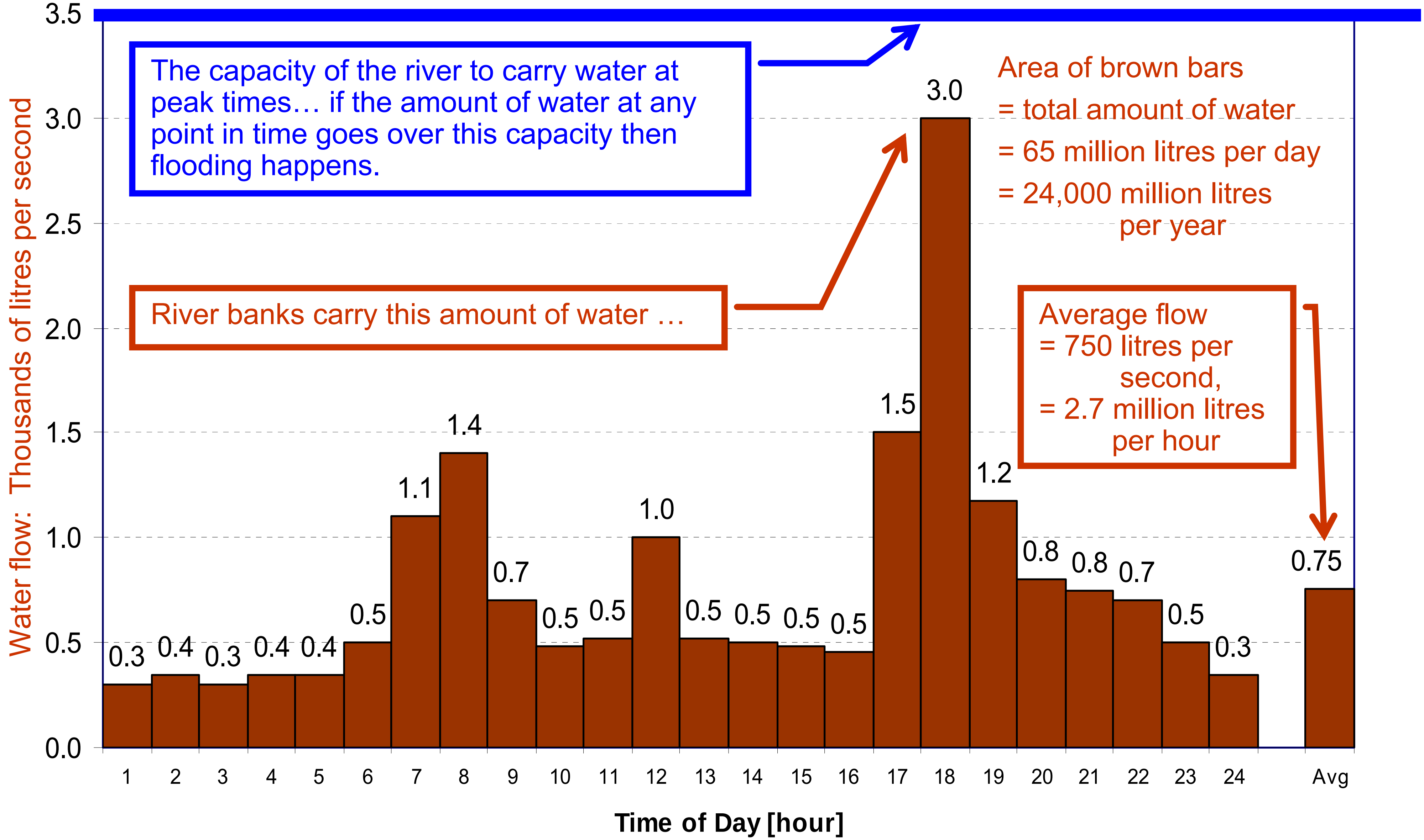
Analogy to Rivers…



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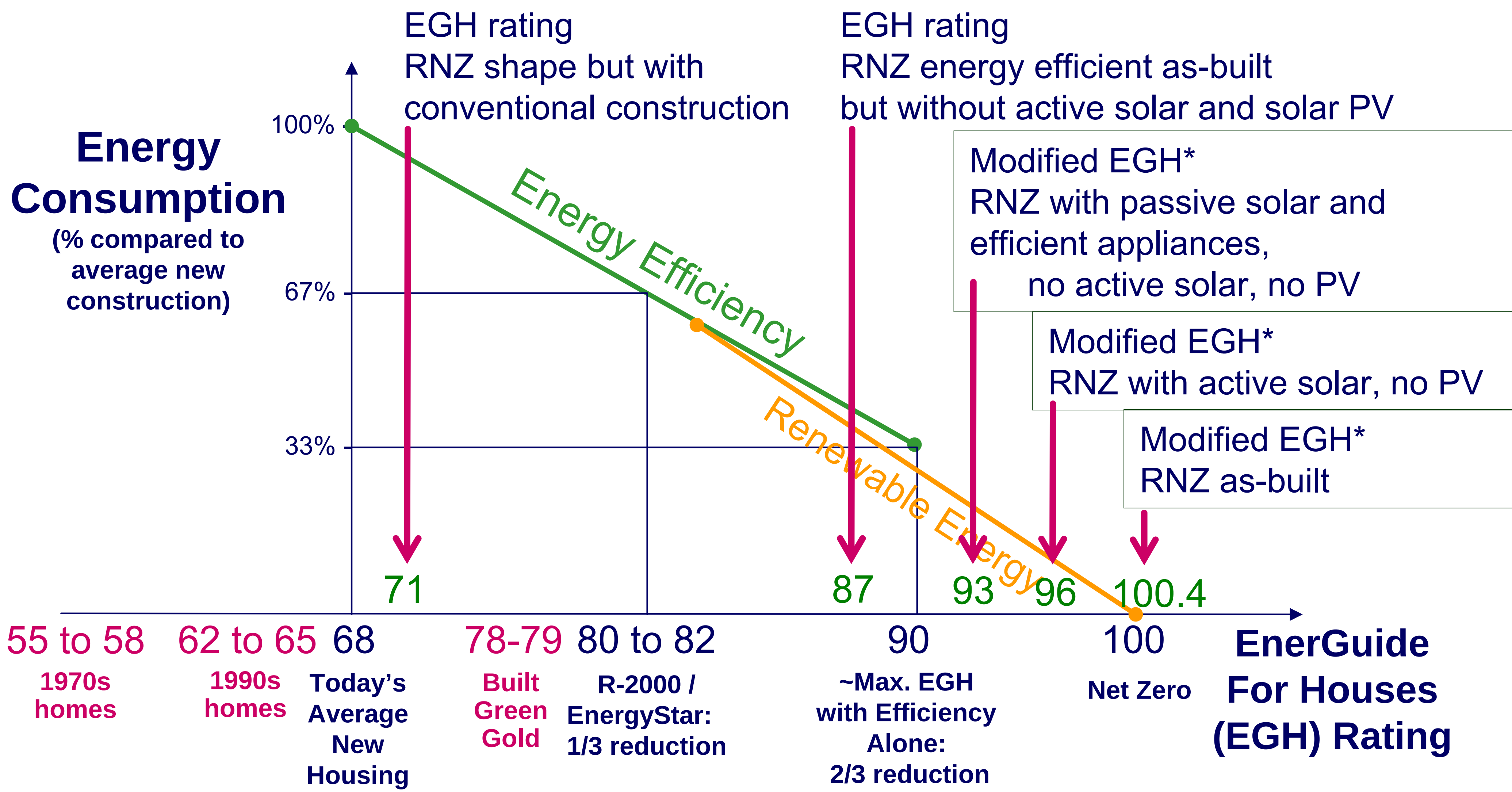
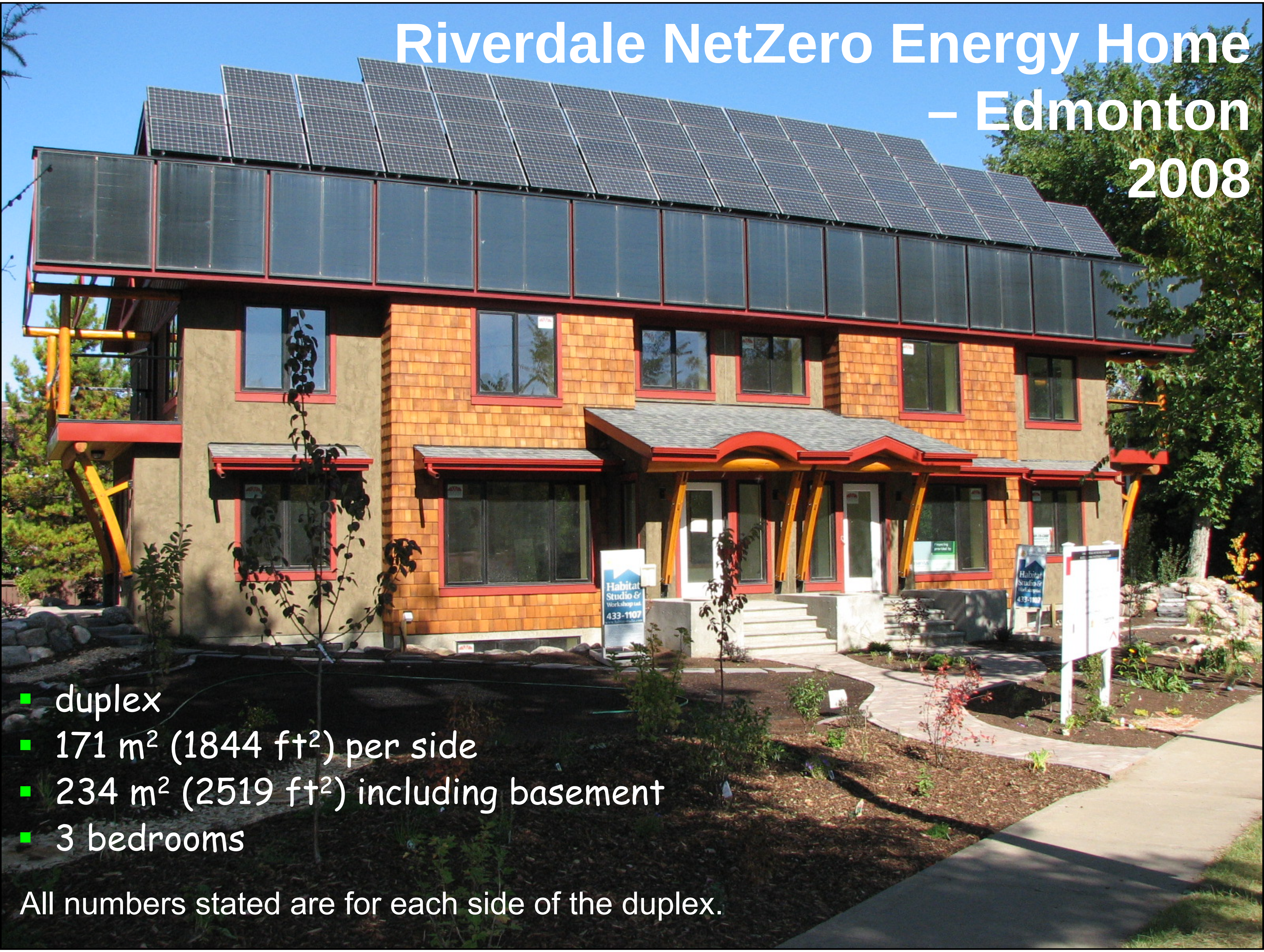
All Energy Supply Systems…

- Very important to understand
  as we discuss energy supply **systems**

- **ALL** energy supply **systems**
  (electrical grid,
  fuel grid (natural gas, propane, Diesel),
  electrical systems,
  heating systems)
  - Have a source of reliable **energy**
  - Have a source of reliable **power**
  - Have energy **storage**
  - Have **backup** of power (not energy)
    (energy systems usually do not run out of energy,
    but they can run out of power)

Efficiency & Renewable Energy to Get to Net Zero





Riverdale NetZero Energy Home – Edmonton 2008

- duplex
- 171 m² (1844 ft²) per side
- 234 m² (2519 ft²) including basement
- 3 bedrooms

All numbers stated are for each side of the duplex.

Mill Creek NetZero Energy House

- Single-family house
- 241 m^2 (2300 ft^2)
- Not including area of finished basement with suite

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Belgravia NetZero House

177 m² (1900 ft²)

(not including basement)

Energy Choices and Options

How do we work with these?

- Electrical fixtures and appliances – electrical
- Water fixtures and appliances – water
- Building envelope – heating

} Ultra-high efficiency <u>technologies</u>

- Passive solar space heating…???
- Active solar liquid for domestic water heating…???
- Active solar liquid for space heating…???
- Active solar air for space heating…???
- Wood heating…???
- Heat pump: ground, air, water, solar…???
- Solar-electric heating: air circulation, electricity…???

} Heating <u>technologies</u>

- Solar photovoltaics…???
- Microwind…??? (likely not in urban settings)
- Microhydro…??? (likely in rural settings)

} Electricity <u>technologies</u>

Focus of Our NZE House Energy Supply

- **Space heating**:
  - Direct-gain passive solar through south windows
  - Heat pump (air- or ground-source where passive solar is not enough)
- **Domestic water heating**:
  - Active solar thermal with flat-plate collectors using water in a drain-back configuration
  - Heat pump, if it is also being used for space heating

- **Electricity**:
  - grid-dependent solar PV
  - since solar PV is typically the most expensive energy source, then the whole of the net-zero energy design process is to minimise the size and cost of solar PV…

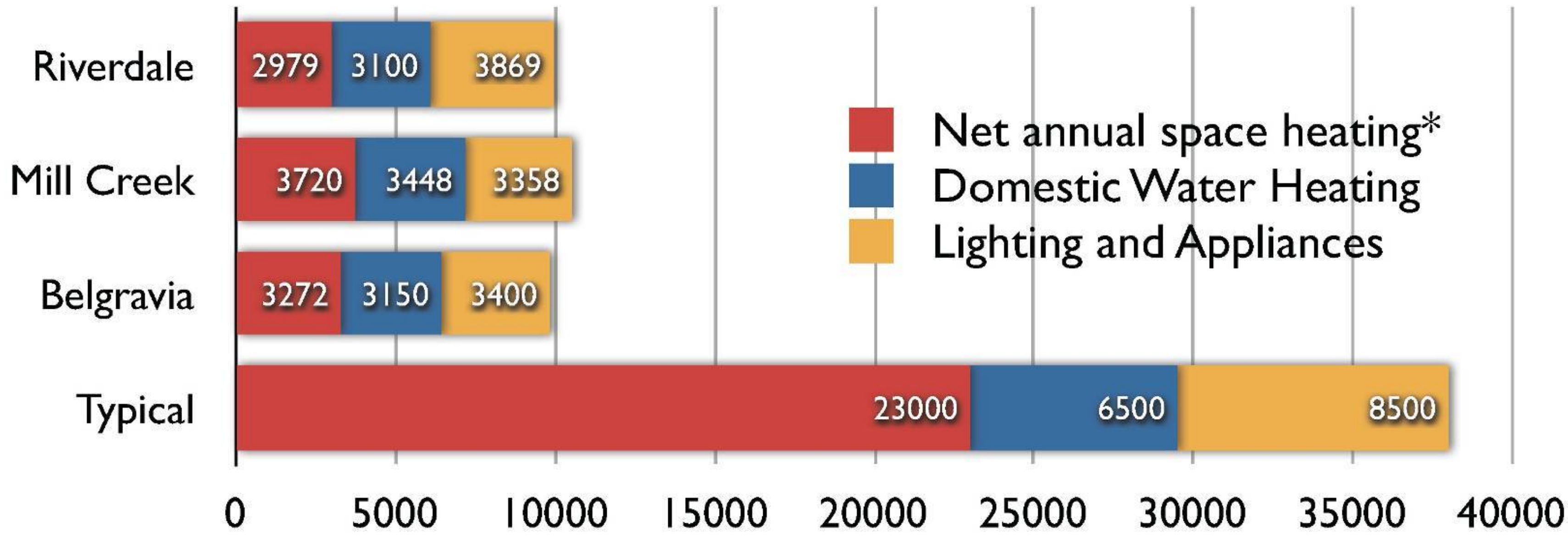
    however this is changing considerably these days because the price of solar PV is dropping quickly…

Next…

1. Energy Performance Modelling
2. Design Choices
3. Expected House Performance
4. Costs and economics
5. What we've learned…

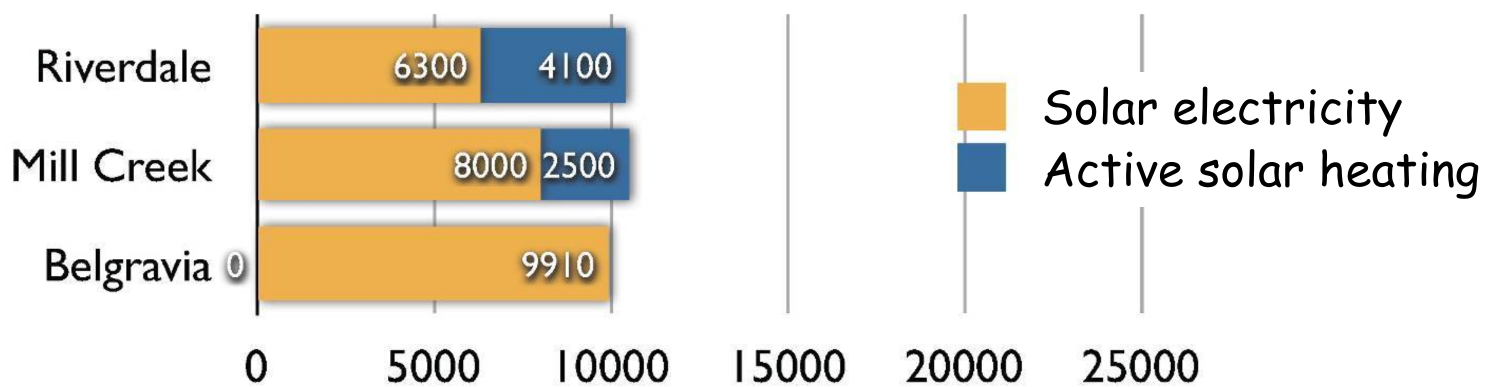
The only thing lacking is some form of leadership
… to focus the public will to make it happen.

Total Annual Energy Consumption (kWh/year)



*After accounting for passive solar and internal gains

Total Solar Energy Production * (kWh/year)



*not including passive solar

Energy Performance Models Employed

- Very very important to simulate the performance of each energy system
- **We used simple modelling**:
  HOT 2000, RETScreen, and custom Excel spreadsheets
  plus lots of previous experience in energy efficiency and solar PV

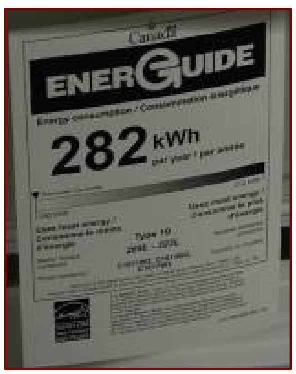
	what we used for modelling:
▪ Domestic electricity consumption	– spreadsheet
▪ Water consumption	– spreadsheet
▪ Building envelope	– HOT 2000
▪ Passive solar heating	– HOT 2000
▪ Active solar heating	– modified RETScreen
▪ Solar PV generation	– RETScreen, PV SYST, spreadsheets
▪ Electric space heating	– spreadsheet
▪ Net zero energy goal	– spreadsheet

(download RETScreen for free from www.retscreen.net)

System Modelling Software

- No budget or expertise (or time) to use TRNSYS or other detailed models (though it would have been great to have the results from them)
- Several pieces of software are available:
  - Energy efficiency: RETScreen, PassivHaus Planning Package, Energy Plus, BEOP
  - Passive solar: ?
  - Solar thermal: RETScreen, Polysun, T*SOL
  - Wood heating: table of wood heating values?
  - Heat pumps: RETScreen, ? (ask the industry)
  - PV: RETScreen, PV SYST, PV*SOL, Polysun, HOMER, PV WATTS, Maui Solar
  - Micro-wind: RETScreen, ? (ask the industry)
  - Micro-hydro: RETScreen, ? (ask the industry)
  - Likely many more modelling software is available

Modelling Process – Energy Efficiency …1

Efficiency Component	Modelling Software and Process
▪ **Electrical fixtures & appliances**    	❖ Made a **spreadsheet** that – listed all electrical devices in each room – estimated for each device: ▪ power rating, ▪ likely daily operating duration per month, ▪ likely days of operation per week, ▪ used EnerGuide ratings for major appliances – incorporated phantom load control switches – total of 3800 kWh/year was used as baseload ❖ "Simulated" my own electrical usage and was pleasantly surprised at the results
▪ **Water fixtures & appliances**   	❖ Made a **spreadsheet** to contain water fixture flow data from various info sources ❖ To help make an educated guess – daily potable water 330 litres, hot water 100 litres

Modelling Process – Energy Efficiency …2

Efficiency Component	Modelling Software and Process
▪ **Building envelope**  	❖ Used NRCan's **HOT 2000**. – Did several iterative simulations along with external solar thermal and PV modelling to achieve goal of the smallest solar thermal and solar PV systems ❖ HOT 2000 has many strengths & many weaknesses – strengths: free, fast, easy to use, validated, flexible, very useful results, strong on building envelope and basement heat loss – weaknesses: bugs, quirky interface, awkward output, too many significant digits displayed in the output numbers, documentation not great – Results for ultra-efficient envelope appear to be conservative (which can be good)

Modelling Process – Passive Solar

Heating Component	Modelling Software and Process
▪ **Passive solar thermal for space heating**	❖ Used <u>**HOT 2000**</u> – <u>strengths</u>: simple to use – <u>weaknesses</u>: overheating estimates, thermal mass not well described, only direct-gain configuration, overhangs ❖ Fixed overhangs are an issue in controlling passive solar space heating because the August sun angles (when you want shading) are the same as the April sun angles (when you want heating)

Modelling Process – Active Solar …1

Heating Component	Modelling Software and Process
▪ **Active solar liquid-thermal for domestic water heating**	❖ Used NRCan's **RETScreen** – strengths: free, fast, easy to use, lots of product info & solar data, angle calculations, easy to use, nice system costing framework, very nice economics & GHG analysis sections – weaknesses: huge size of data files, some awkwardness with interface ❖ Used NRCan's WATSUN (Mill Creek House) ❖ Did not use HOT 2000 because of concerns with its active solar DWH modelling process

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Modelling Process – Active Solar …2

Heating Component	Modelling Software and Process
▪ **Active solar liquid-thermal for space heating**	❖ Used **RETScreen** – weaknesses: doesn't permit monthly loads ❖ Used **HeatVision** – proprietary hour x hour spreadsheet used by solar thermal collector supplier – No other info is known about it. ❖ Did not use HOT 2000 because of concerns with its active solar modelling.
▪ **Active solar air-thermal for space heating**	❖ Did not consider this ❖ Not aware of modelling software

Modelling Process – Heating Supply …3

Heating Component	Modelling Software and Process
▪ **Ground-source heat pump** **(also called geothermal)**	❖ Used the marketing claims about COP to estimate the annual electrical energy required to operate it ❖ Considered this technology, but did not use it because we found it to be too expensive for the small amount of additional heat that we needed… This could be very good to use on a larger house, or if we didn't have active or passive solar thermal space heating.
▪ **Air-source heat pump (like an air conditioning system)**	❖ Did not consider because we perceived that it would not work in the winter in Edmonton ❖ It could be worth re-evaluating
▪ **Water-source heat pump**	❖ Did not consider for an urban house ❖ Would likely treat it like a ground-source heat pump

Modelling Process – Heating Supply …4

Heating Component	Modelling Software and Process
▪ **Solar PV-thermal air** (recovery of heat off the back of solar PV array)	❖ Not aware of modelling software or case studies to give us confidence to try this
▪ **Electric resistance**	❖ Made a **spreadsheet** to account for the annual amount of electricity used by resistance heaters for space and water heating ❖ As with all electric loads in the house, the electric heaters are energised either by PV directly, by both PV and the grid, or by the grid solely and re-supplied by PV in the summer ❖ No accounting for electric loads co-incident with PV generation – Expect 70% to 80% of PV energy to be exported to the electric grid

Modelling Process – Electricity Supply …1

Electricity Component	Modelling Software and Process
▪ **Solar PV**	❖ Used **RETScreen** plus experience borne from monitoring several solar PV systems – strengths: lots of product info & solar data, easy to use, costing framework, good economics & GHG analysis – weaknesses: huge data files, no consideration for snow cover, has two significant loss coefficients that can skew results for uninformed users ❖ Made a PV system performance **spreadsheet** linked to RETScreen data to present monthly performance and graphs ❖ For Mill Creek NZE house, made a **spreadsheet** to consider snow cover for each month at various tilt angles plus monthly shading – Based on premise that local knowledge of snow conditions provides better results than ignoring snow cover ❖ Did not use HOT 2000 because it did not allow PV electricity to be exported to the grid (at that time) ❖ Other simulation software: PV SYST, PV*SOL, Maui Solar

Modelling Process – Electricity Supply …2

Electricity Component	Modelling Software and Process
▪ Microwind	❖ Did not consider this ❖ Probably would not be used in urban settings ❖ Would likely use data from the Canadian Wind Energy Atlas www.windatlas.ca plus RETScreen plus ask wind colleagues

Modelling Process – NetZero Goals

The Journey to Net Zero	Modelling Software and Process
▪ **Summary of the performance and costs of all the technologies and strategies**	❖ Made a **spreadsheet** based on CMHC's NZE EnerGuide algorithms. ❖ Energy and cost data is entered from other software models – It contains all performance data in one place. – It prepares summaries, portions and charts to show how the house is progressing towards the NZE goal. ❖ Helps NZE designers organise strategies and evaluate energy and cost options.

Next…

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Designing for Net Zero

- Do a site assessment
- Do a preliminary design
- Model energy performance in the HOT2000 software
- Optimise the building envelope
- Optimise passive solar
- Reduce the DWH load
- Reduce the lighting and appliance loads
- Examine and model solar DWH
- Examine and model geothermal
- Size solar PV to meet remaining total load
- Finish detailed architectural and system design

Design: Heat Sources

	Riverdale	Mill Creek	Belgravia
Source of heat for space:	Domestic electricity Passive solar thermal Active solar thermal Electric resistance supplied by PV and the grid	Domestic electricity Passive solar thermal Active solar thermal **(excess from solar DWH)** Electric resistance resupplied by PV and the grid **Scrap wood**	Domestic electricity Passive solar thermal Electric resistance resupplied by PV and the grid
Heat distribution:	**Fan-coil forced air**	**Electric baseboard**	**Electric baseboard**
Source of heat for domestic hot water:	Drain water heat recovery Active solar thermal Electric resistance supplied by PV and grid	Drain water heat recovery Active solar thermal Electric resistance supplied by PV and grid	Drain water heat recovery Electric resistance supplied by PV and grid

(words in red show differences between houses)

Design: Passive Solar Space Heating

	Riverdale	Mill Creek	Belgravia
Window area:	**17** m^2 **10**% of floor area	**23** m^2 **11**% of floor area	**23** m^2 **12**% of floor area
Energy production:	4400 kWh/year 40% of space heat	**8300** kWh/year **50%** of space heat	**8600** kWh/year **61%** of space heat
Direction of windows:	**22**° E of S	Due **south**	Due **south**
Thermal mass:	Basement floor Concrete counter tops **Concrete pillars in feature walls**	Basement floor Concrete counter tops **65 mm concrete floors on main and second floors**	Basement floor Concrete counter tops **65 mm concrete floors on main and second floors**

Design: Active Solar Heating

	Riverdale	Mill Creek	Belgravia
Heating loads:	**Combined** space and domestic water heating	Domestic water heating with a **minor amount of space heating in shoulder seasons**	**None**
System configuration:	Water-based drainback configuration	Water-based drainback configuration	**Not used**
Brand of collectors:	**Zen** (Belgium), flat-plate	**Trimline** (Canada), flat-plate	
Collector array:	**Seven**, **21** m^2, **vertical** tilt, **22**° E of S	**Three**, **12** m^2, **53**° tilt, due **south**	
Heat storage:	**17,000** litres + **300** litres	**1500** litres + **175** litres	
Expected production:	**4200** kWh/year (modelled)	**2500+** kWh/year (modelled)	
Backup heating:	6 kW electric heater in small tank	4.5 kW standard electric water heater	

Wood Heating

This is not counted into the NZE equation.

	Riverdale	Mill Creek	Belgravia
Type of system:	**not** used	**Wood stove**	**not** used
Source of heat:		Scrap wood from construction sites	
Purpose:		Provide heat-energy security Send more PV electricity back into the grid	
Brand of stove:		Scan Anderson 10 (Denmark)	
Capacity:		3 to 10 kW, 78% efficient	
Simulation:		Not simulated, not aware of any modelling software	
Expected production:	0 kWh/year	Maximum of 1500 litres of wood per year if all heating systems failed. (except the homeowners loved their fireplace so much they used all their wood pile in the 1st winter!)	0 kWh/year

Design: Solar PV System

	Riverdale	Mill Creek	Belgravia
Configuration:	Grid-dependent, no battery bank	same…	same…
Brand of PV modules:	28 Sanyo **200** W **monofacial**	12 Sanyo **190** W **monofacial** 20 Sanyo **186** W **bifacial**	36 Sanyo **205** W **monofacial**
PV array:	**5.6** kW, 33 m^2, 53° tilt, **22**° E of S	Total: **6** kW, due S **2.3** kW, 53° tilt **3.7** kW, **variable** tilt	Total: **7.4** kW, due S **2.5** kW at **60°** tilt, **4.9** kW, **variable** tilt
Inverter:	SMA SunnyBoy **6000**	SMA SunnyBoy **3000**, **4000**	SMA SunnyBoy **3000**, **5000**
Energy storage:	"on the grid"	"on the grid"	"on the grid"
Expected generation:	**6600** kWh/year (measured)	**~8000** kWh/year (modelled)	**~9700** kWh/year (modelled)
Annual surplus or deficit?	surplus of 500 to 1000 kWh	surplus of 1000+ kWh	surplus of 1000+ kWh

Energy Consumption Summary

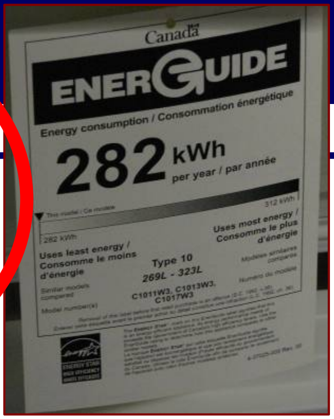
	Riverdale	Mill Creek	Belgravia	Typical Alberta house	Passiv Haus
Annual Space Heating/Cooling (kWh/year)	3000	3200	3000	23,000	
Annual Space Heating/Cooling (net of passive solar & internal gains) (kWh/year/m2)	15	15	14	90	15
Lighting and Appliances (kWh/year)	3900	3400	3100	7500	
Domestic Water Heating (kWh/year)	3100	3400	2900	8300	
Total Annual Energy (kWh/year)	9900	10,000	9100	49,000	
Total Annual Energy (kWh/year/m^2)	43	46	41	160	42
Net Energy from Grid (kWh/year/m^2)	-3	-3	-3	160	42

Brentwood Apartments NetZero Ready

- Ultra low space heating was not a problem – using ultra EE and GSHP
- Biggest issue was very high electricity consumption per m^2 of exposure to the sun because we are packing people in on top of each other…

#1. Domestic Electricity

- Electricity consumption reduced by **50%**
  - ❖ EnerGuide energy efficient appliances
  - ❖ ECM ventilation motors
  - ❖ Lighting
    - – compact fluorescent, LEDs,
    - – halogen task lighting
    - – daylighting
  - ❖ Phantom load control
- Domestic electricity consumption calculated to be 3800 kWh/year (2800 kWh saving) (compared to 6600 kWh/year for average household)



Fridge

Clothes dryer

Dishwasher

- LED lighting:
  Dining room
  Living room
  Master bedroom

CF lighting

#2. Domestic Water Heating

Drain water heat recovery

- Fuel consumption for water heating reduced **75%**
  - Water efficient shower heads, faucets,
  - EnerGuide dishwasher, clothes washer
  - Shower drain water heat recovery (50% recovery)
- Hot water 105 litres per day (28 Amgal)
  (compared to 227 L/day average (60 Amgal))
- Potable water modelled at
  330 litres per day (87 Amgal)

Shower heads and faucets

Dish washer

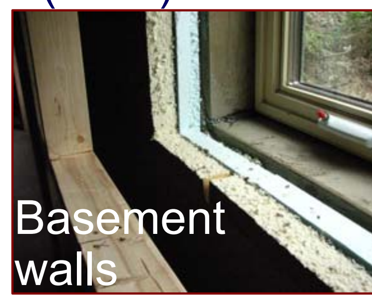
Clothes washer

#3. Building Envelope

- Fuel consumption for space heating reduced by **70%**
  - Ultra high insulation levels
  - High performance windows
  - Ultra low air leakage rate
  - High efficiency heat recovery ventilator
- Space heat consumption modelled at 10,800 kWh per year (39 GJ/year, 37 MMBTU))
- Heat loss at -32°C = 6600 W (22,500 BTU/h), = 6 hair dryers

Ceiling Usi-0.057 (R-100) cellufibre

Double-stud 2x4 walls with Usi-0.10 (R-56) cellufibre



Basement walls

Usi-0.105 (R-54)

Windows

Triple glazed

south:
Usi-0.78 (R-7.3)

East/West: Usi-0.68 (R-8.3)

North windows

Quadruple glazed

Usi-0.57 (R-10)

Air tight envelope

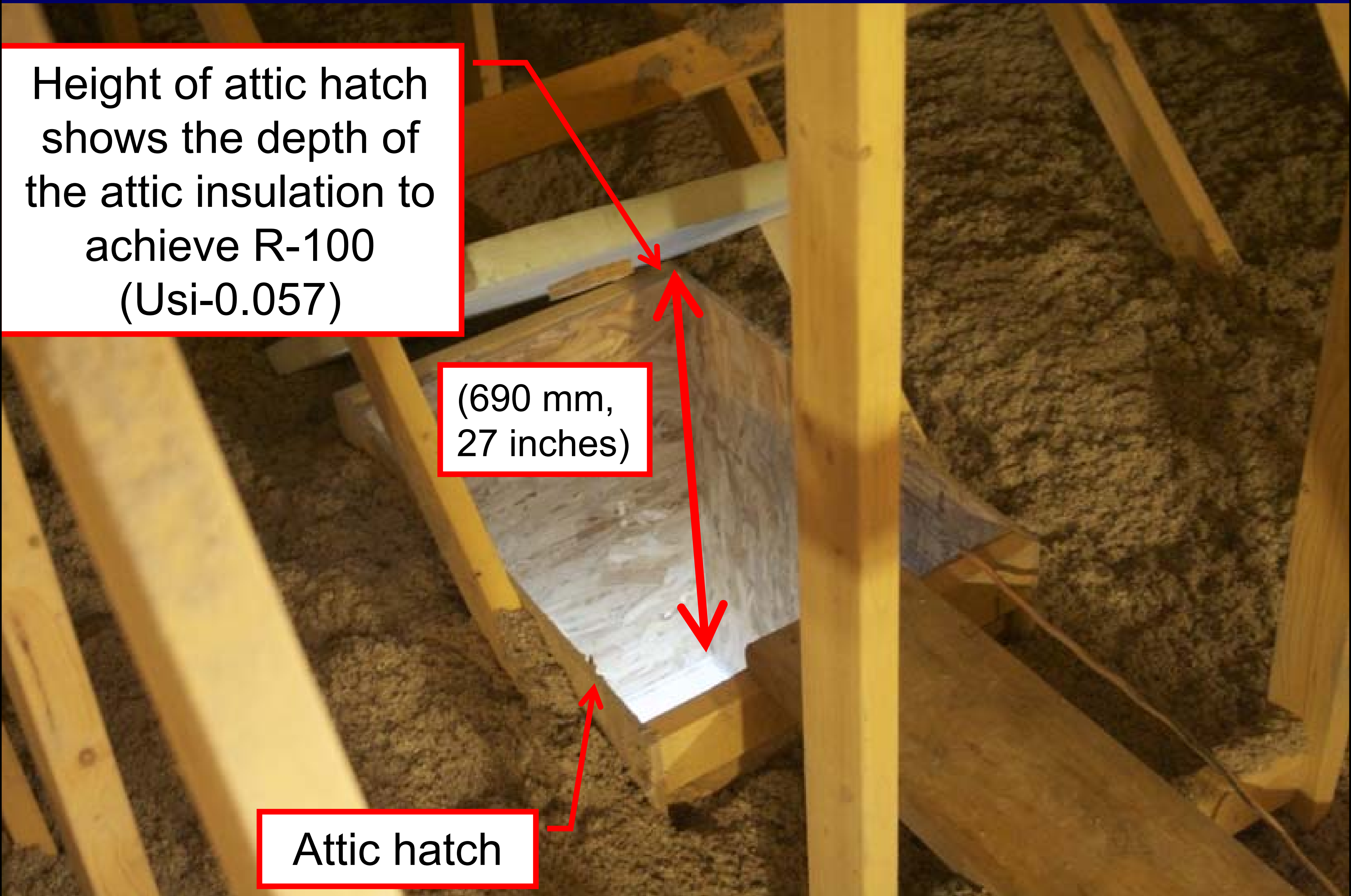
0.50 AC/h

Heat recovery ventilator

72% efficient

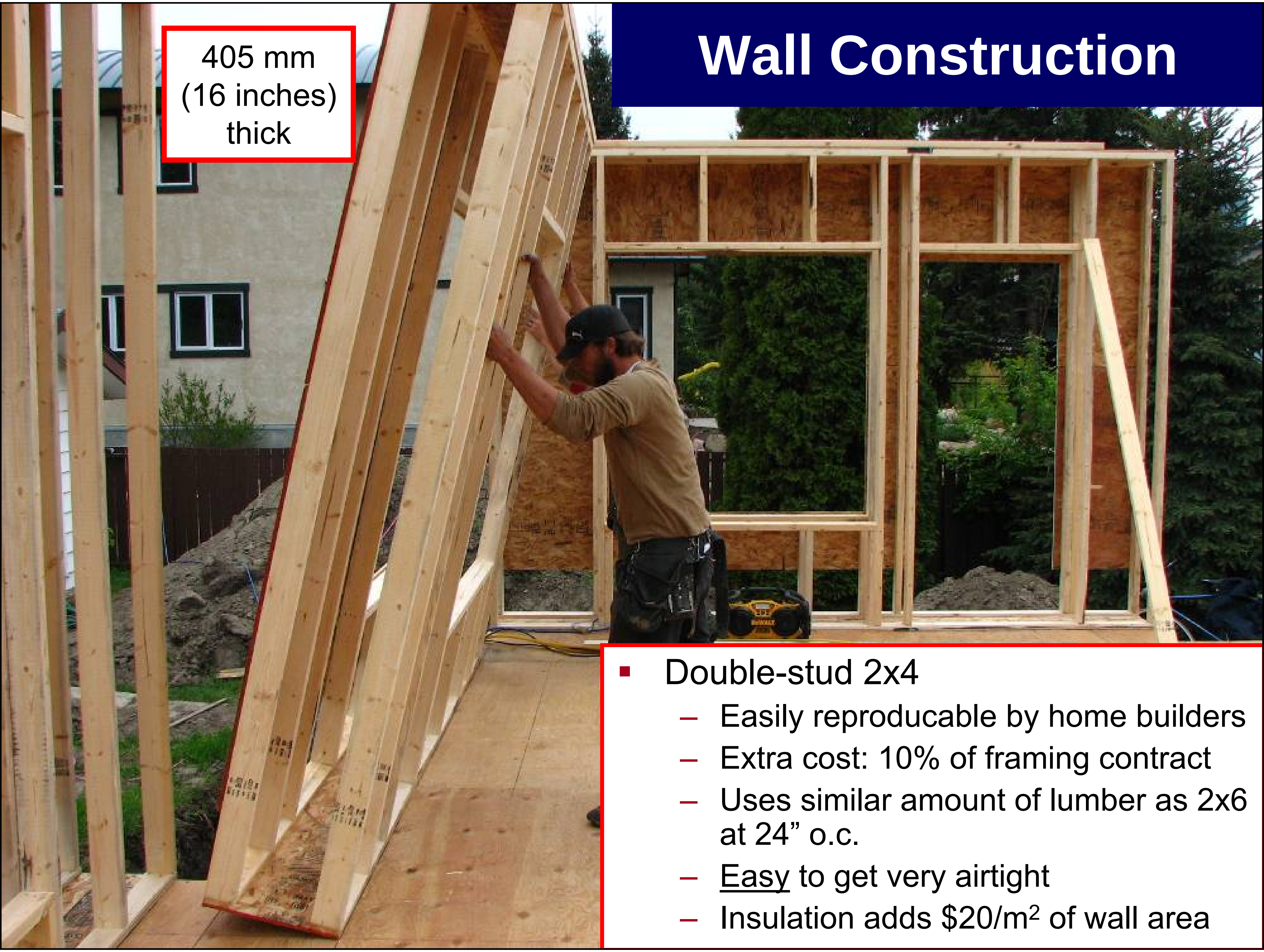
Basement floor Usi-0.237 (R-24)

Ceiling Insulation

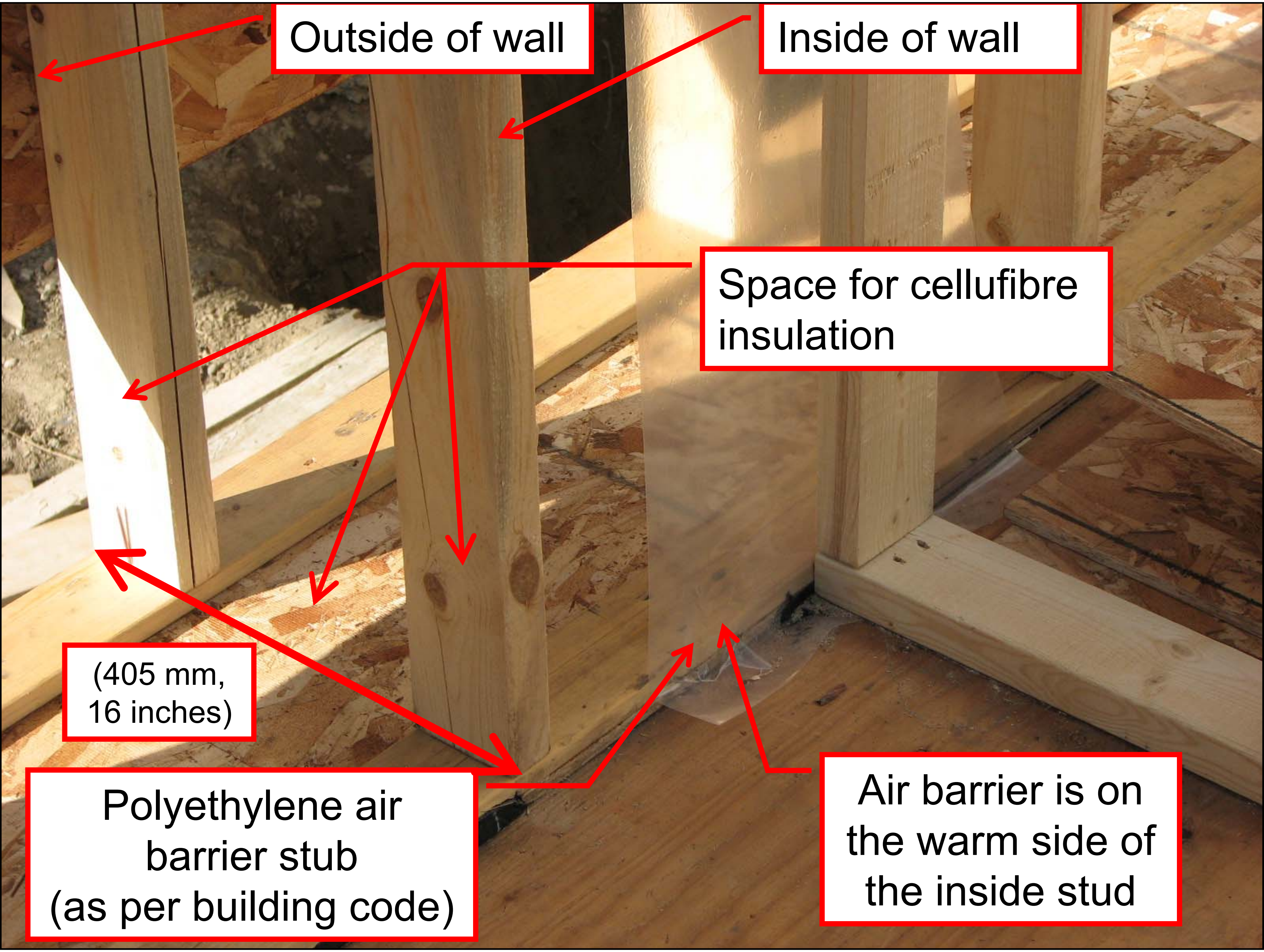


Ceiling Insulation

Wall Construction



- Double-stud 2x4
  - Easily reproducable by home builders
  - Extra cost: 10% of framing contract
  - Uses similar amount of lumber as 2x6 at 24” o.c.
  - <u>Easy</u> to get very airtight
  - Insulation adds $20/m² of wall area



Outside of wall
Inside of wall
Space for cellufibre insulation
(405 mm, 16 inches)
Polyethylene air barrier stub (as per building code)
Air barrier is on the warm side of the inside stud

Cellulose Fibre Insulation

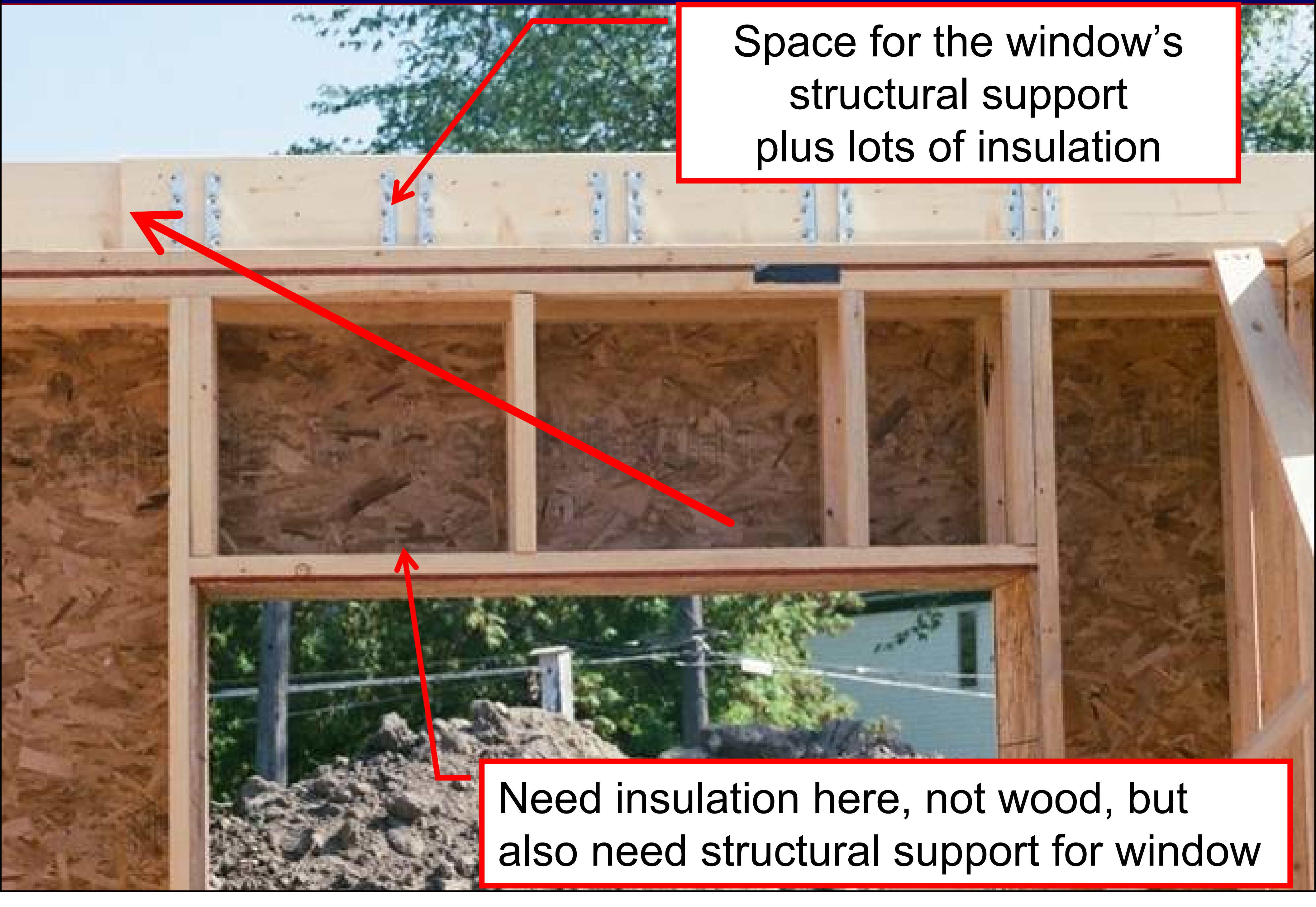
- Recycled newspapers
- Low embodied energy
- Locally produced
- Sequestered carbon
- Not a hydrocarbon product

- Walls: 400 mm, Usi-0.10 (16”, R-56)

Insulation itself is very airtight

Wall is covered with a fibre mesh to keep insulation intact during installation

Window Headers in Rim Joist Area



Achieving Ultra-Airtightness

Electrical poly-vapour hats and backers

- Not hard to do
  - Framers need to be very aware of this
  - No deviation from normal construction sequence.
  - Builder doing this for 20 years.
- Extremely effective performance
- Extremely cost-effective
- at -50 Pascals (= 30 km/h wind) (=20mph)
  - Riverdale NetZero house: 0.50 AC/h
  - Mill Creek NetZero house: 0.36 AC/h

Rim joist air barrier wrap

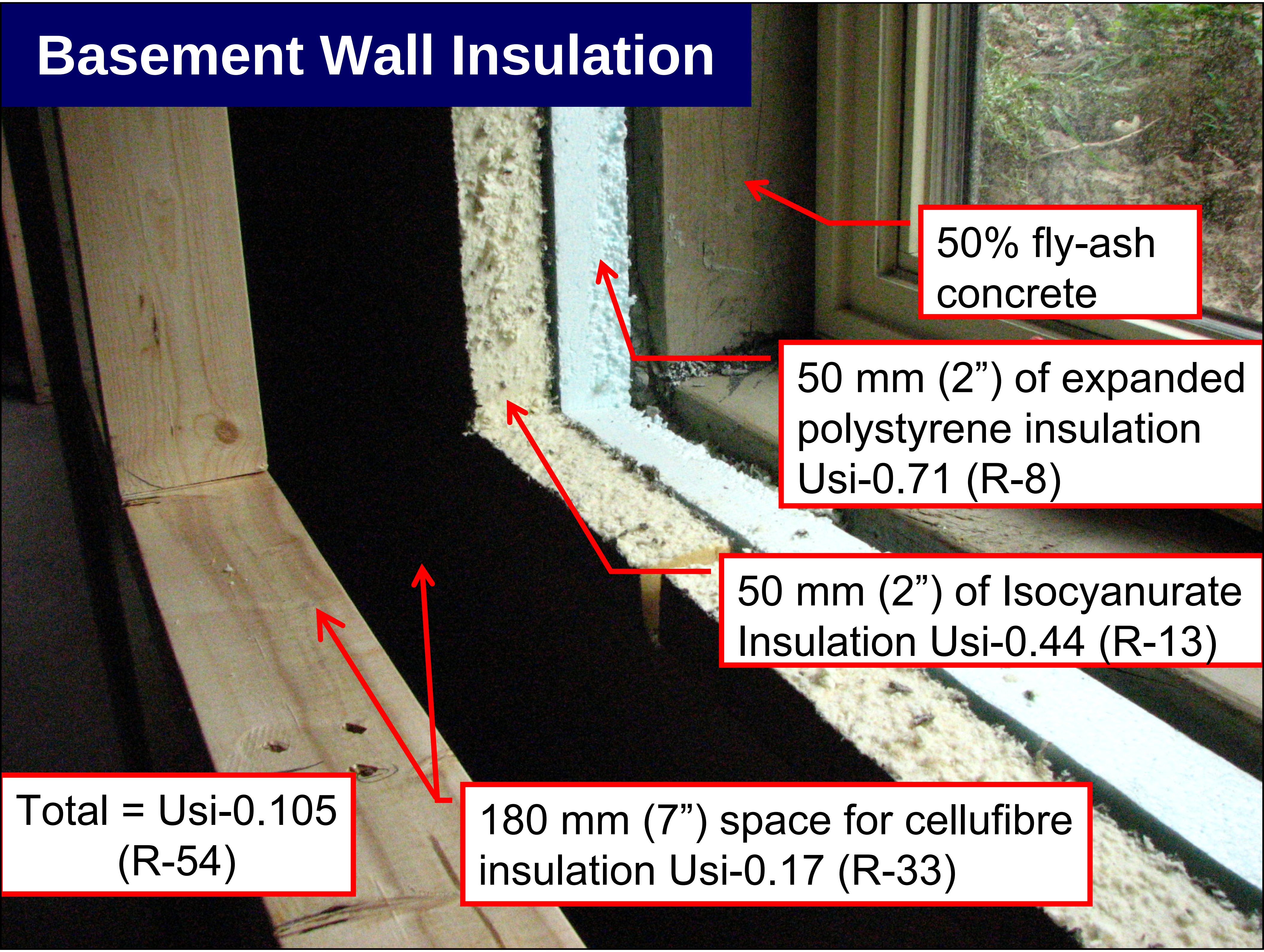
Spreader plate joints sealed

Windows foamed

All penetrations sealed

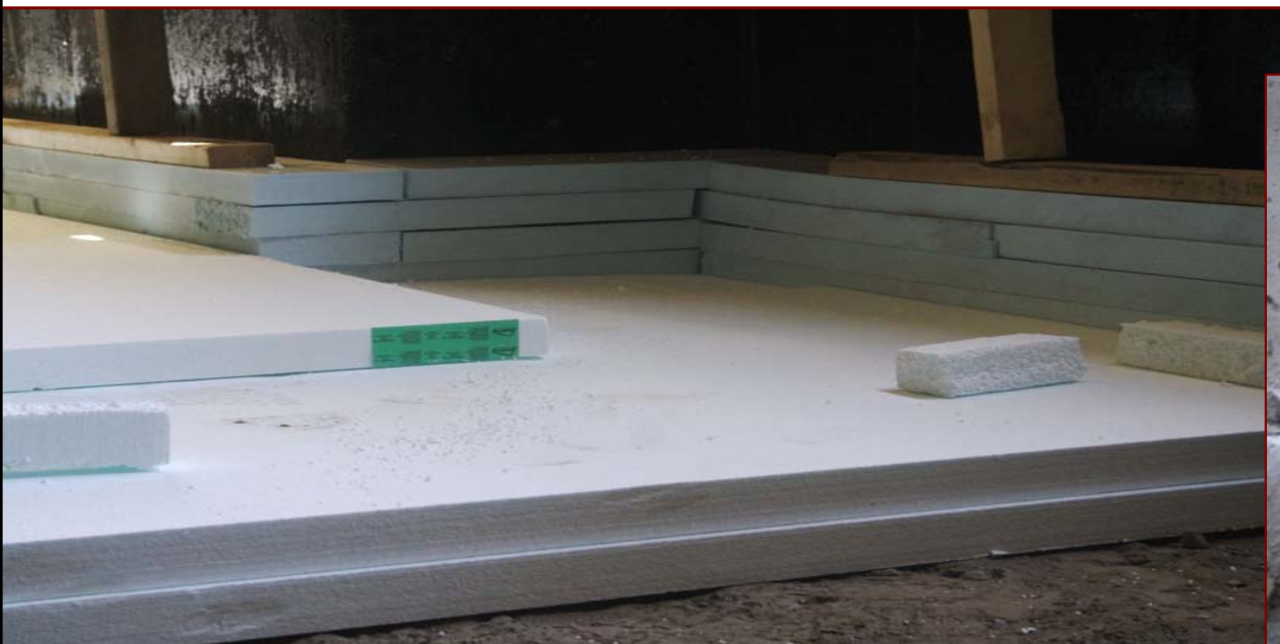
Rim joist vapour barrier

Basement Wall Insulation



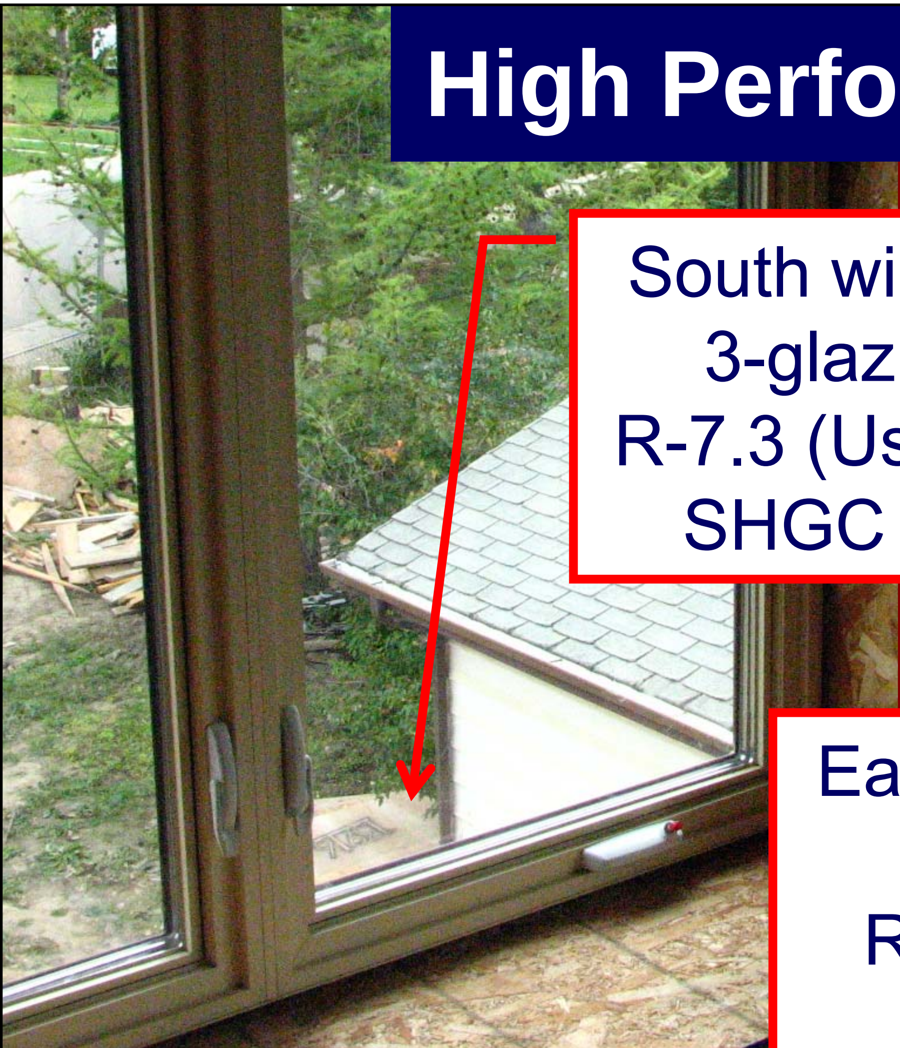
Basement Floor Insulation

- Usi-0.237 (R-24) underneath the concrete
- Extruded polystyrene



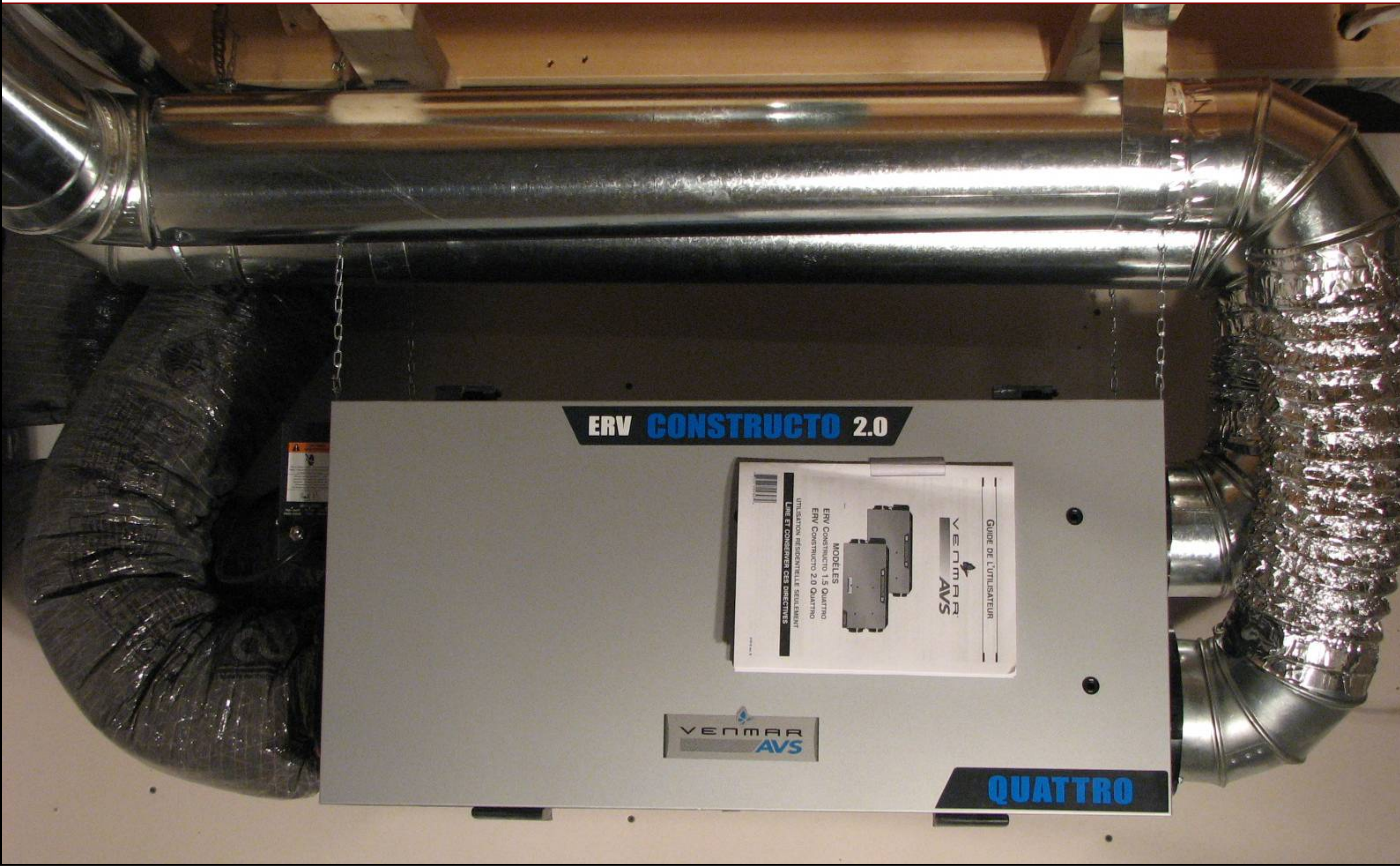
howell-mayhew engineering, inc.

High Performance Windows

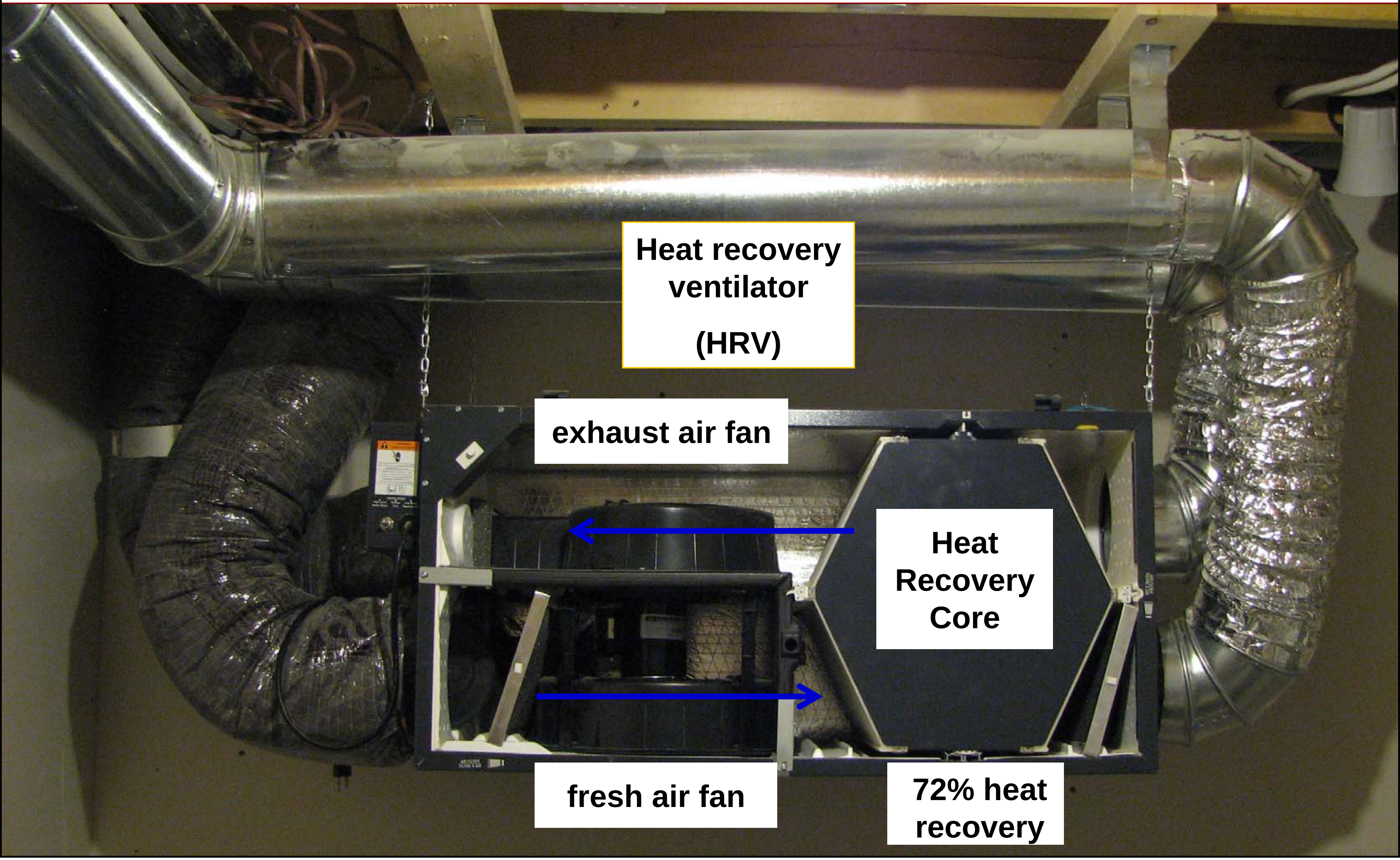


- Soft low emissivity coatings
- Argon gas between the glazings
- “Warm edge” glazing spacer
- Urethane insulated fibreglass frames
- Duxton Windows, Winnipeg

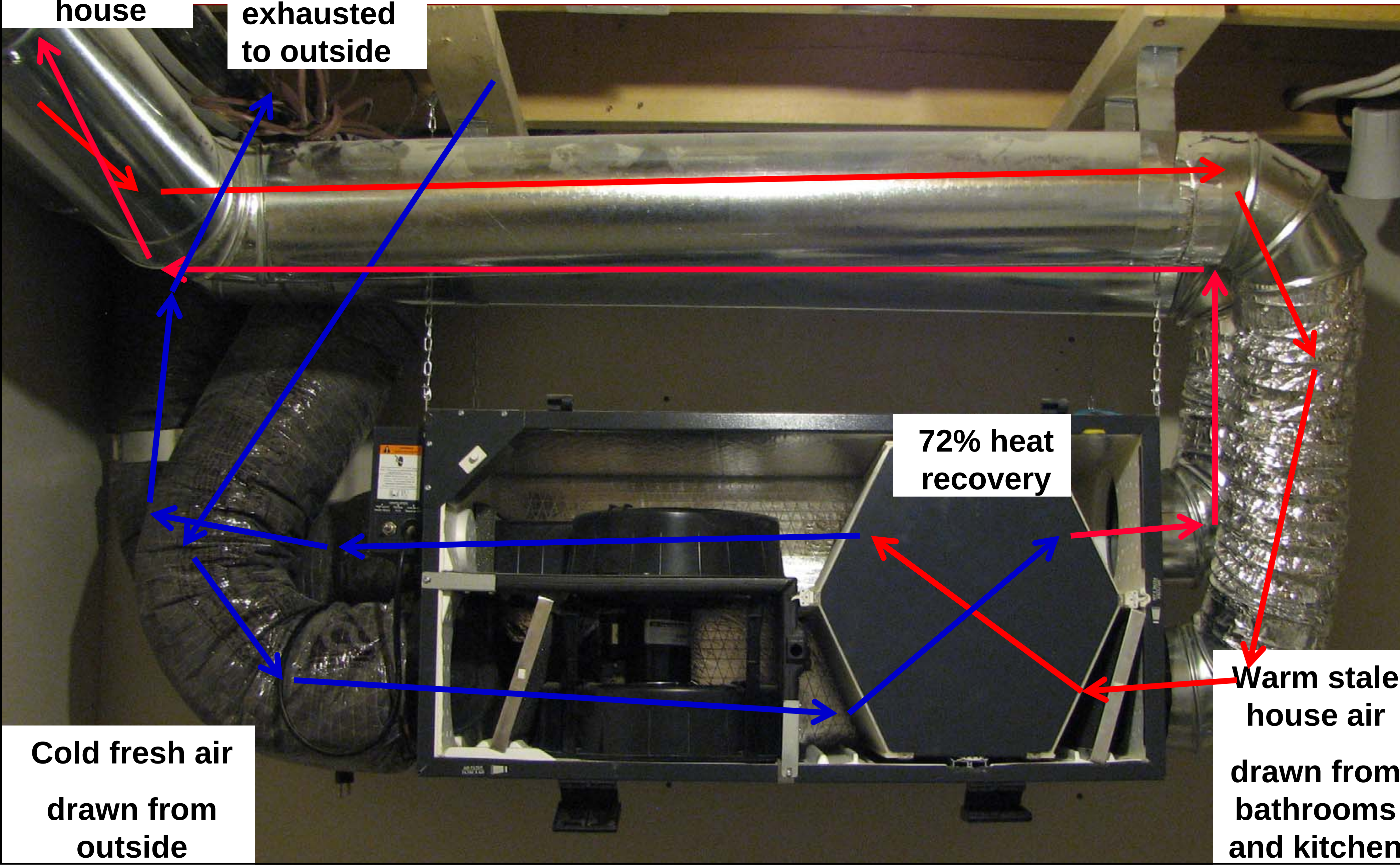
Ventilation with Heat Recovery Unit (HRV)



Ventilation with Heat Recovery - Insides



HRV Operation



#4. Passive Solar Space Heating

All south windows: 17 m² (183 ft²) 10% of floor area
Estimated production = 4400 kWh per year

Provides
~40% of space heating

Mill Creek – Passive Solar Space Heating

Maximise the south window area

South windows: 23 m^2, 11% of floor area

Passive solar heating: 8300 kWh per year

Add thermal mass: 64 mm concrete floor overlay

Summer shading is <u>really</u> important

Other space heating is solar PV-electric baseboard

Passive solar provides ~50% of annual space heating

Belgravia – Passive Solar Space Heating

- Under construction – PV awnings not yet installed

All south windows: 23 m^2 (248 ft^2) 12% of floor area
Estimated passive solar = 8600 kWh per year
Other space heating is solar PV-electric baseboard

Passive solar provides ~61% of space heating

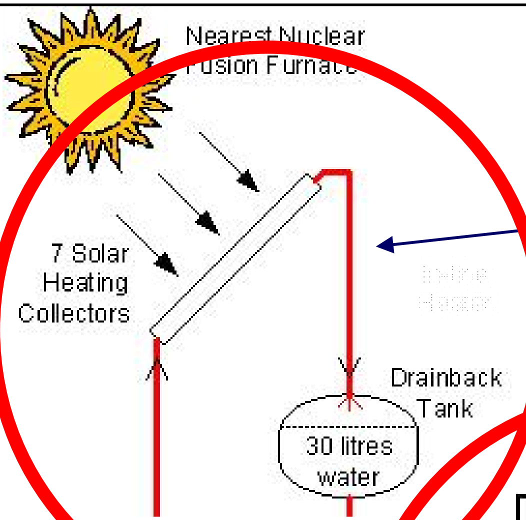
#5. Active Solar Thermal Heating – Space & Water

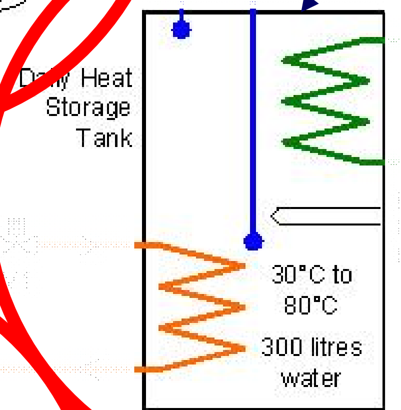
Drainback collectors: 7, 21 m² (226 ft²) vertical
DWH heat storage: 300 litres (79 Amgal)
Space heat storage: 17,000 litres (4500 Amgal)
Heat distribution: fan-coil, forced-air
Supplemental: electric resistance
Estimated production = 4200 kWh per year

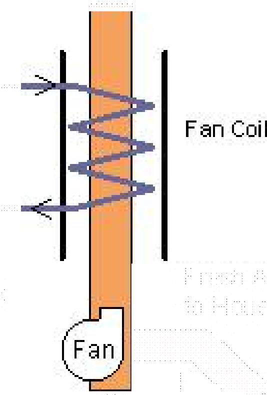
Provides
83% of domestic water heating,
21% of space heating

Major solar thermal components at RNZ

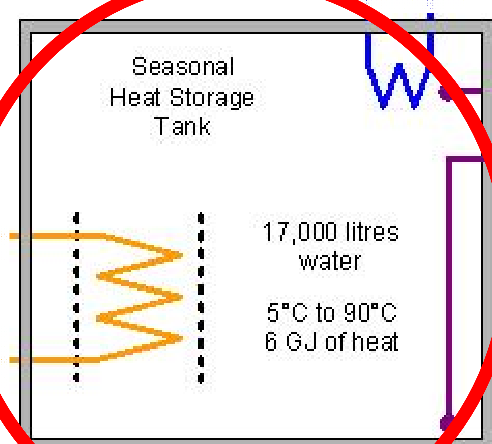
1. Solar collector array – 7 collectors
2. DWH tank – 300 litres (79 Amgal)
3. Space htg tank – 17,000 litres (4500 Amgal)
4. Fan coil





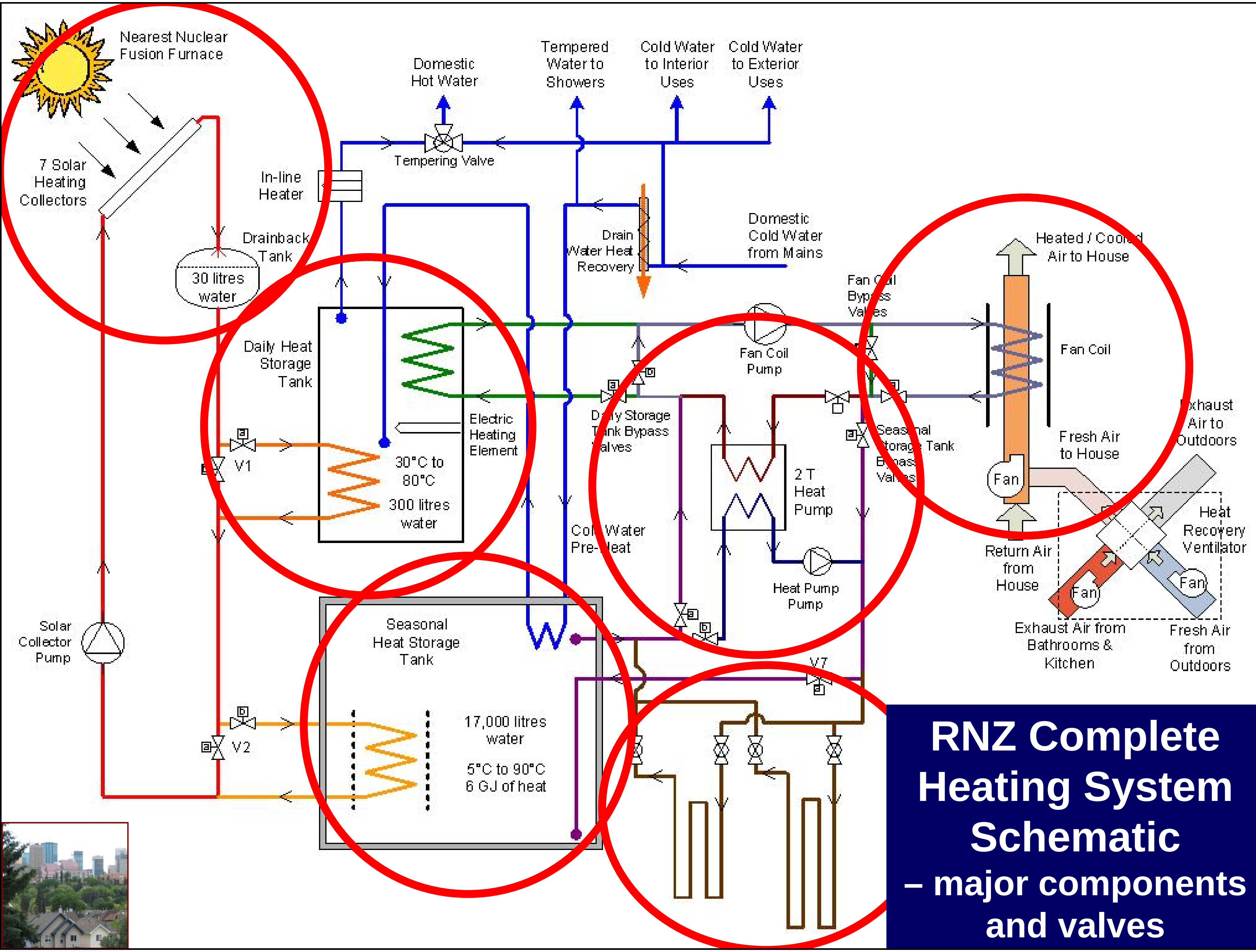


- Drainback tank in bedroom

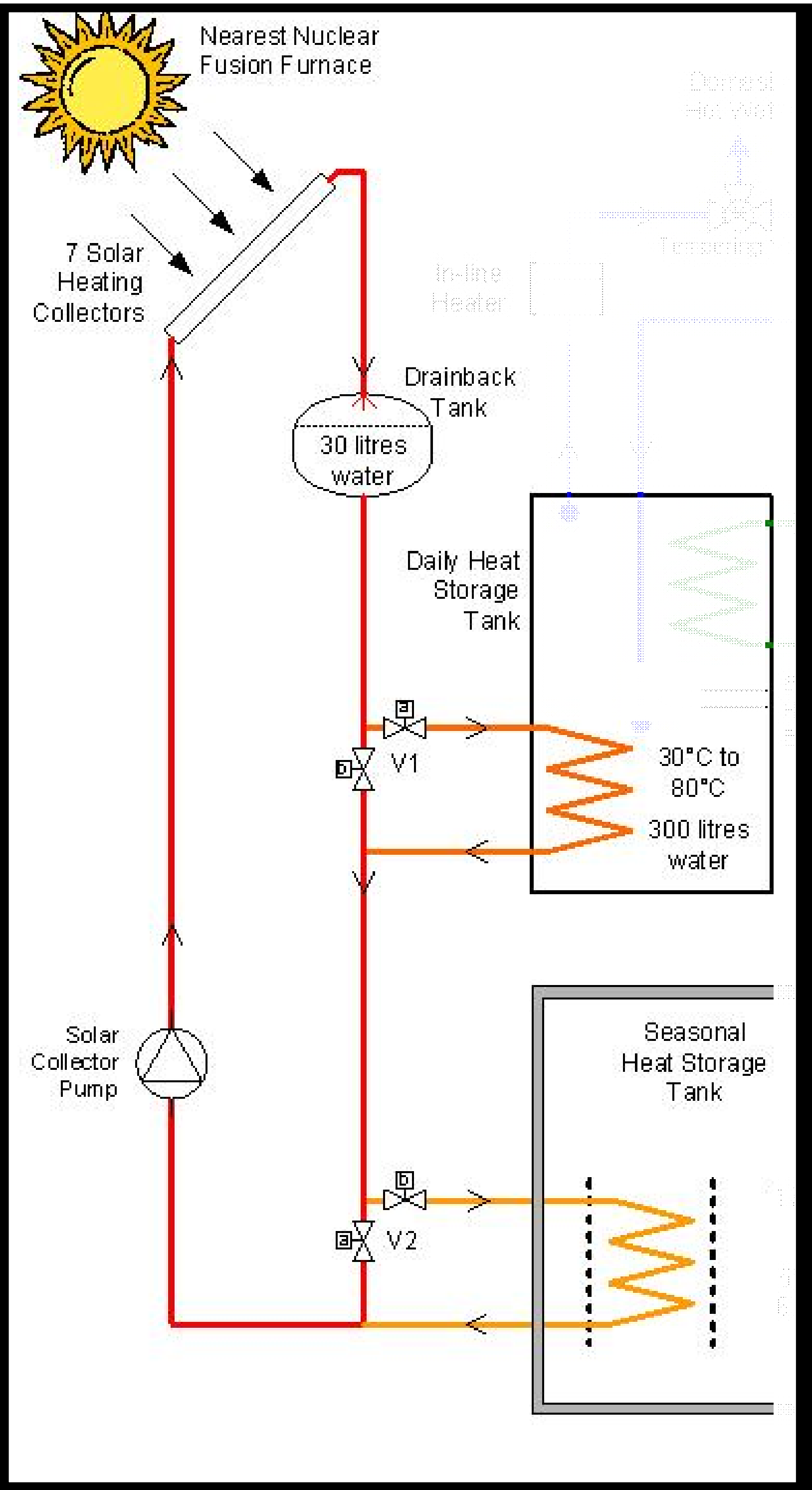


- Heat exchangers in large tank

- Fan coil



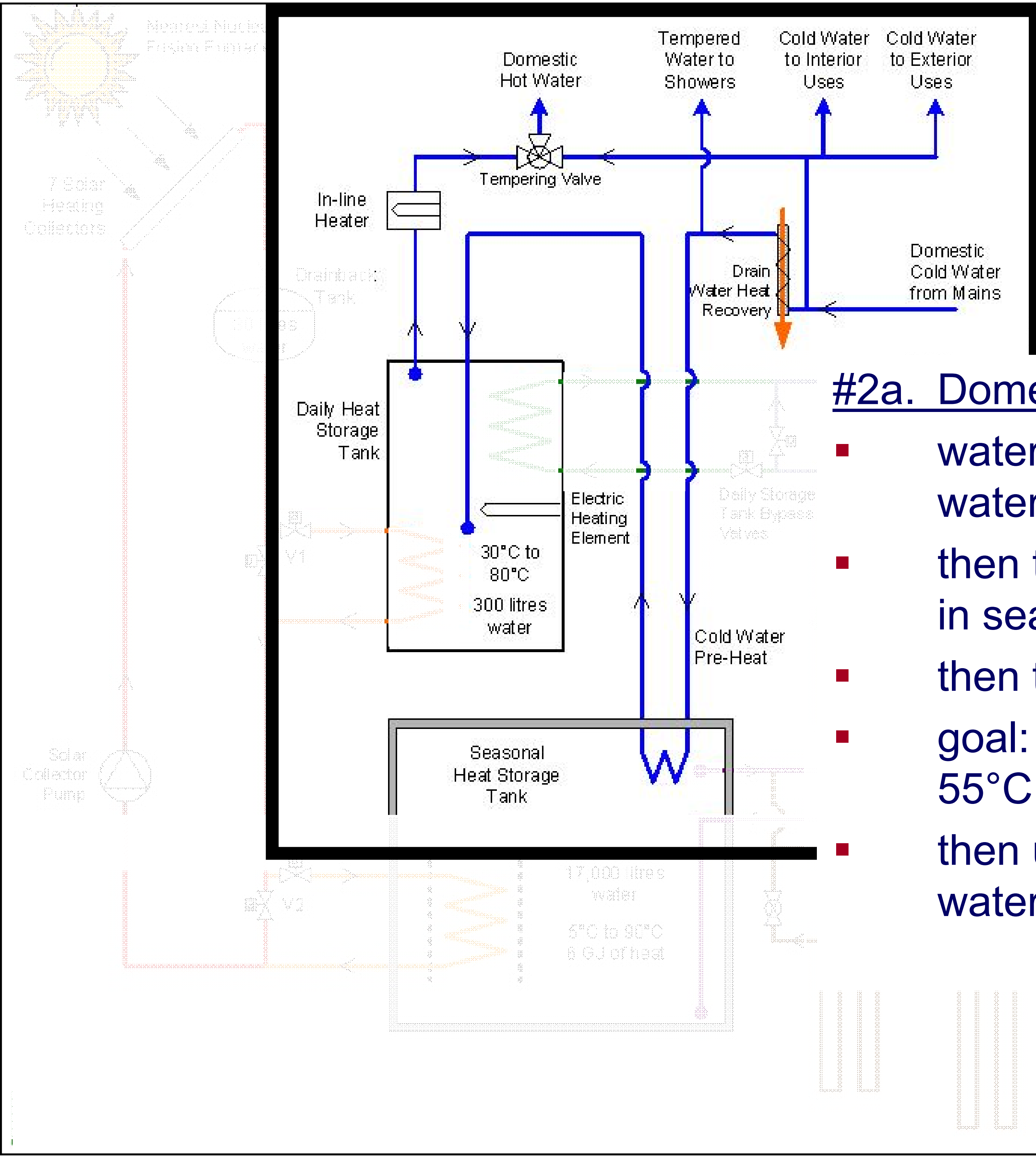
RNZ Complete Heating System Schematic – major components and valves



#1. Solar collection loop

- solar heat first to DWH tank
- then to space heating tank

- Plumbing in walls

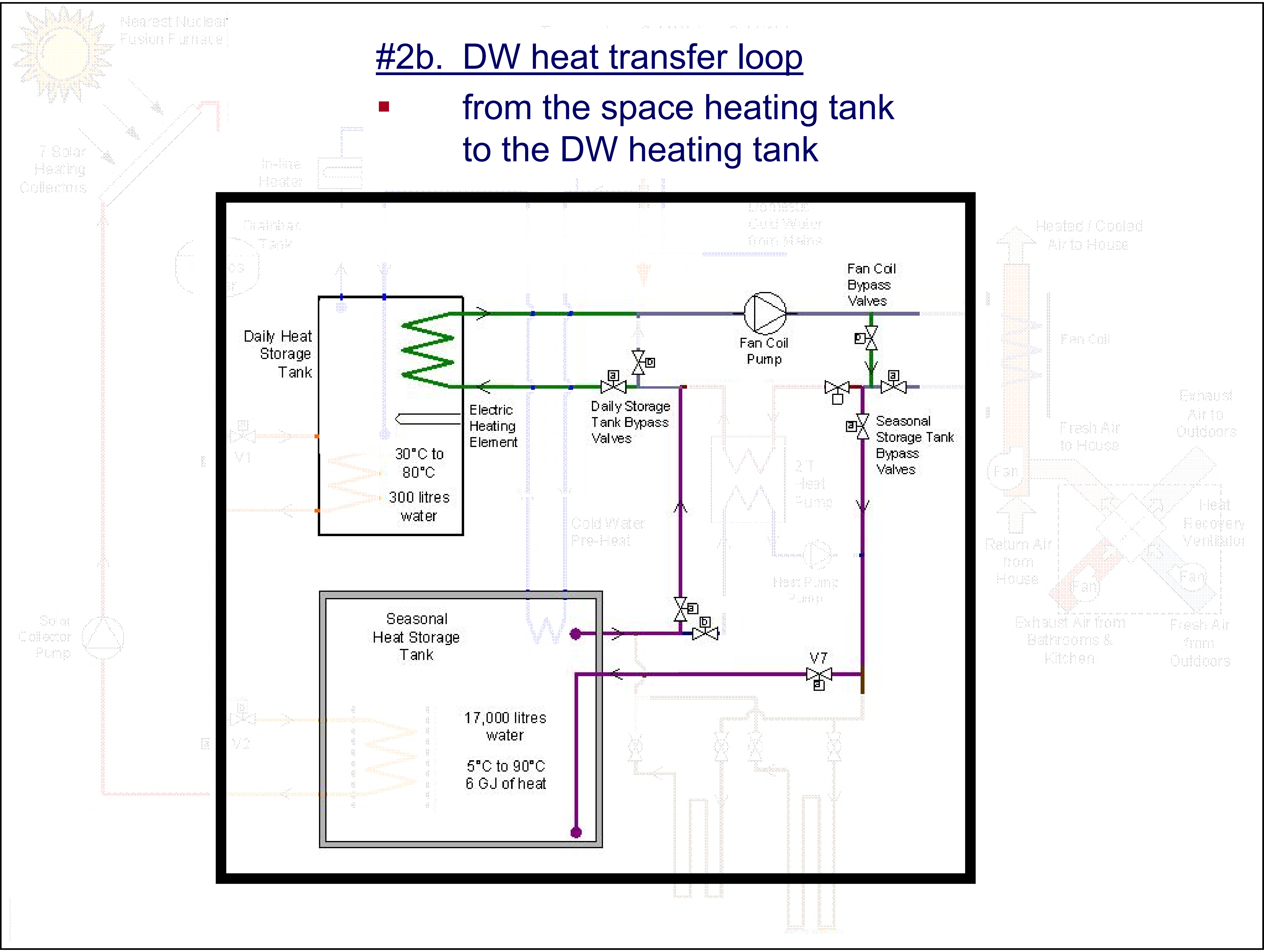


#2a. Domestic water heating

- water first goes through drain water heat recovery unit
- then through heat exchanger in seasonal storage tank
- then to solar DW tank
- goal: keep DWH tank at 55°C.
- then use instantaneous water heater

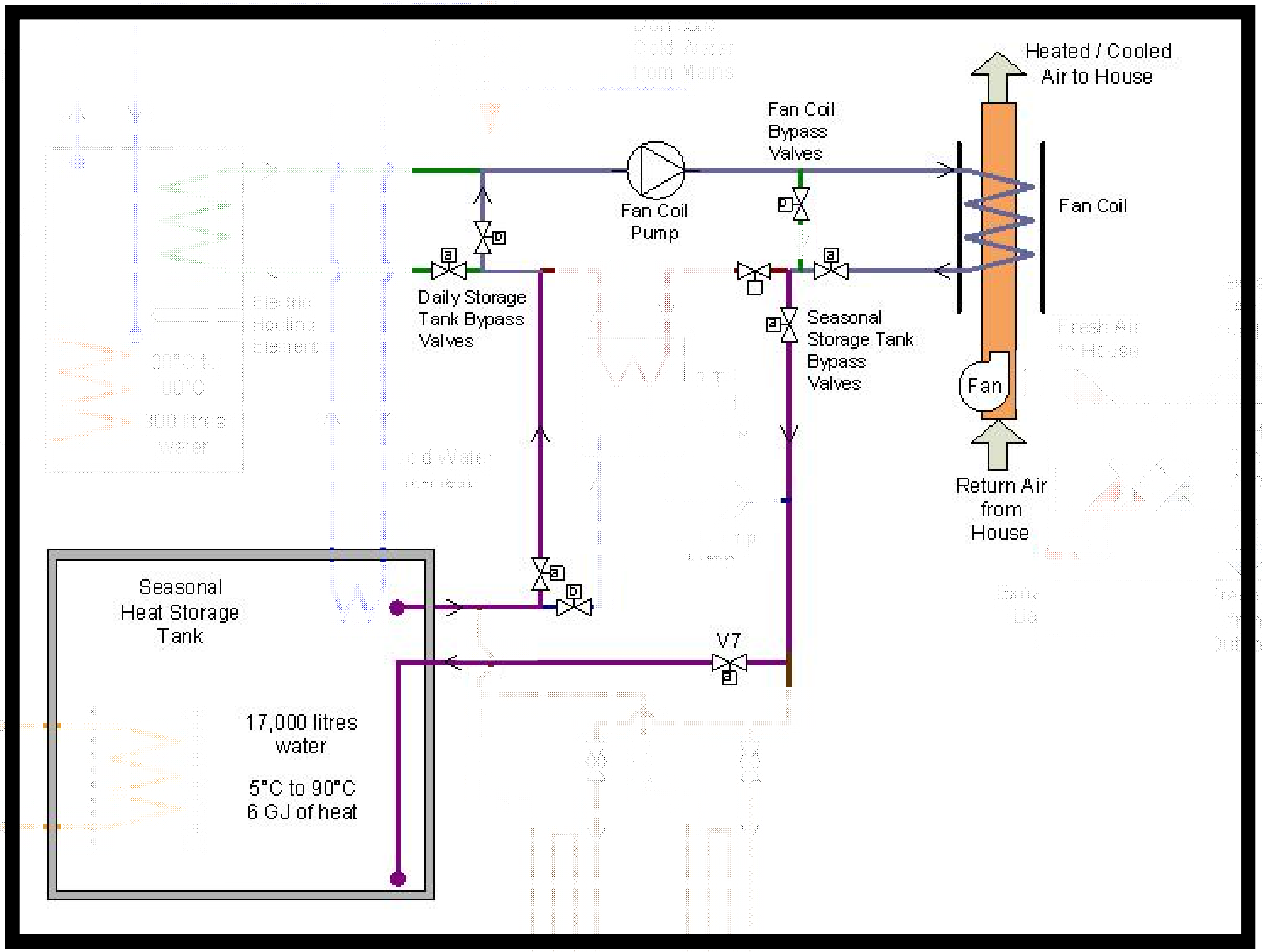
#2b. DW heat transfer loop

- from the space heating tank to the DW heating tank



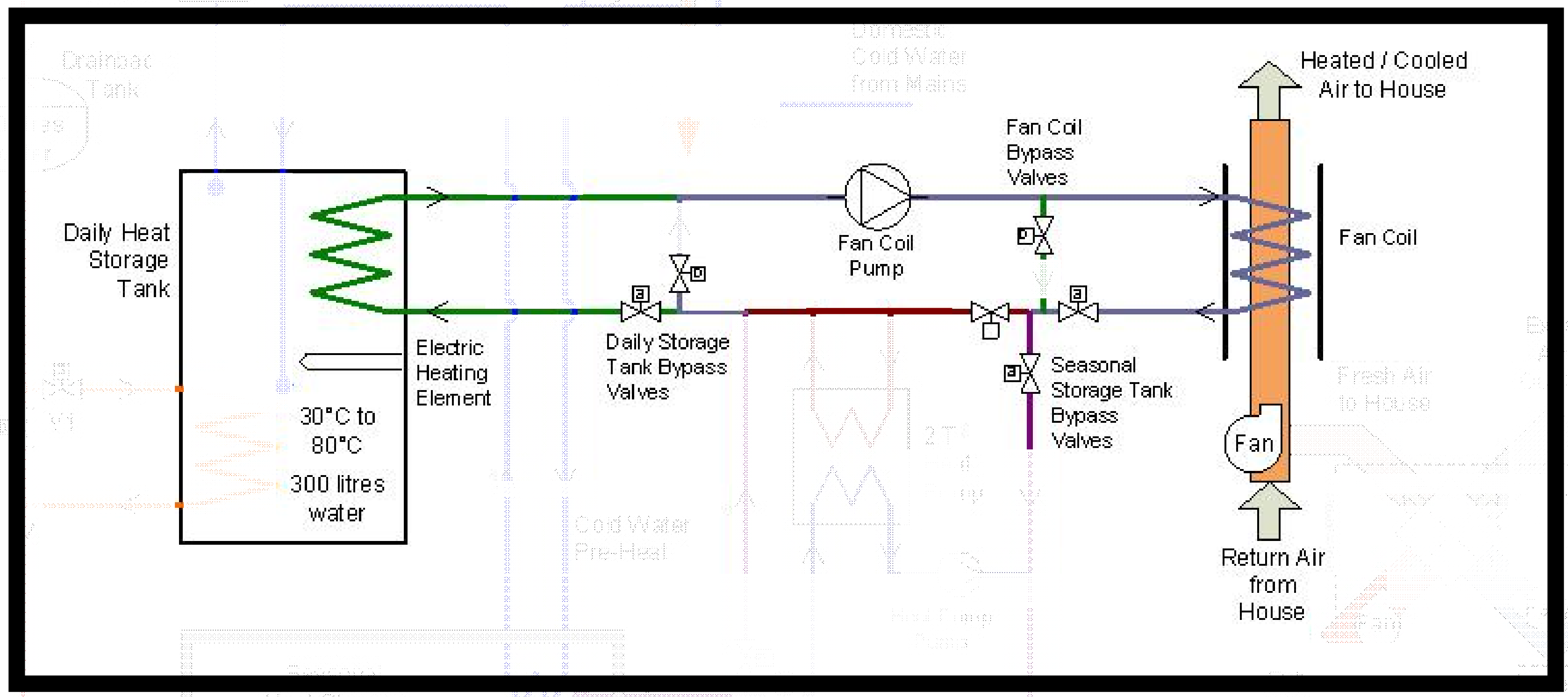
#3a. Space heat transfer loop – primary source

- from the space heating tank to the fan coil



#3b. Space heat transfer loop – backup source

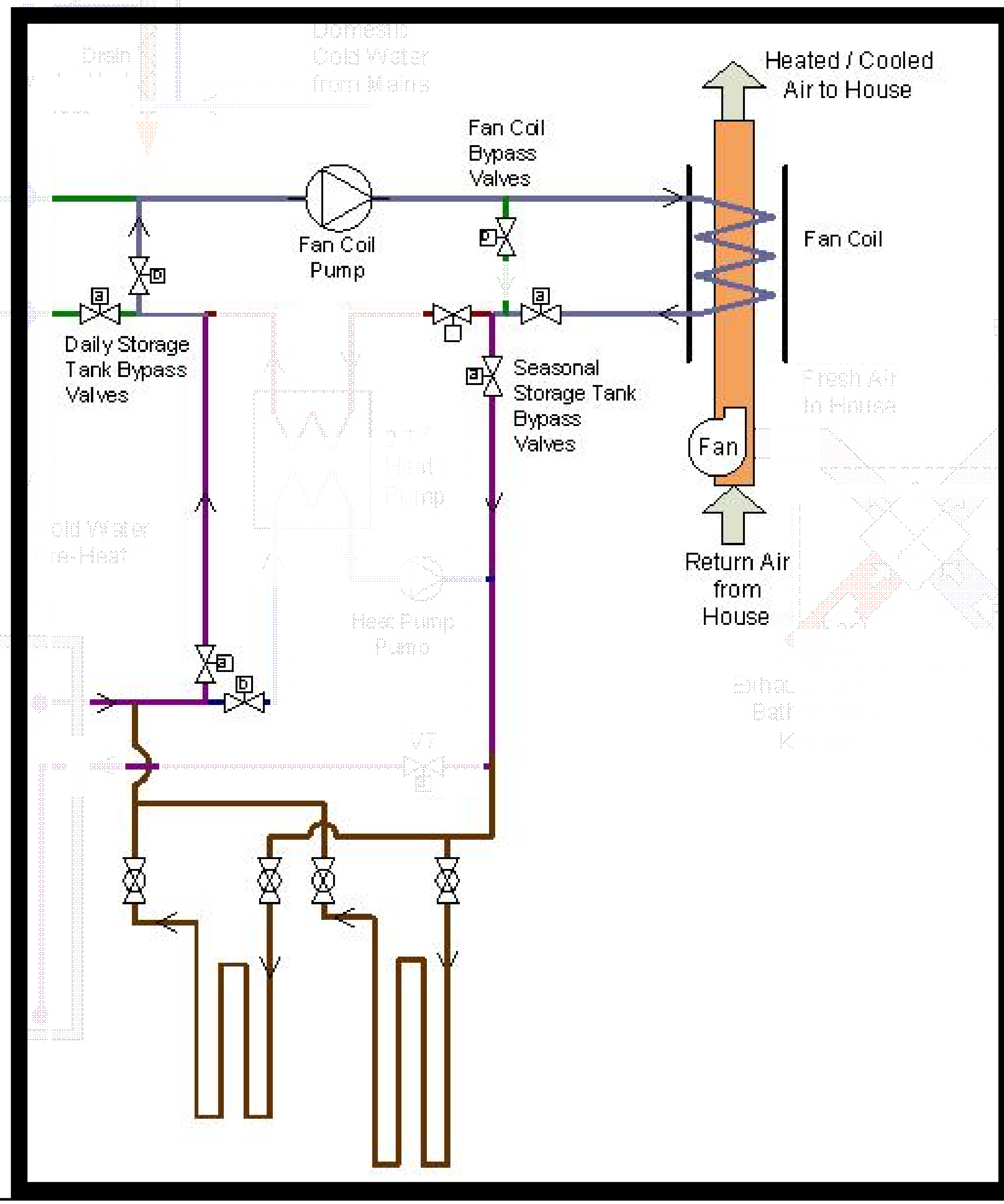
- from the DW heating tank to the fan coil



- the DW heating tank is the only source for grid-backup electric space heating in the house

#4. Ground cooling loops

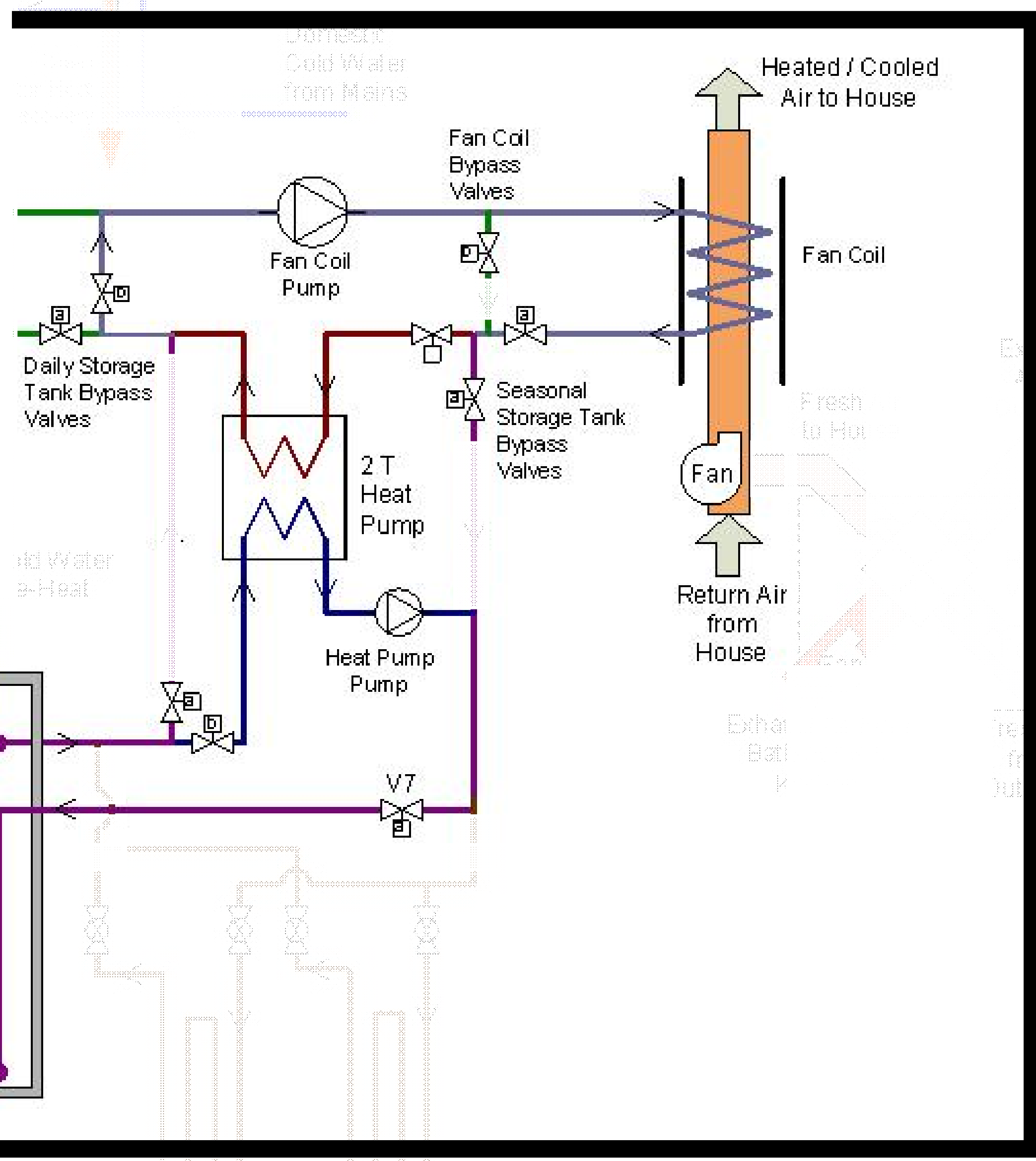
- 41m under the garage slab
- 55m around the foundation
- manual valves set seasonally for cooling and heating seasons

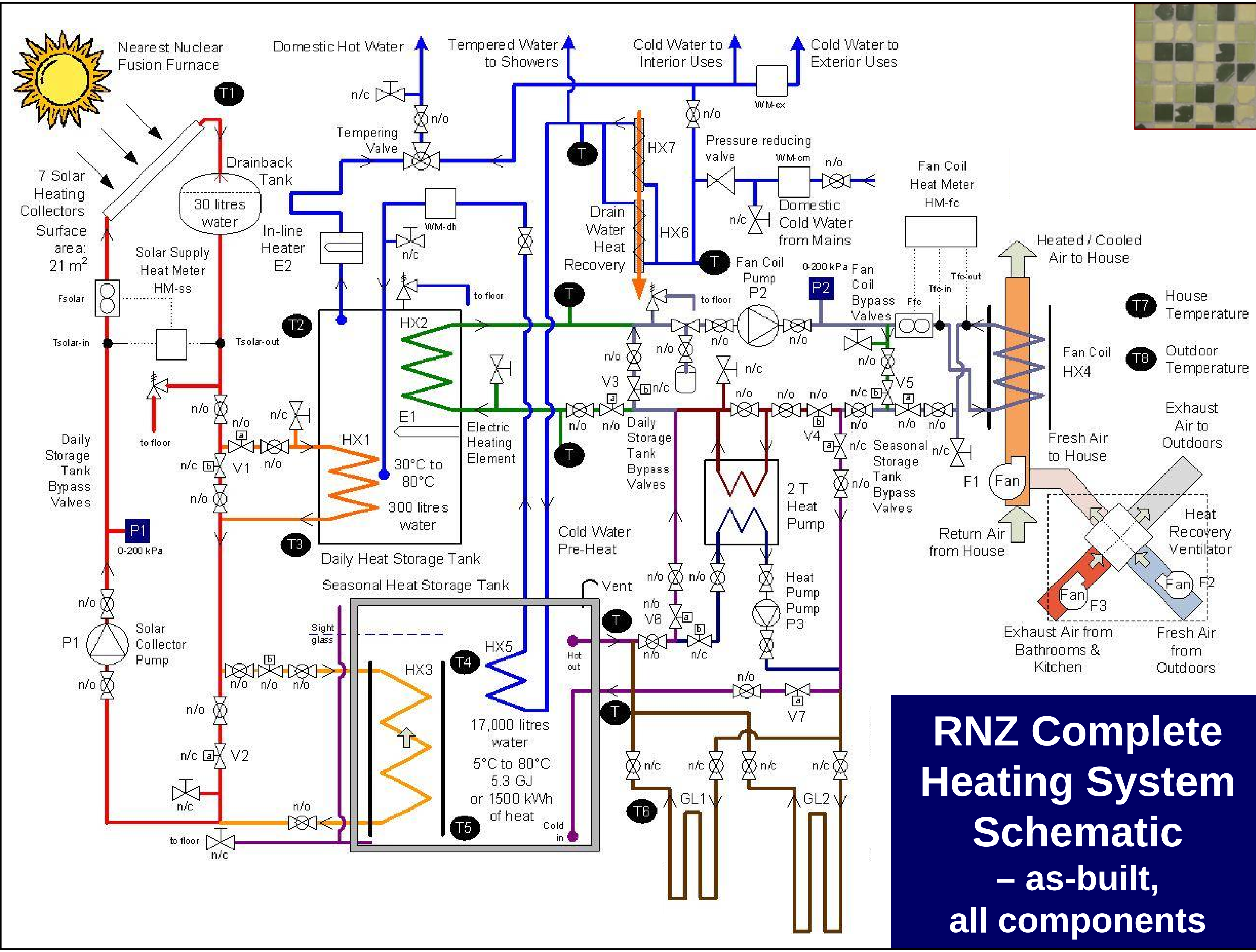


#5. Solar-assisted heat pump

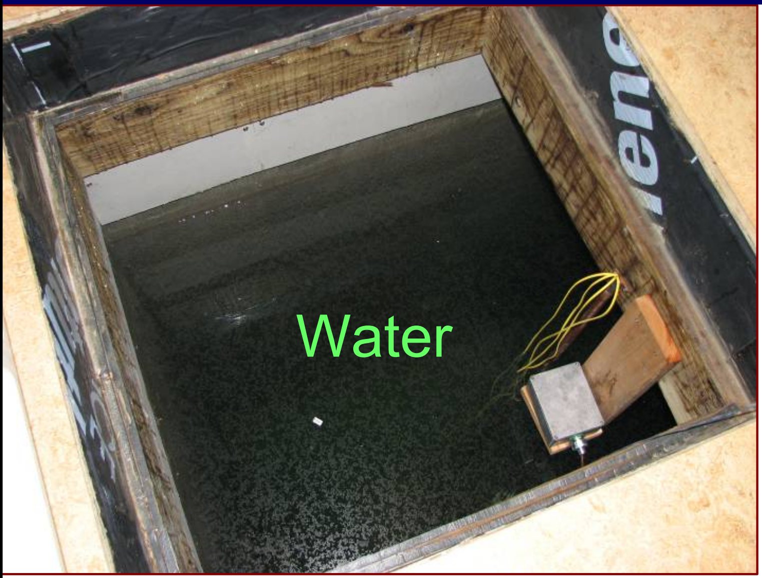
(optional, not installed)

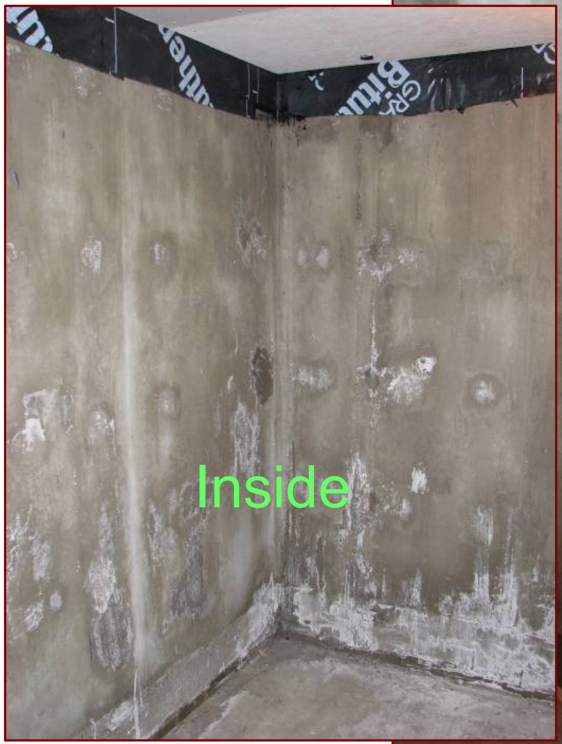
- accesses an additional 2 GJ (500 kWh) of heat in the space heating tank
- by drawing the tank down from 30°C to +5°C
- Each cycle is worth $60 in reduced electricity purchases
- HP purchase cost is an additional $4k, which equals an energy price of 39 ¢/kWh for one tank draw-down cycle per year




RNZ Complete Heating System Schematic – as-built, all components
Nearest Nuclear Fusion Furnace
7 Solar Heating Collectors
Surface area: 21 m²
Drainback Tank
30 litres water
Solar Supply Heat Meter HM-ss
Fsolar
Tsolar-in
Tsolar-out
Domestic Hot Water
Tempering Valve
Tempered Water to Showers
Cold Water to Interior Uses
Cold Water to Exterior Uses
WM-cx
WM-dh
WM-cm
In-line Heater E2
Drain Water Heat Recovery
HX7
HX6
Pressure reducing valve
Domestic Cold Water from Mains
Fan Coil Heat Meter HM-fc
Fan Coil Pump P2
0-200 kPa
Fan Coil Bypass Valves
Ffc
Tfc-in
Tfc-out
Heated / Cooled Air to House
Fan Coil HX4
House Temperature
Outdoor Temperature
Exhaust Air to Outdoors
Fresh Air to House
Return Air from House
Heat Recovery Ventilator
Exhaust Air from Bathrooms & Kitchen
Fresh Air from Outdoors
Fan
F1
F2
F3
T1
T2
T3
T4
T5
T6
T7
T8
HX1
HX2
HX3
HX5
E1
Electric Heating Element
30°C to 80°C
300 litres water
Daily Heat Storage Tank
Daily Storage Tank Bypass Valves
Seasonal Storage Tank Bypass Valves
Seasonal Heat Storage Tank
Cold Water Pre-Heat
Vent
Sight glass
Hot out
Cold in
17,000 litres water
5°C to 80°C
5.3 GJ
or 1500 kWh of heat
2 T Heat Pump
Heat Pump Pump P3
Solar Collector Pump
P1
0-200 kPa
V1
V2
V3
V4
V5
V6
V7
GL1
GL2
to floor
n/o
n/c

17,000 Litre (4500 Amgal) Solar Storage Tank



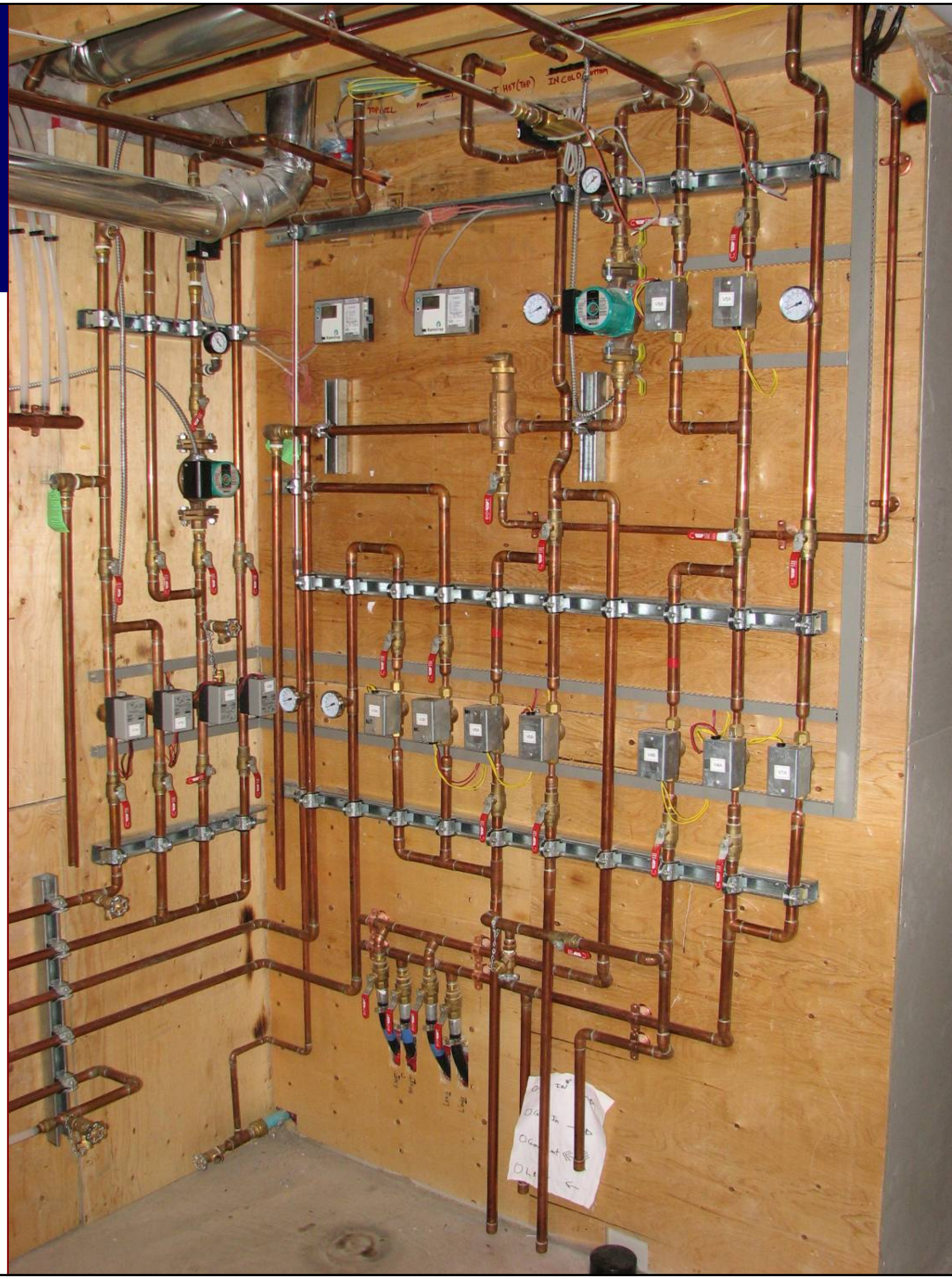


Tank has RSI8.8 (R50) insulation (on walls and ceiling, RSI3.5 (R20) under floor)

- Holds 3.6 GJ (990 kWh, 3.4 MMBTU) of heat in the space heating tank when the tank temperature is drawn down from 80°C to 30°C (176°F to 86°F)
- Stored heat in tank is worth $180 in 18 ¢/kWh grid electricity or $90 in 92 ¢/litre ($3.50/Amgal) Diesel fuel

Utility Room Solar Plumbing Layout

- When completed, the piping will be insulated, colour-coded and have direction arrows.
- Complex to
  - design, model,
  - install, commission,
  - control,
  - describe, document, and train
- Takes up floor space for:
  - space heating tank
  - domestic water tank
  - fan coil
- Unknown maintenance
  - Can have air locks in piping
  - Risk of valve and tank leaks



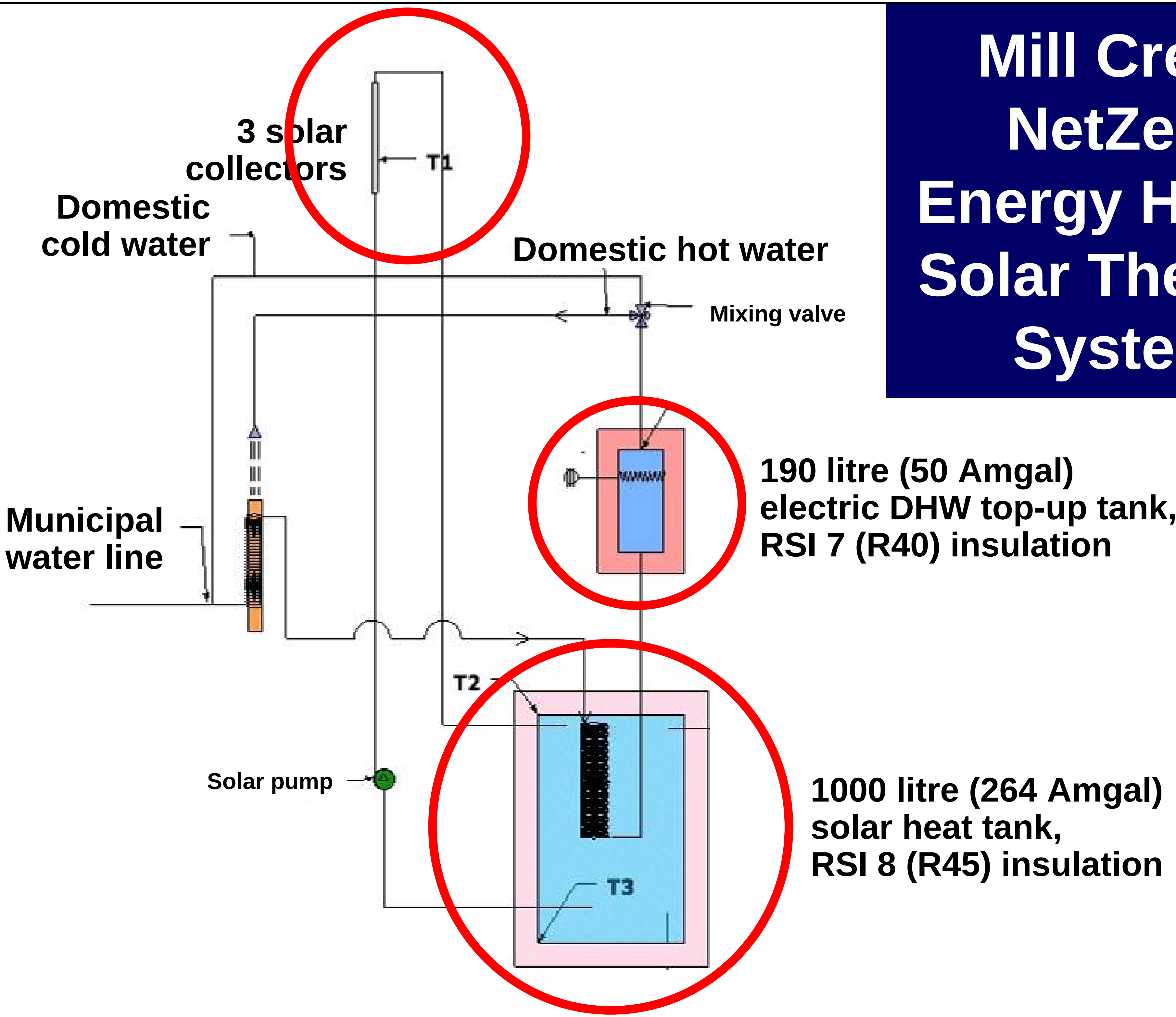
Mill Creek NetZero Energy House – Active Solar Domestic Water Heating

Simple solar domestic water heating system

Drainback collectors: 3 for 9 m² (97 ft²) 53° tilt
DWH heat storage: 1000 litres (264 Amgal)
Supplemental: electric water tank
Estimated production = 2500 kWh per year

Provides
85% of domestic water heating

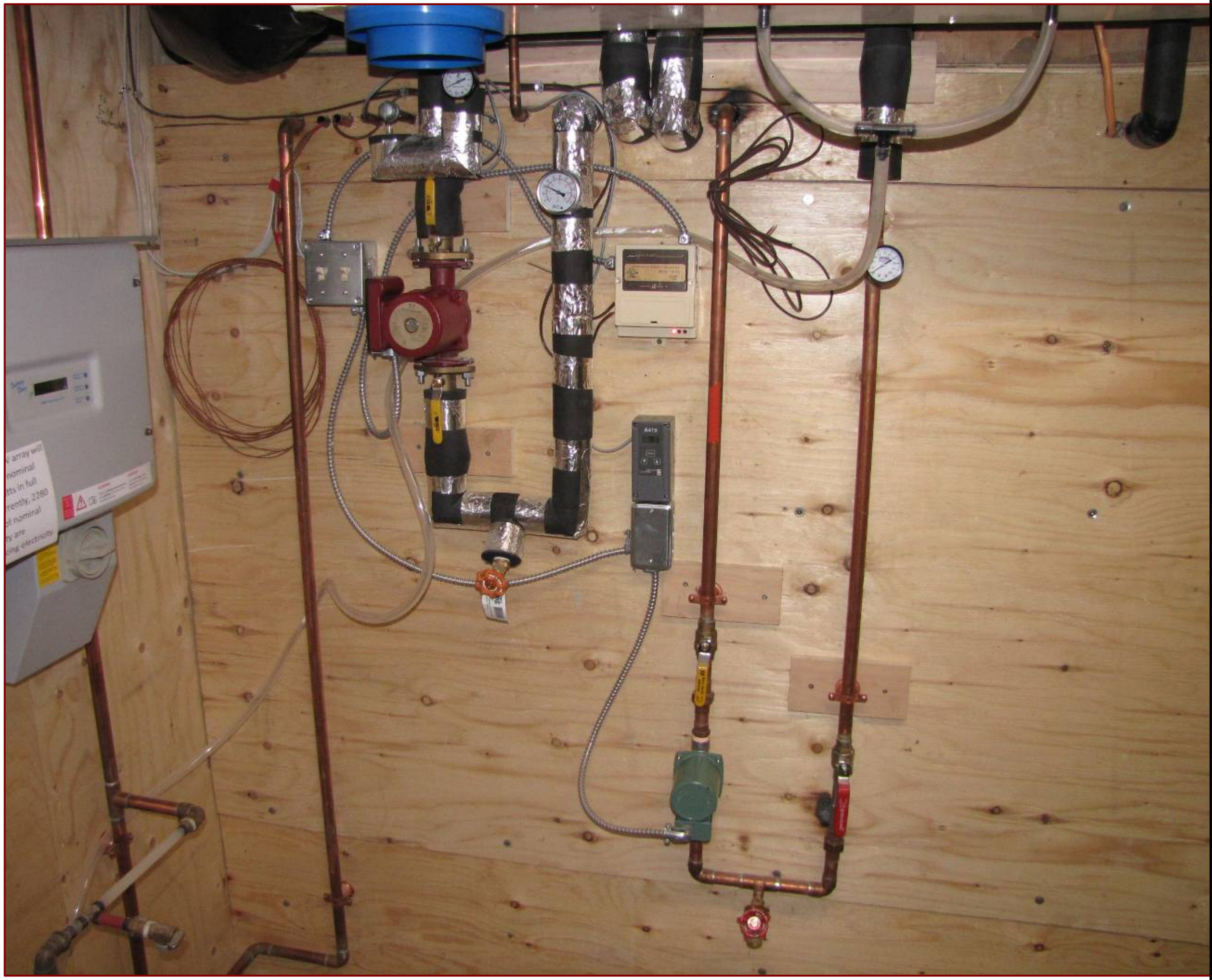
Mill Creek NetZero Energy House Solar Thermal System



Mill Creek NetZero Energy House Utility Room Solar Plumbing Layout

- Much easier to
  - design, model,
  - install, commission,
  - control,
  - describe, document, and train
- Domestic water heating tank takes up 16 m^2 (170 ft^2) of floor space

- Unknown maintenance
  - Can have air locks in piping
  - Some risk of valve and tank leaks



Belgravia NetZero Energy House – Active Solar Domestic Water Heating

No solar thermal system

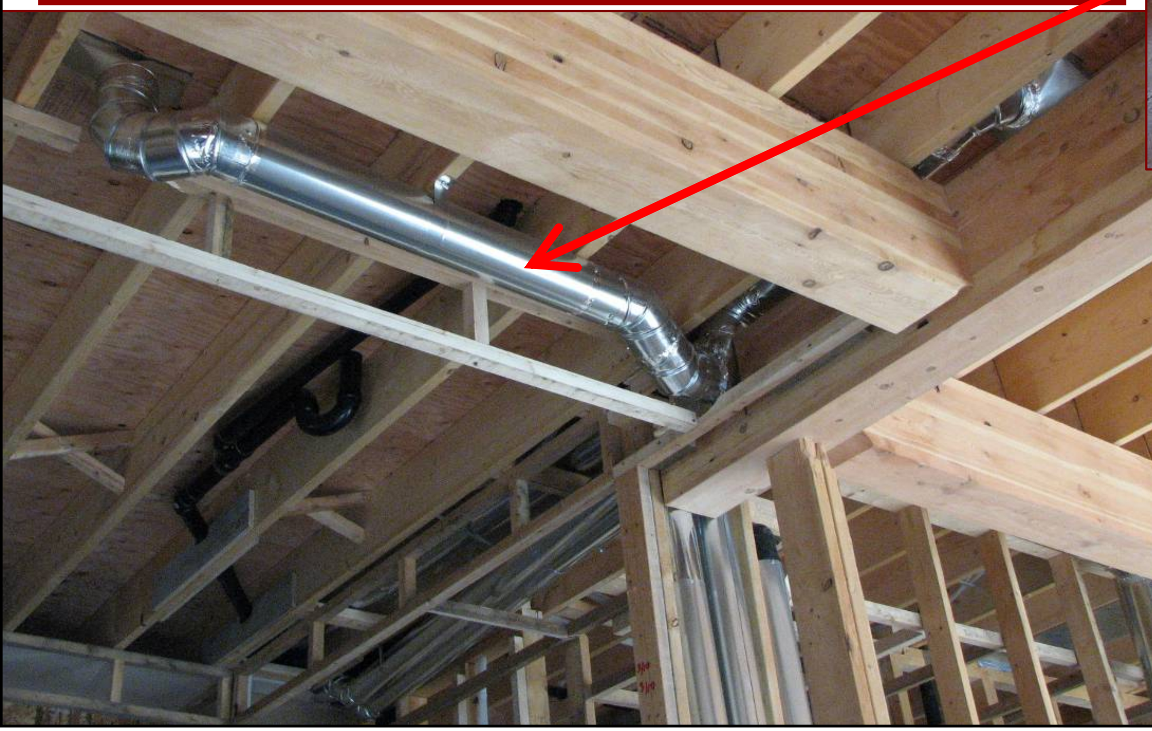
All other heating is solar PV-electric: baseboard + electric water tank

Belgravia NetZero Energy House Solar Thermal System Schematic

There is none….

RNZ Heating System…

- Standard, forced air heating system
  - also provides ventilation to each room
  - Low-speed fan, very quiet
  - Give uniform room temperatures
- Solar furnace: fan coil connected to the solar heating system
- BUT we don't specifically need to heat the rooms themselves…
  all we need to do is heat the house!



- Can do this because the walls and windows have such high R-values and so:
  - the walls and windows will be warmer; and
  - the rooms will need very small amounts of heat.

Mill Creek and Belgravia Heating System

#6. Solar Electricity – domestic <u>and heating</u>

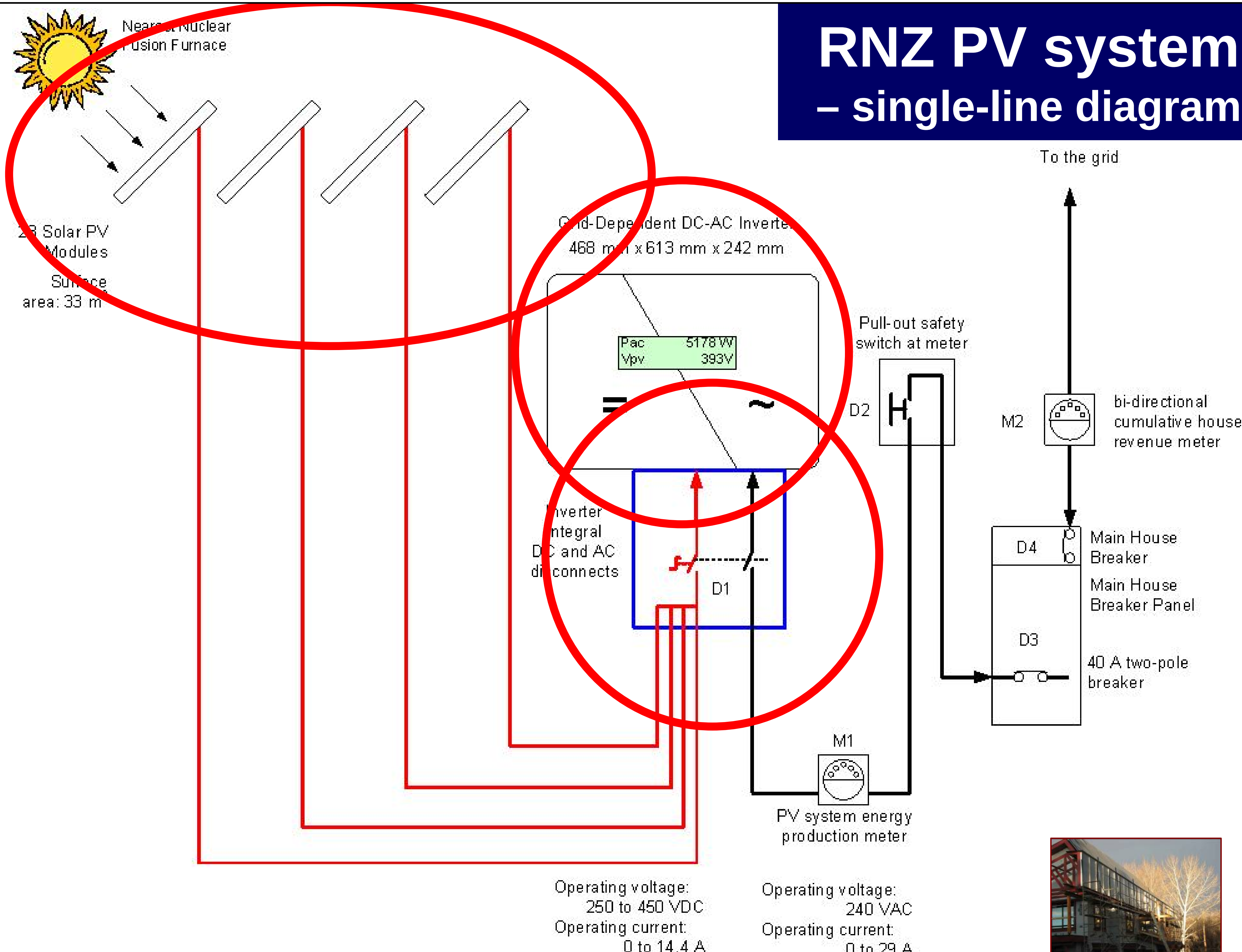
PV array: 28 modules, 33 m² (355 ft²),
5.6 kW, 53°tilt

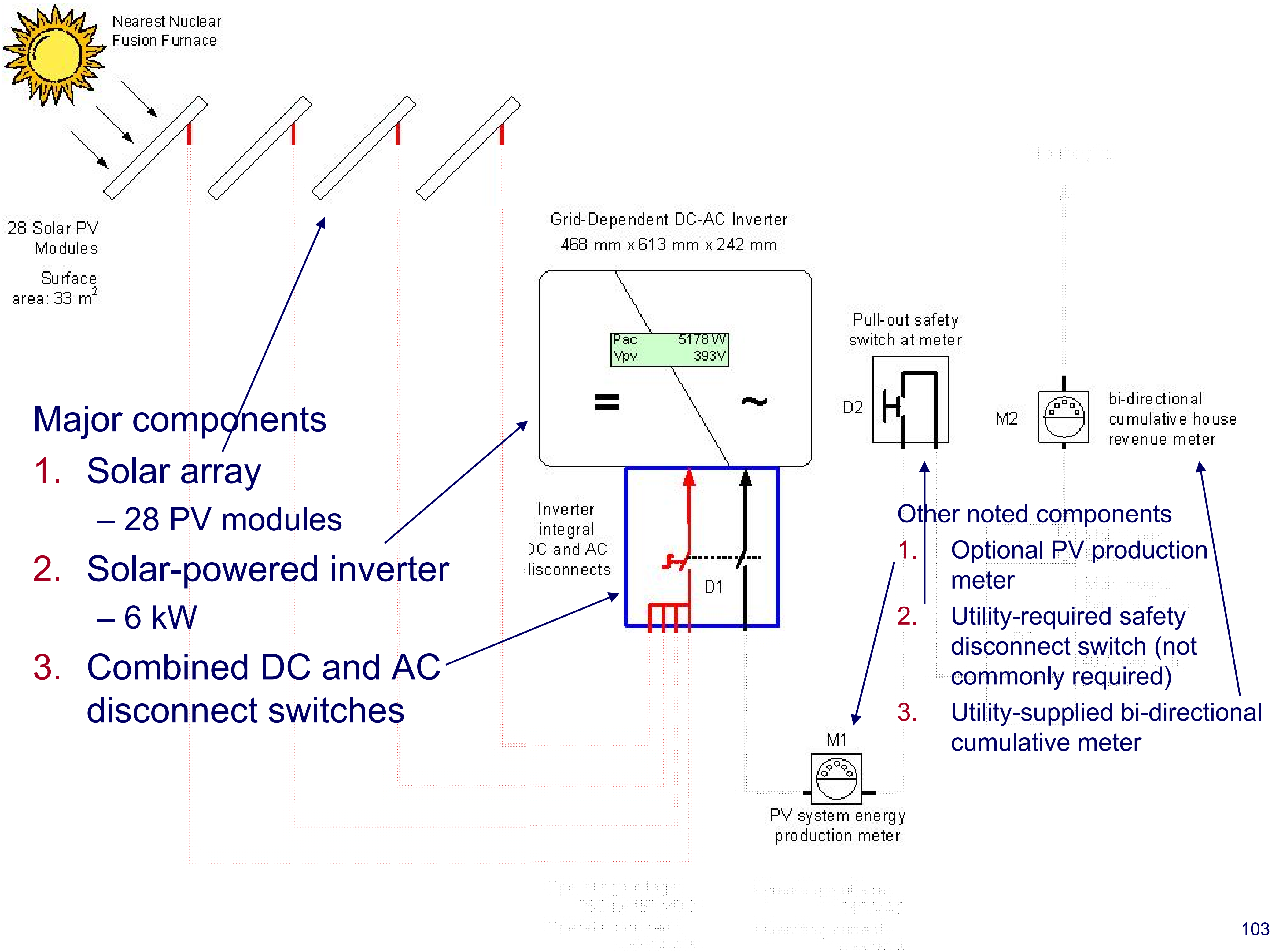
Electricity storage: "on the grid"

Measured production = 6600 kWh per year

Provides
112% of electricity consumption,
6% of domestic water heating,
11% of space heating

RNZ PV system – single-line diagram



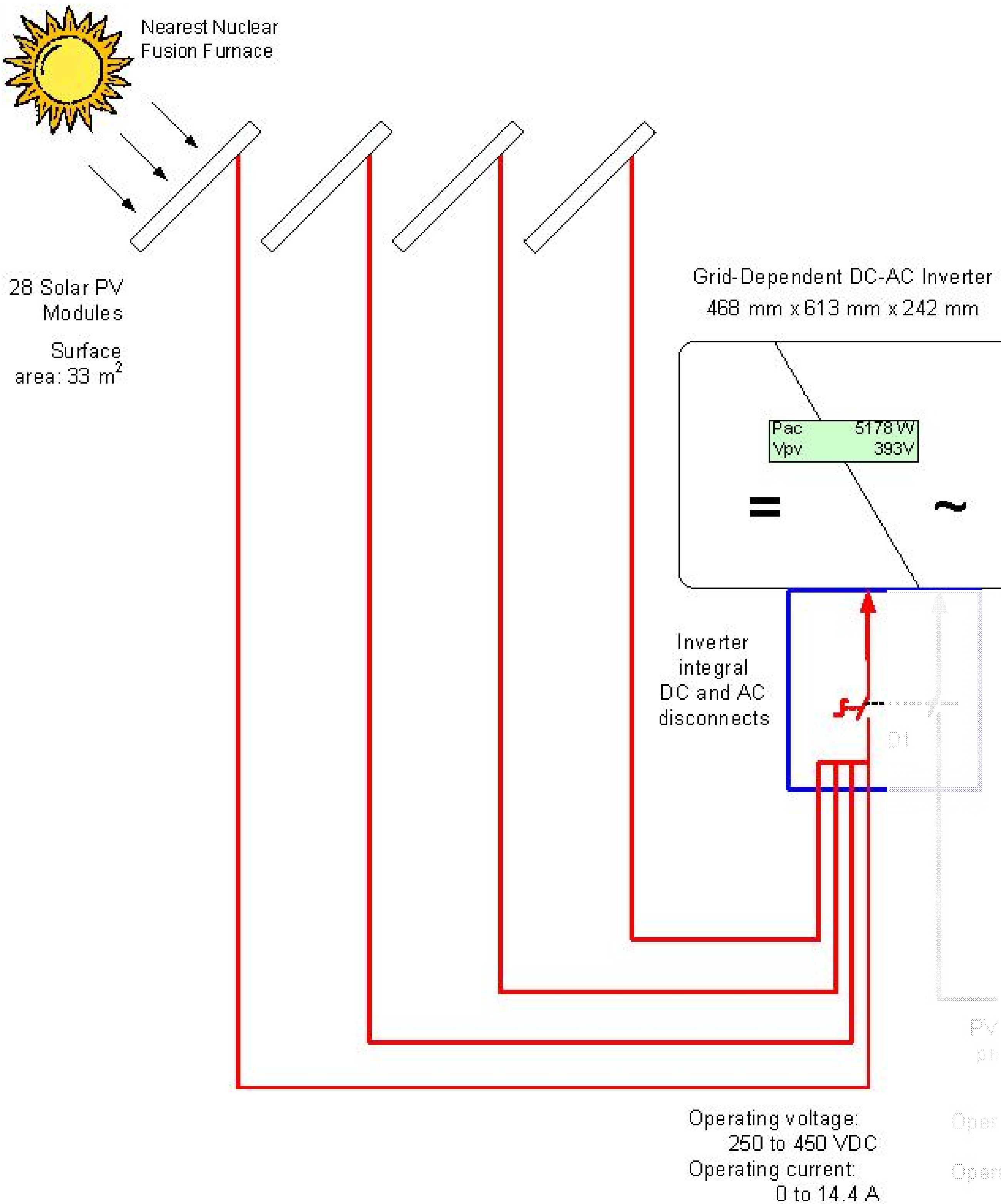


Major components

1. Solar array
   - 28 PV modules
2. Solar-powered inverter
   - 6 kW
3. Combined DC and AC disconnect switches

Other noted components

1. Optional PV production meter
2. Utility-required safety disconnect switch (not commonly required)
3. Utility-supplied bi-directional cumulative meter

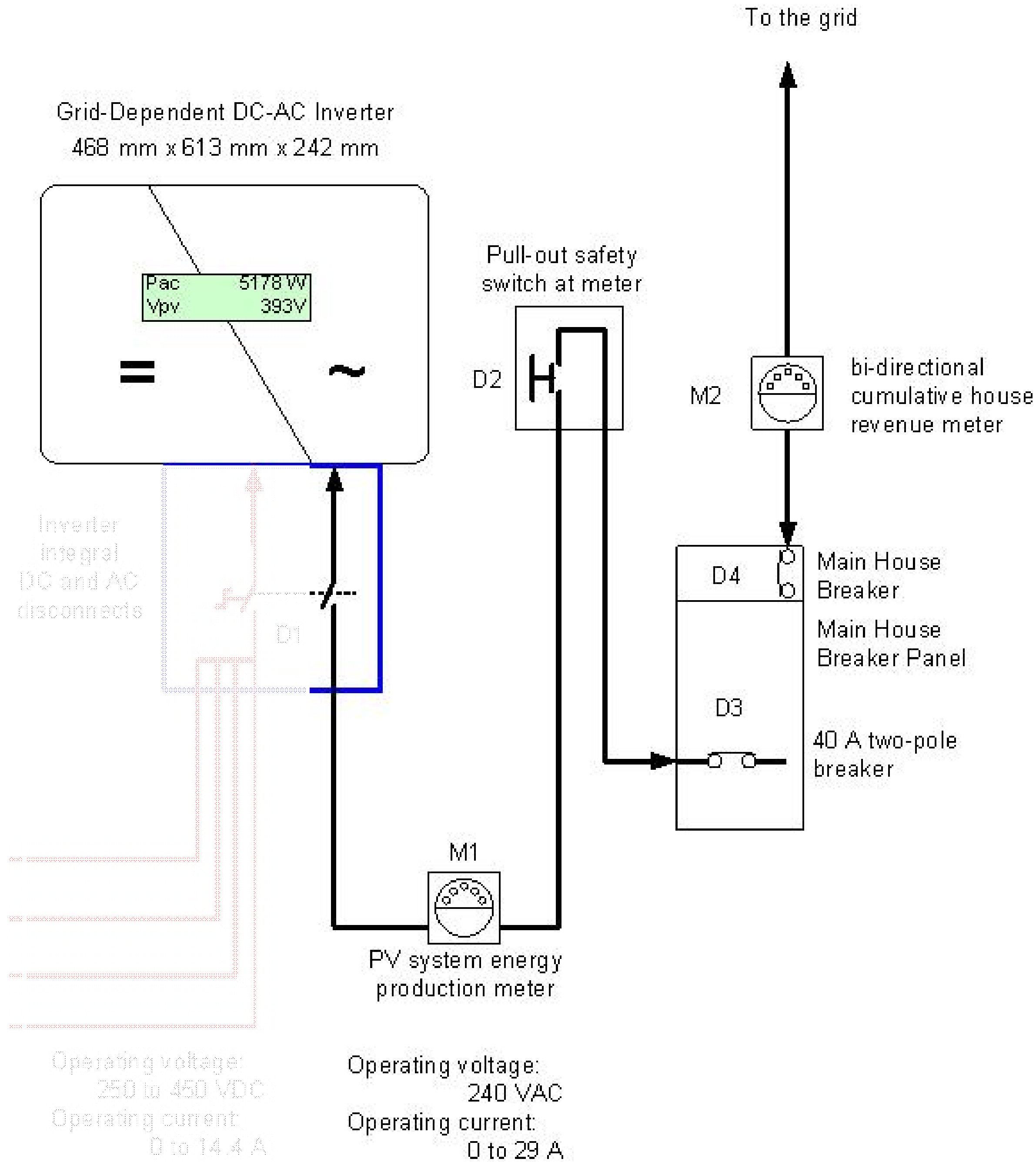


#1. DC feed

- from the array of PV modules
- to the grid-dependent inverter
- running between 250 and 450 volts DC
- open-circuit voltage at 480 VDC twice per day, up to 560 volts DC at -45°C

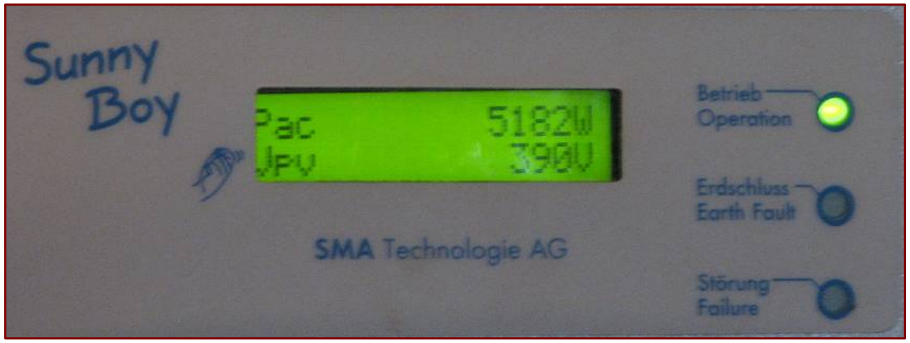
#2. AC feed

- from the grid-dependent inverter
- through an exterior utility-required safety disconnect switch (about which we disagree)
- to the house main breaker panel
- at 240 volts AC
- injects current into the breaker panel in synch with the utility mains
- current first feeds the house
- any excess must be exported
- no practical way to prevent it from being exported



Electrical Room Solar Inverter Layout

- Simple to design, model, install, control, describe, document and train
- Compact
  - only takes up wall space
- Quiet
  - inverter relays click every 5 minutes at the start and end of each day
- No maintenance



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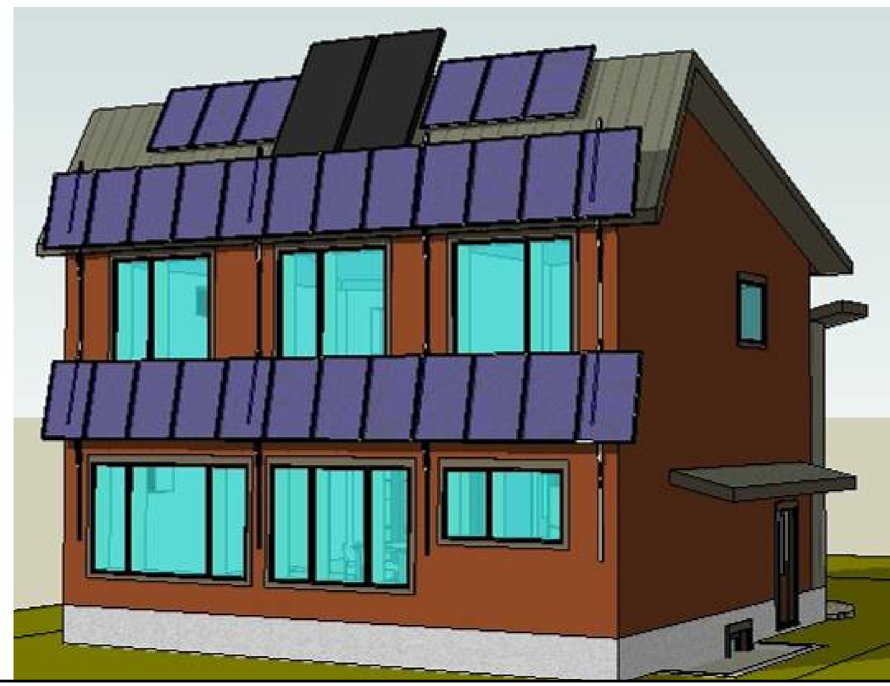
Moveable Solar PV Awning

Fixed
PV array

PV
awning

Position
in August

Position
in December



Space Cooling…

- Our climate presents us with very small cooling requirements…
  - There are 8 house features that keep the house cool.

- **Passive cooling:**
  - **Ultra-insulated walls** that keep out the heat energy caused by the solar radiation incident on the outside of the house
  - **Ultra-insulated windows** that keep out the heat energy also
  - **Overhangs** on the south windows to shade the windows from high summer sun angles
  - Low **solar heat gain coefficient** (tinting) on east and west windows
  - **Ventilation** through openable windows
- **Active cooling**:
  - Circulating water through the **ground loops** under garage (41 m) and next to foundation (53 m) to provide cooling to the fan coil
  - Possibility: Circulating water through the **solar thermal collectors** at night to provide cooled water to the fan coil
  - Last resort: using an optional **heat pump** to further chill the water from the ground loops

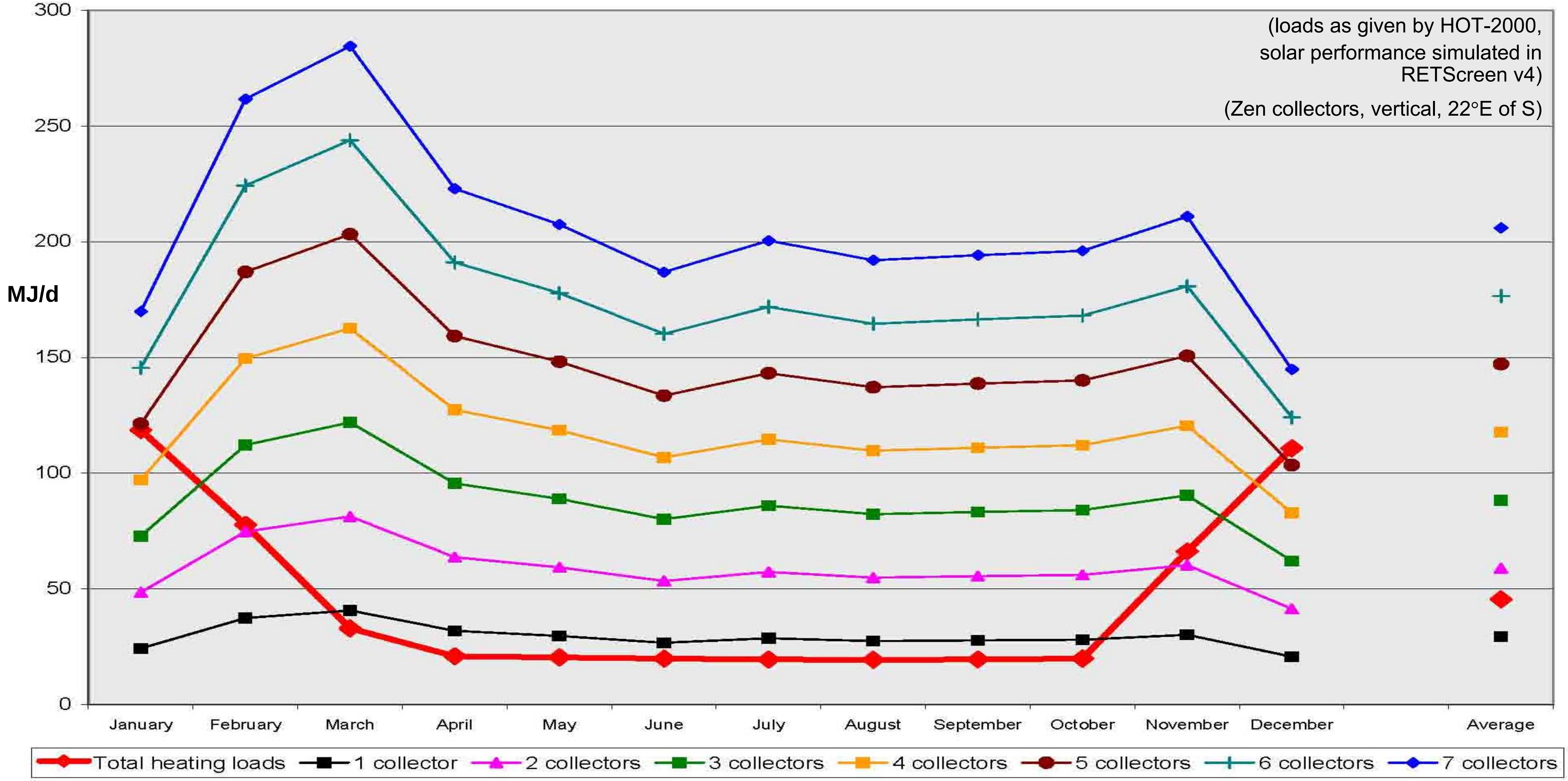
Comparisons… two great solar technologies

- **Active solar thermal heating system (for space and DW heating)**
  1. Water- or glycol-based drainback configuration
  2. It needs to store its own heat energy – complexity in moving and storing heat
     - Heat losses from the storage tank degrades its annual performance.
     - Increases capital costs, complexity of system design, modelling & installation
     - Temperature of heat needs to be sufficiently high for its heating application
  3. It is sized and oriented for annual winter-time production.
     - It is oversized for summer, and so doesn't use excess summer heat.

- **Solar PV electricity generating system**
  1. Grid-dependent, no on-site energy storage
  2. It uses the electric grid to store its energy – very tiny energy losses.
     - Electricity grid storage maximises its annual performance.
     - Minimises capital cost, complexity of system design, modelling & installation
     - Electric energy is always ready to be used.
  3. It is sized and oriented for annual maximum production.
     - Electricity grid absorbs all the energy it can produce. None is wasted.

RNZ Solar Thermal System Performance – potential

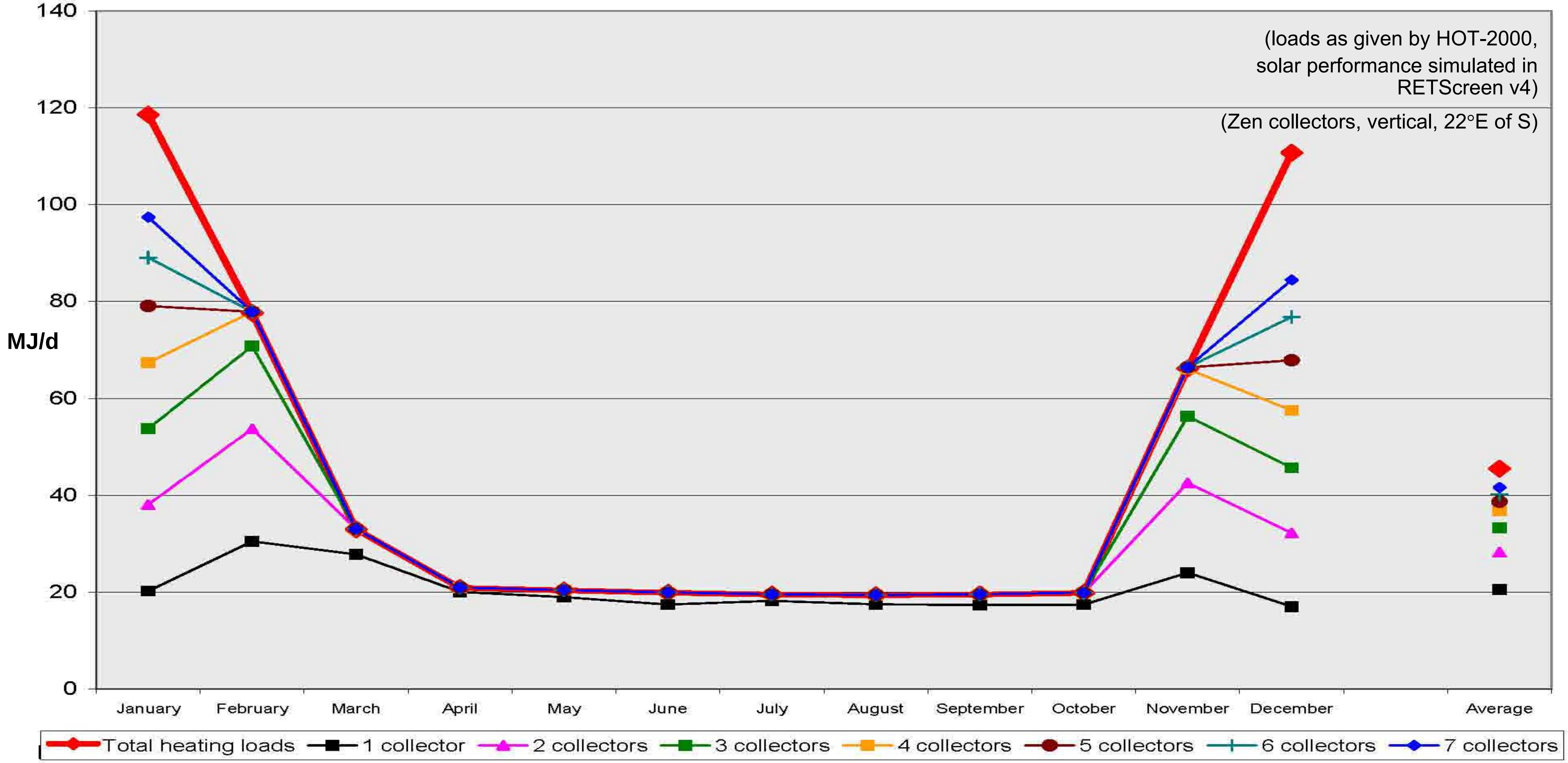
simulated as if it were connected to a utility grid that could absorb all its thermal energy



- If the loads for solar thermal could absorb all the heat that could be produced then system performance would be much higher.
- Any production above the red heating-loads line is spilled in real life.

RNZ Solar Thermal System Performance – realistic

simulated with 880 L/m² storage tank, with actual house space and water heating loads



- Collectors cannot provide heating to their maximum ability due to restrictions in the ability of the loads and the storage to absorb heat.
- Greater than 1+ collector just fills in the winter and shoulder seasons.
- This is the chief reason for the "diminishing returns" that fetters the performance of additional collectors.

Solar Thermal Heating compared to PV Electric Heating

Htg Options:	Solar Thermal (Space+DWH)	PV Electric Thermal
Cost: including builder markup	$36,700 (net of $5k of "learning")	$30,000 to $34,000 (portion that supplies heating)
Annual energy production:	4150 kWh modelled 21.8 m^2	4150 kWh modelled 20.7 m^2, 3.5 kW
Capacity price:	$8.84/annual kWh	$8.18/annual kWh
GHG savings:	1000 kg	1000 kg
Maintenance:	Leaks? Air locks? Valves? Pumps?	Inverter?
Annual cost savings:	$582, = $175 heat savings + $407 to eliminate gas connection fees	$582, = $175 + $407 (to eliminate gas line)
Energy price (simple):	**26 ¢/kWh, $71 /GJ (over 25 years)**	**23 ¢/kWh, $64 /GJ (over 25 years)**
Return on investment:	1.6% /year (including eliminating natural gas line)	1.7% /year

Next… Some Technologies

1. Solar thermal for heating domestic water (DWH)
2. Geothermal heat pumps for space and DWH
3. Solar photovoltaic (PV) electricity

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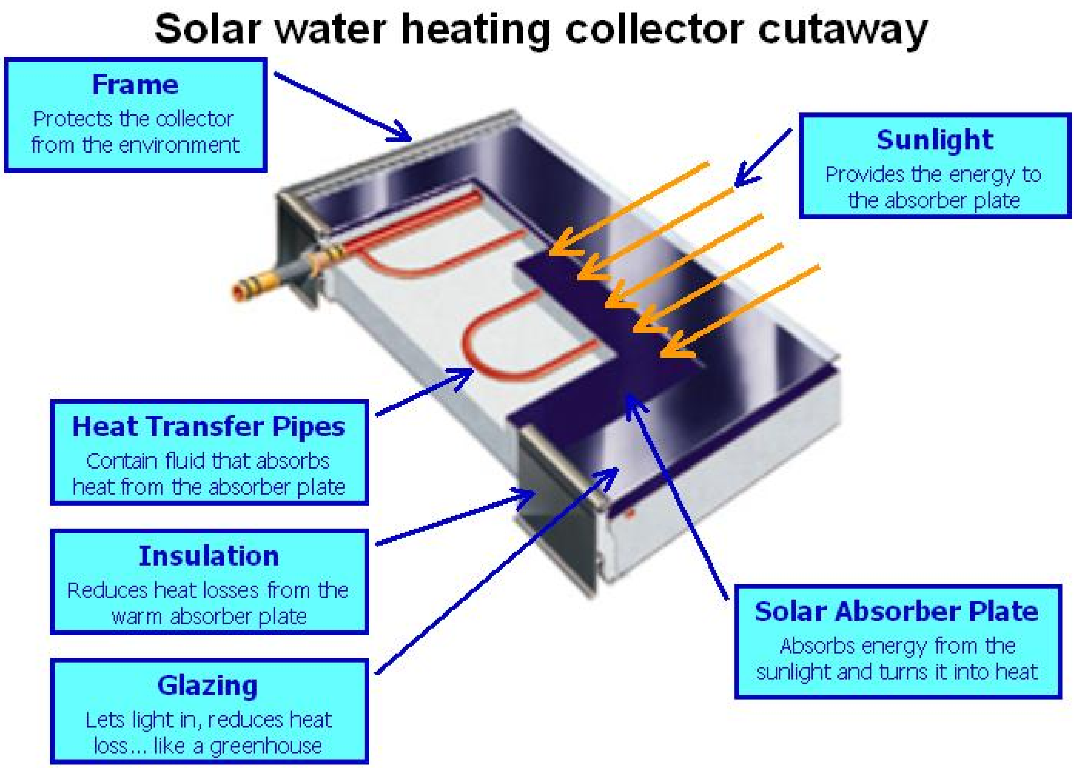
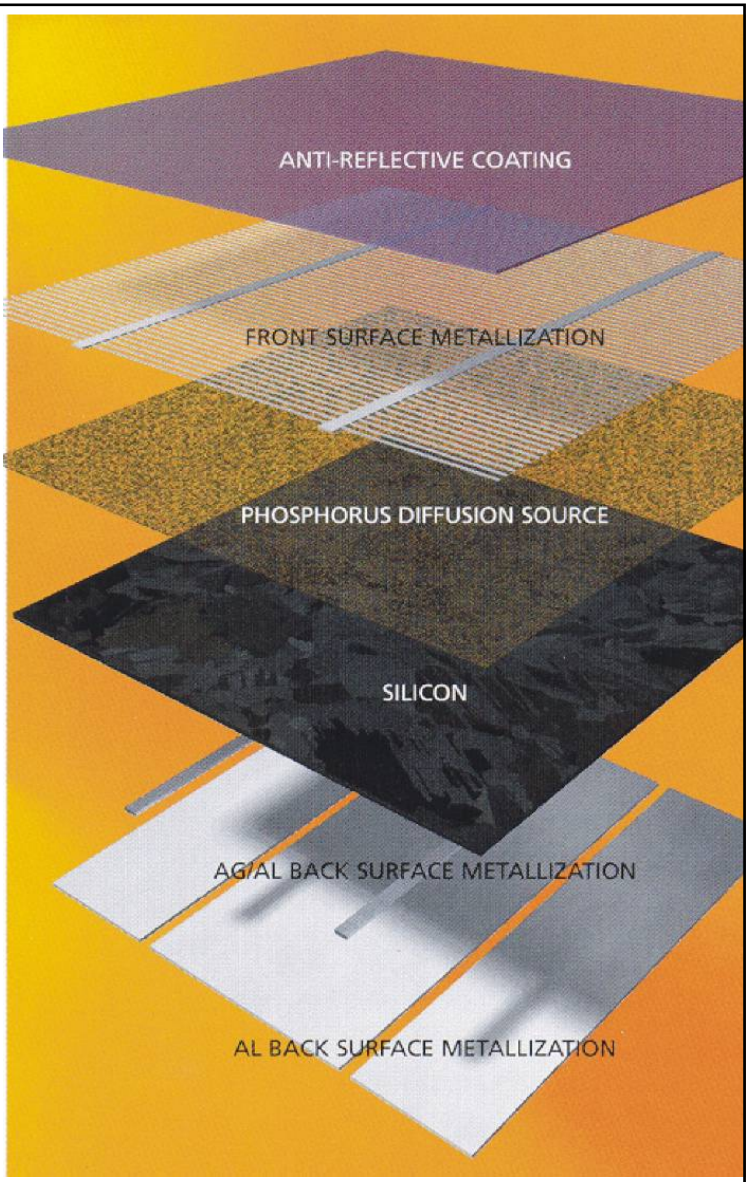
Solar heating and solar electricity are NOT the same…





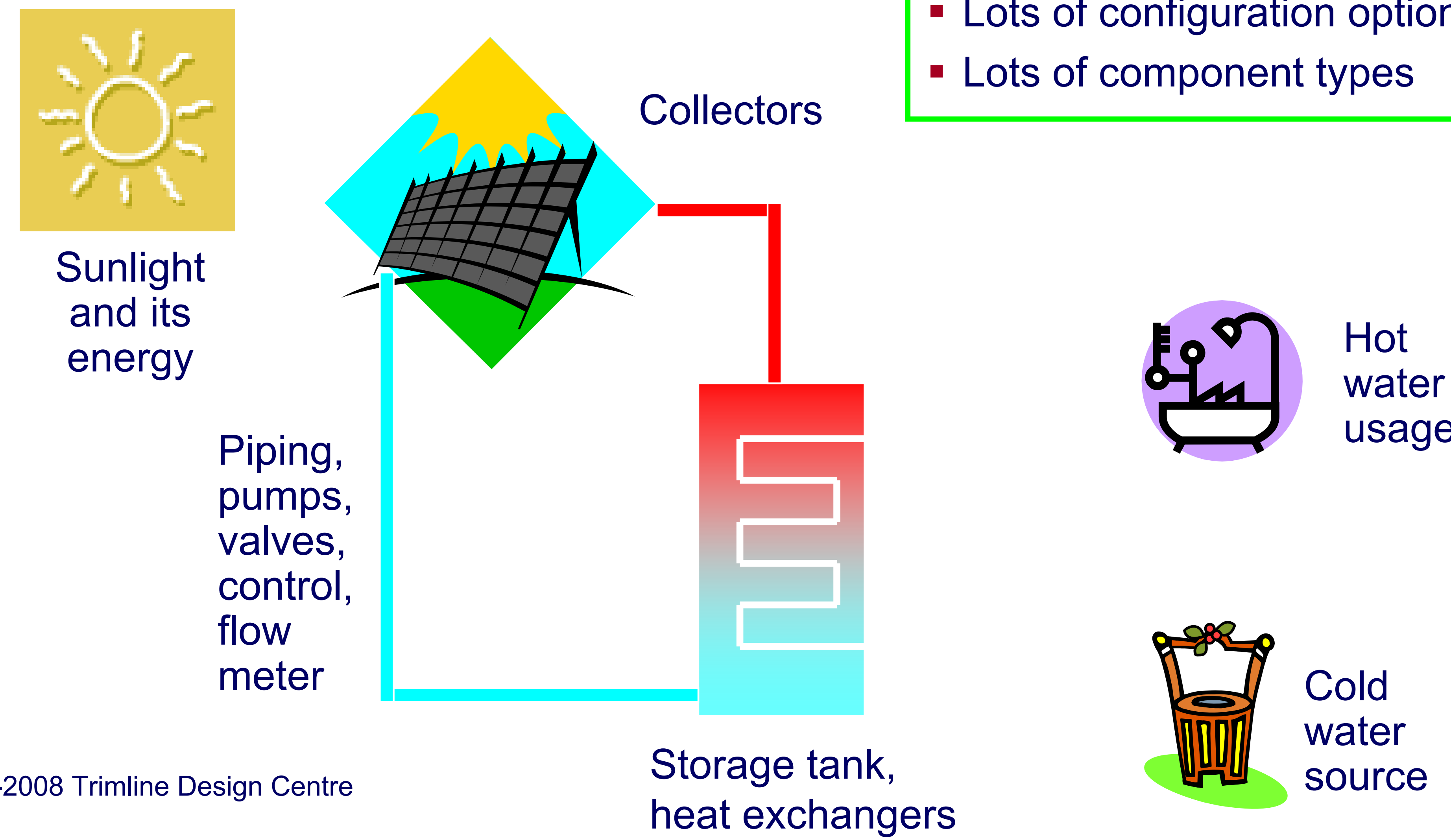
- Solar heating
  - A dark surface sitting in the sunshine
  - Water or air runs past the solar heated surface carrying heat to the building.

- Solar electricity
  - A semiconductor device like a computer chip
  - Photons bump electrons out of an atom.
  - Wires carry the electrons away.


Solar
Domestic
Water Heating

Solar Domestic Water Heating System - Concept

- Lots of configuration options
- Lots of component types



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Solar Water Heating – Major Components

Solar collectors

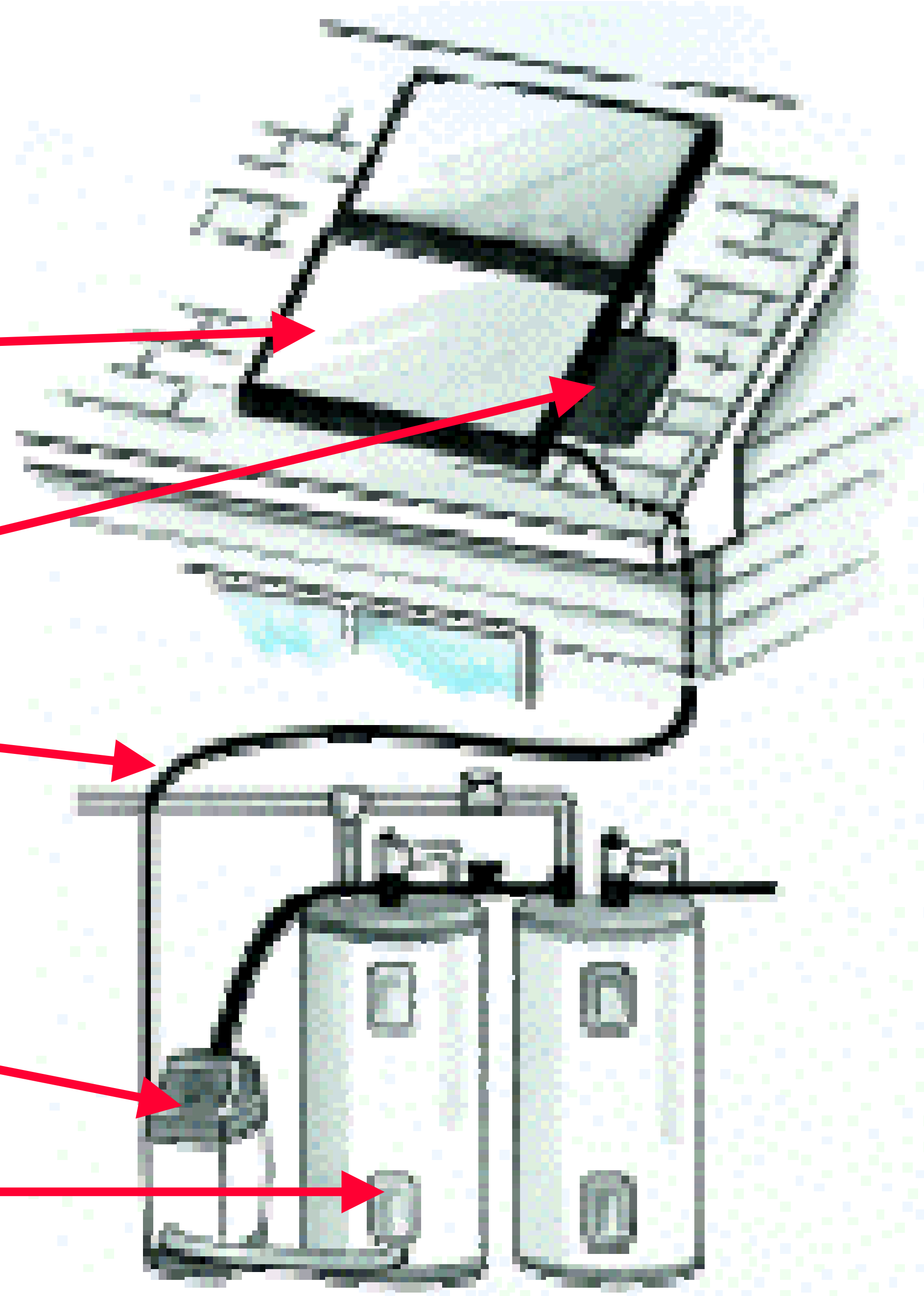
(~$1000 each)

Solar controller (one type)

Piping connections

Heat exchanger

Pre-heat water tank



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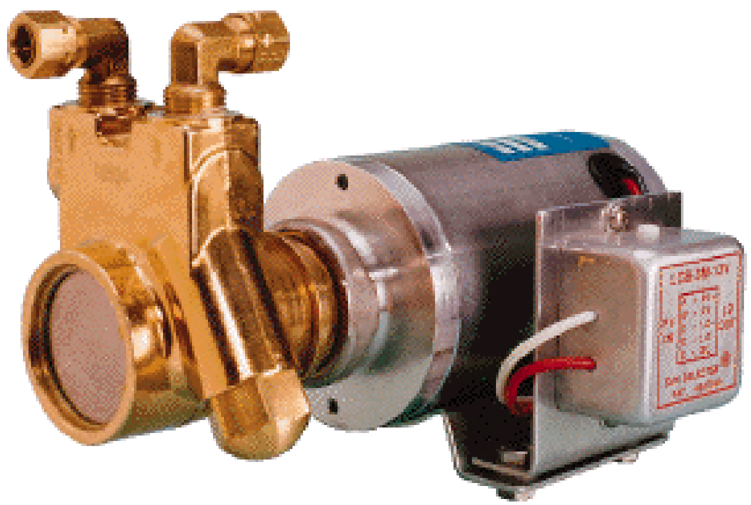
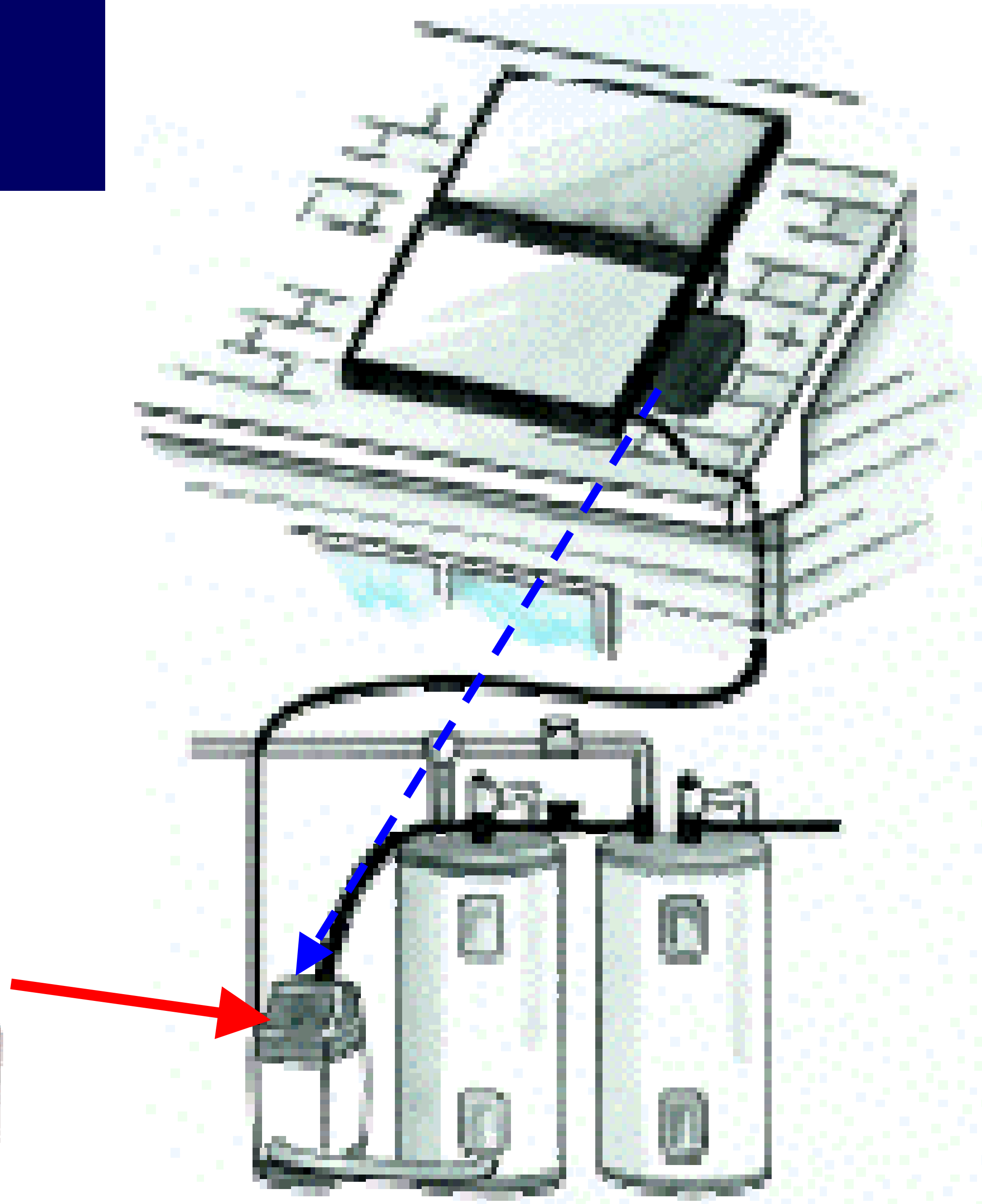
Solar Water Heating – Controller Turns On Pump

In this example, a solar pump is located on top of the heat exchanger;

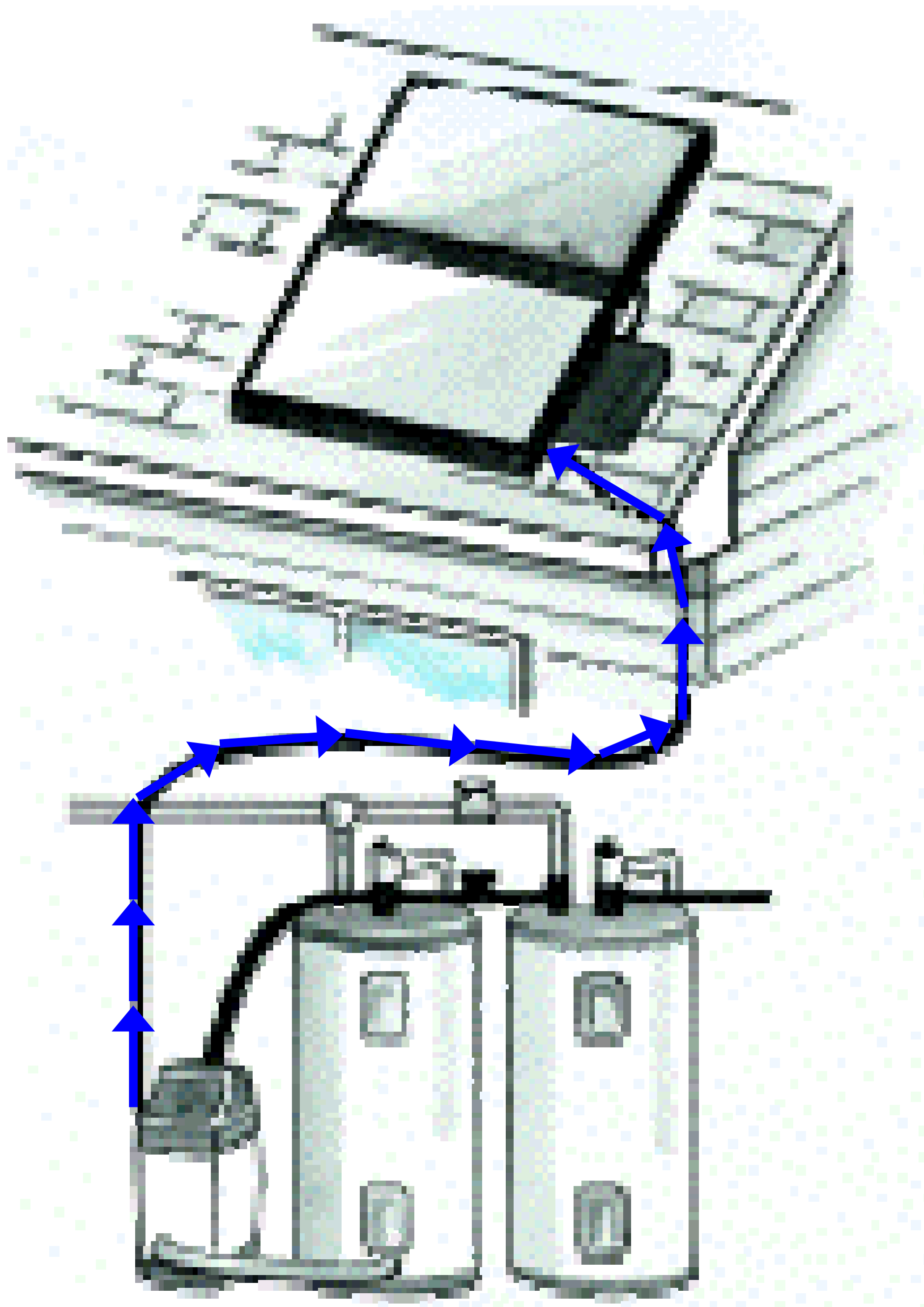
The controller sends a signal to the pump to turn on…





Solar Water Heating – Liquid is Circulated

Glycol (anti-freeze) is then circulated between the heat exchanger and the solar collectors…



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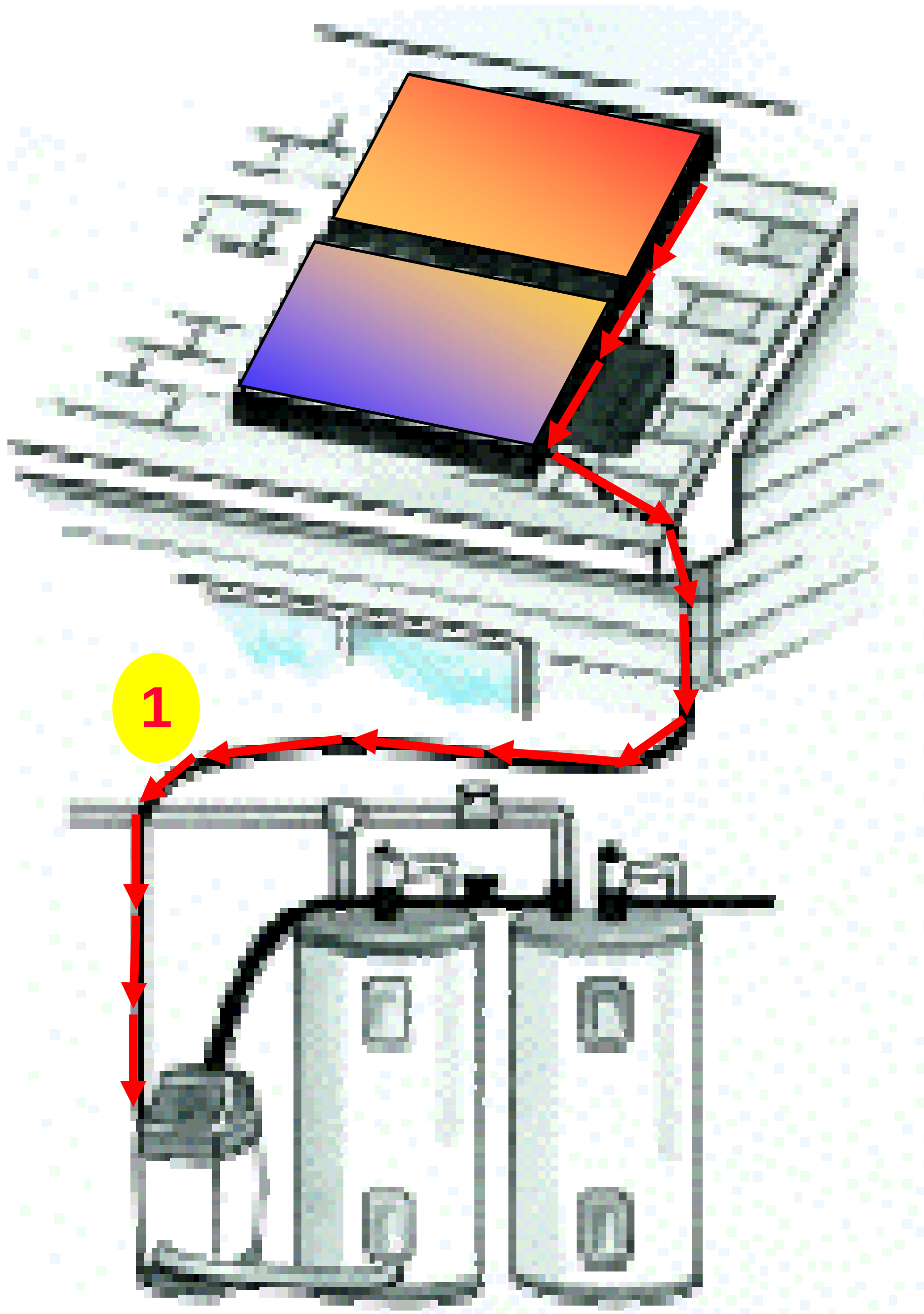
Solar Water Heating – Liquid is Heated

Within the collectors, the glycol absorbs the solar heat…

The collected solar heat circulates back to the heat exchanger…

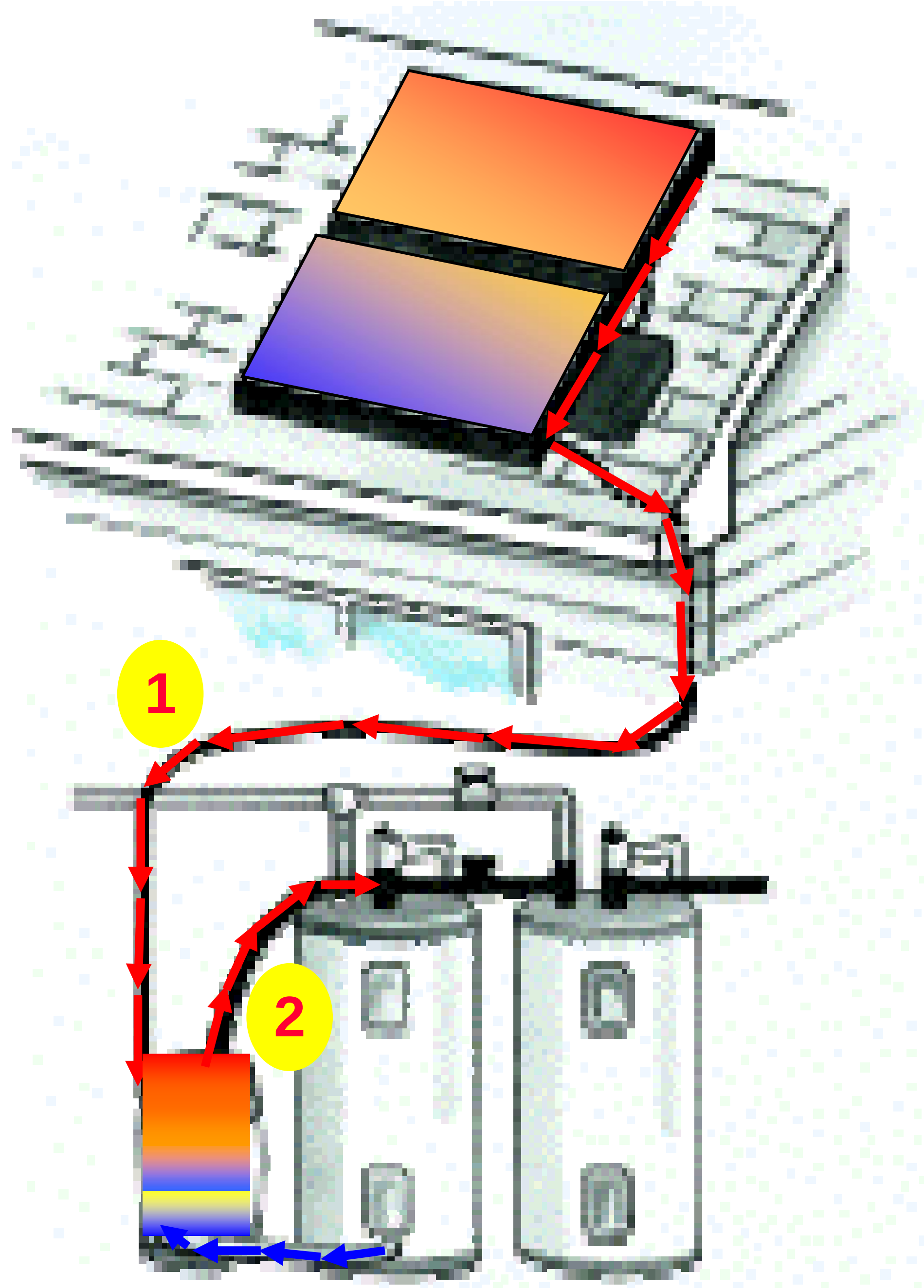


Solar Water Heating – Heat is Transferred

Cold water is circulated between the solar tank and the heat exchanger…

The heat exchanger transfers the solar heat into the water…

The heated water returns back into the solar tank.



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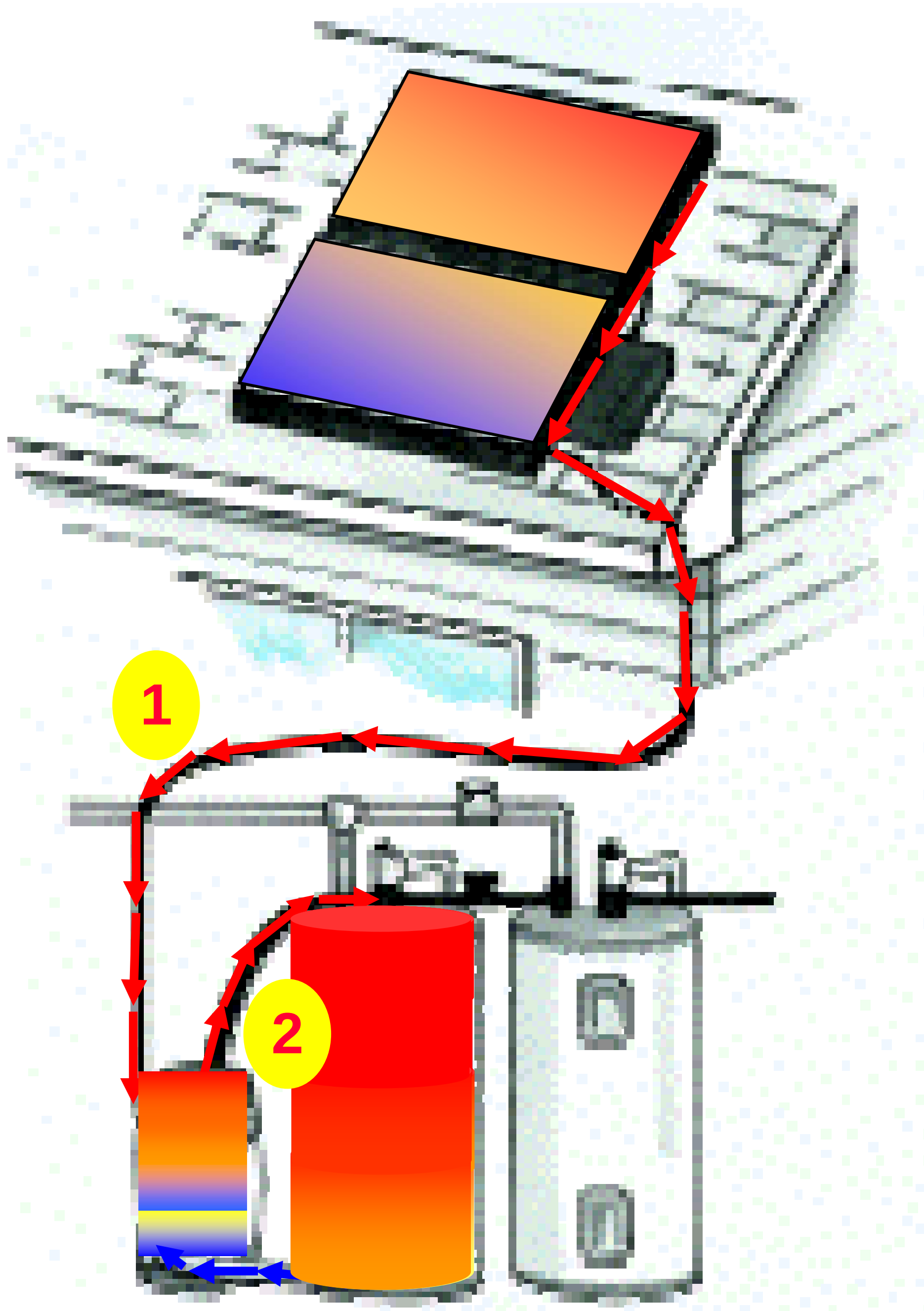
Solar Water Heating – Hot Water is Stored

The heat collection process operates over the whole day…

The solar tank water heats up throughout the day…

Until the whole solar tank is filled with hot water!



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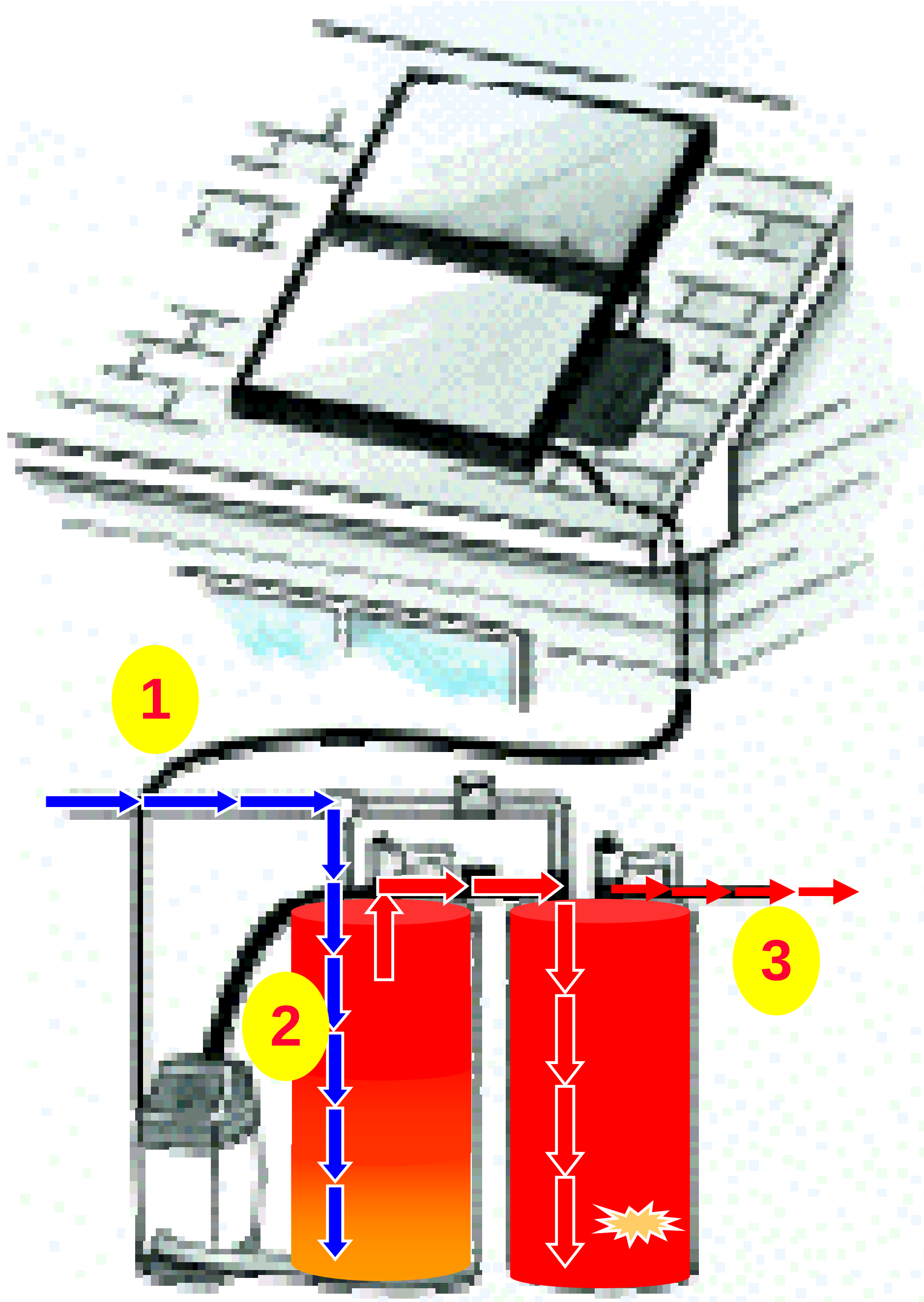
Solar Water Heating – Delivery to You

When hot water is drawn off for usage…

Solar heated water flows into the gas or electric booster tank…

And cold water from the city is drawn into the solar tank…



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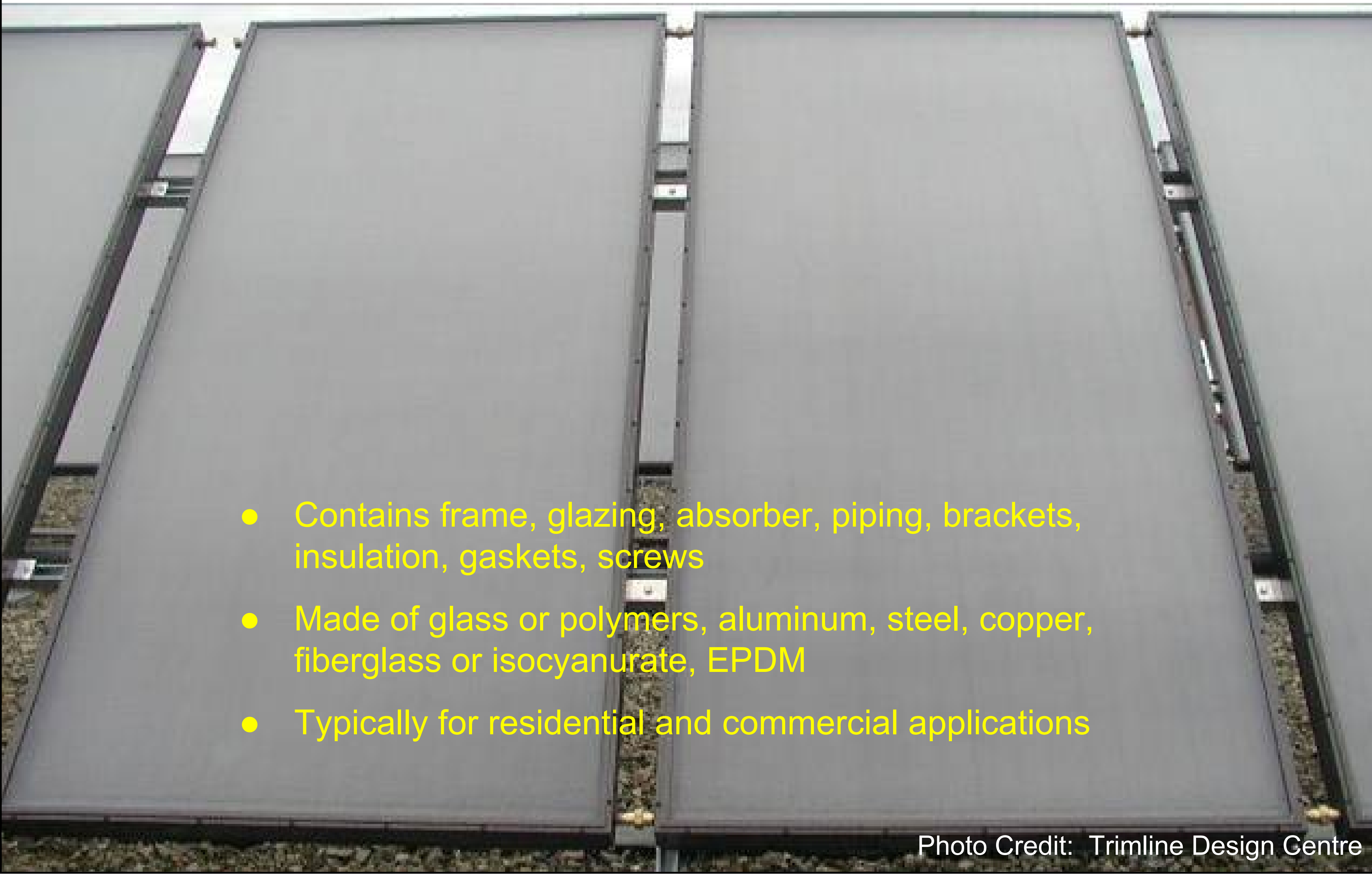
Components

- Collectors
  - unglazed, glazed, evacuated tube
- Tanks
- Heat exchangers
  - in tank and side-arm
- Pumps
  - centrifugal and positive displacement
- Controls
  - differential, digital, solar intensity
- Piping, fittings
  - only copper, bronze, brass, stainless steel
- Heating fluid
  - glycol, water

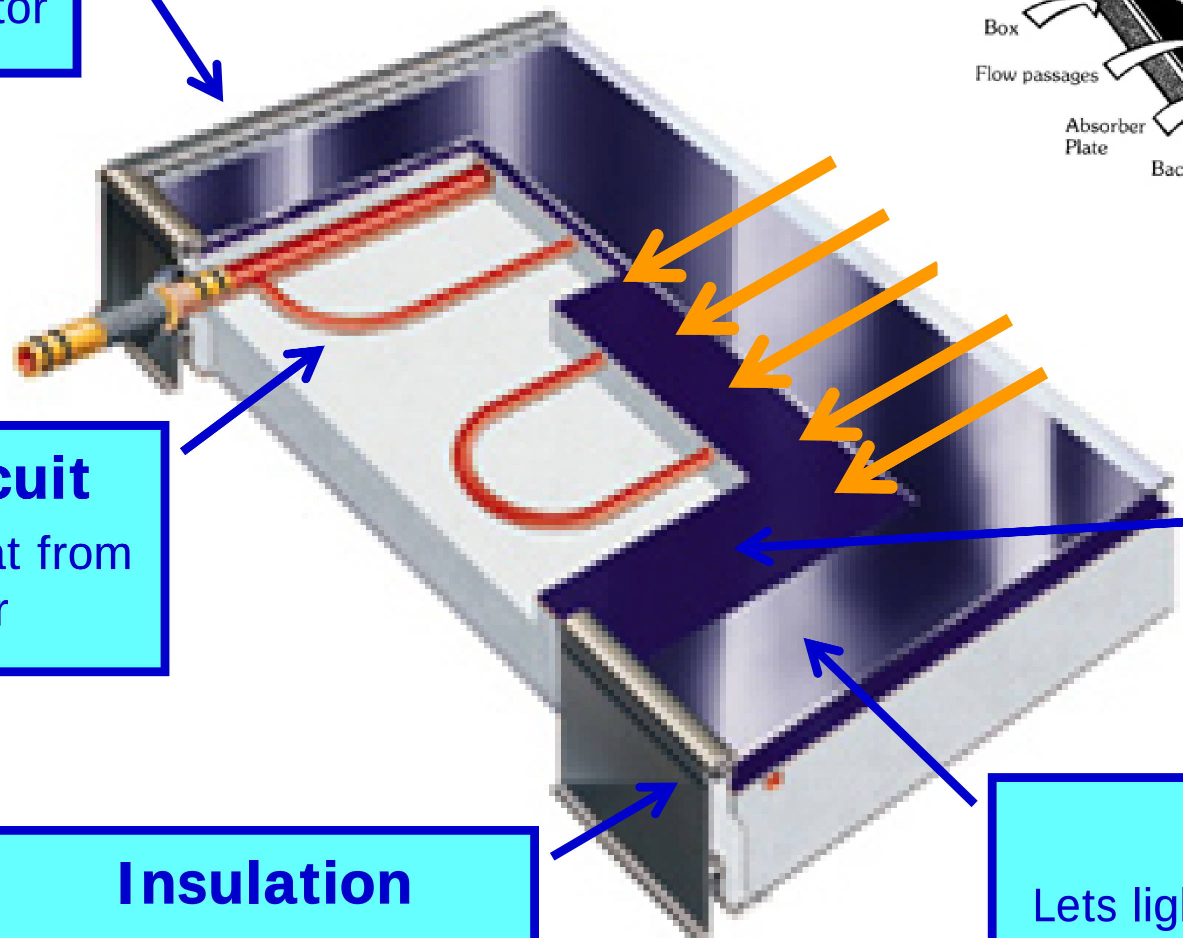
Glazed Flat Plate Collectors



- Contains frame, glazing, absorber, piping, brackets, insulation, gaskets, screws
- Made of glass or polymers, aluminum, steel, copper, fiberglass or isocyanurate, EPDM
- Typically for residential and commercial applications

Photo Credit: Trimline Design Centre

Solar Water Heating Collectors – Concept



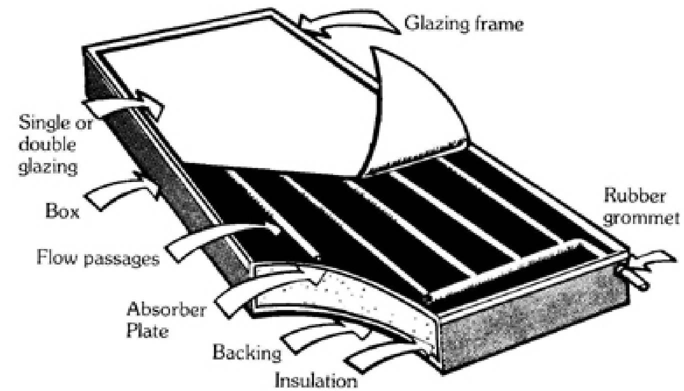
Frame
Protects the collector

Fluid circuit
Harnesses heat from absorber

Absorber
Converts sunlight into heat

Insulation
Reduces heat losses

Glazing
Lets light in, reduces heat loss, like a greenhouse



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Flat Plate - Glazed

- Application
  - Used for domestic water or space heating, pools
- Advantages
  - Very low or zero maintenance costs
  - Very low operating costs
  - Permanent installation – withstands the environment
  - Can be used throughout the year
  - Can be used for solar cooling at night
- Drawbacks
  - Less efficient than an evacuated tube in extreme cold weather
  - More wind drag than evacuated tube (doesn't matter)

Text Credit: Trimline Design Centre

Evacuated tube collectors

- Single glass tube with an internal plate absorber.

or

- Double glass tube with an integral coated inner glass curved absorber.

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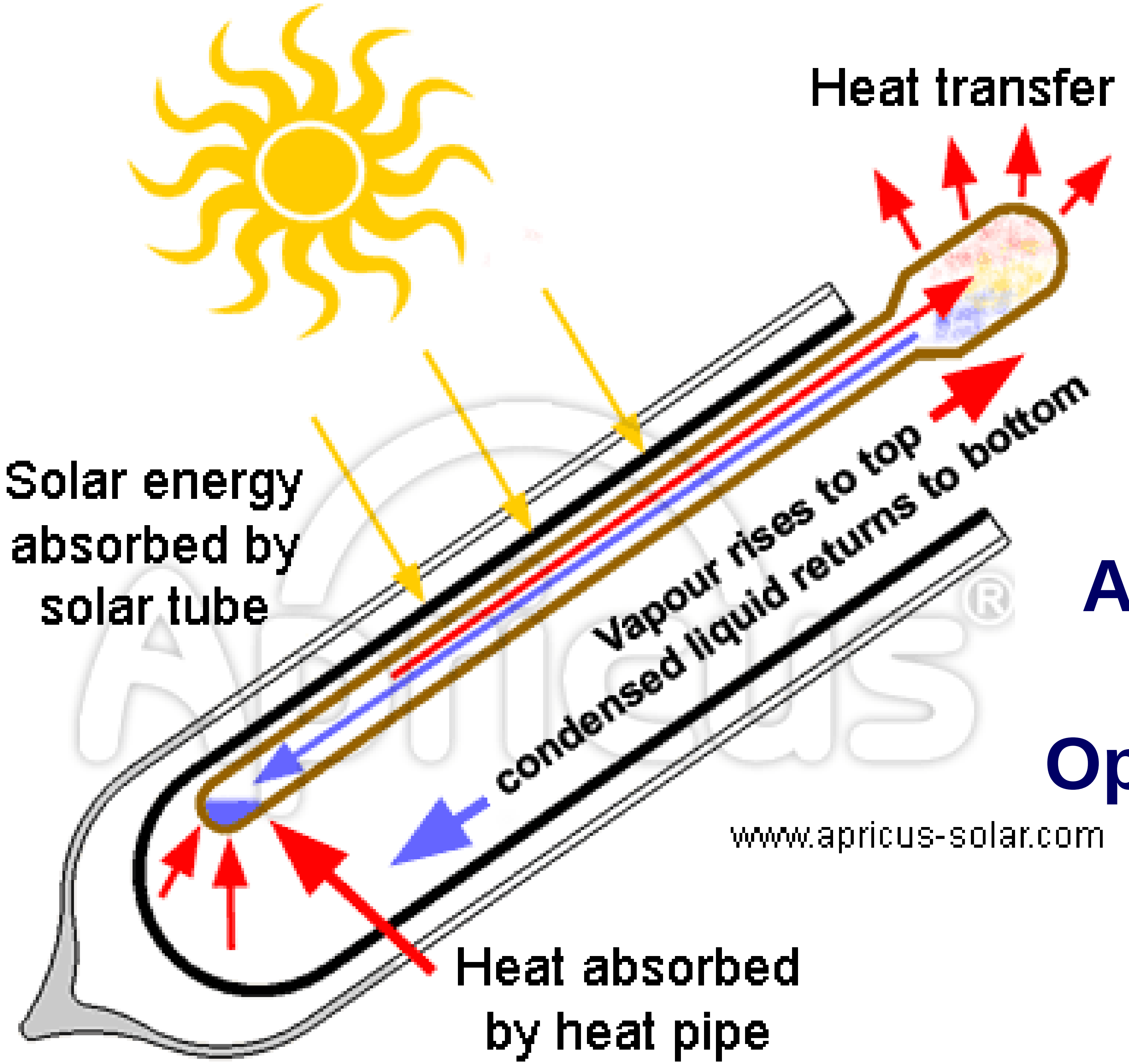


Apricus ETC Operation

Evacuated Tube

- Applications
  - Used for domestic water or space heating, pools
- Benefits
  - Very good at collecting heat in cold and cloudy conditions
  - Very low or zero maintenance costs
  - Very low operating costs
  - Permanent installation – withstands the environment
  - Can be used throughout the year
- Drawbacks
  - Higher cost for extra efficiency
  - Limited design function – tubes must be mounted near to vertically
  - Expensive – $2500 for 30 tubes
  - Concern about durability
  - Snow cover for longer time periods
  - Cannot be used for summer cooling (except if you use an absorption chiller)

Text Credit: Trimline Design Centre

Residential-Sized Solar Heat Storage Tank

Pump controller

Storage tank with heat exchanger inside

Solar circulation pump

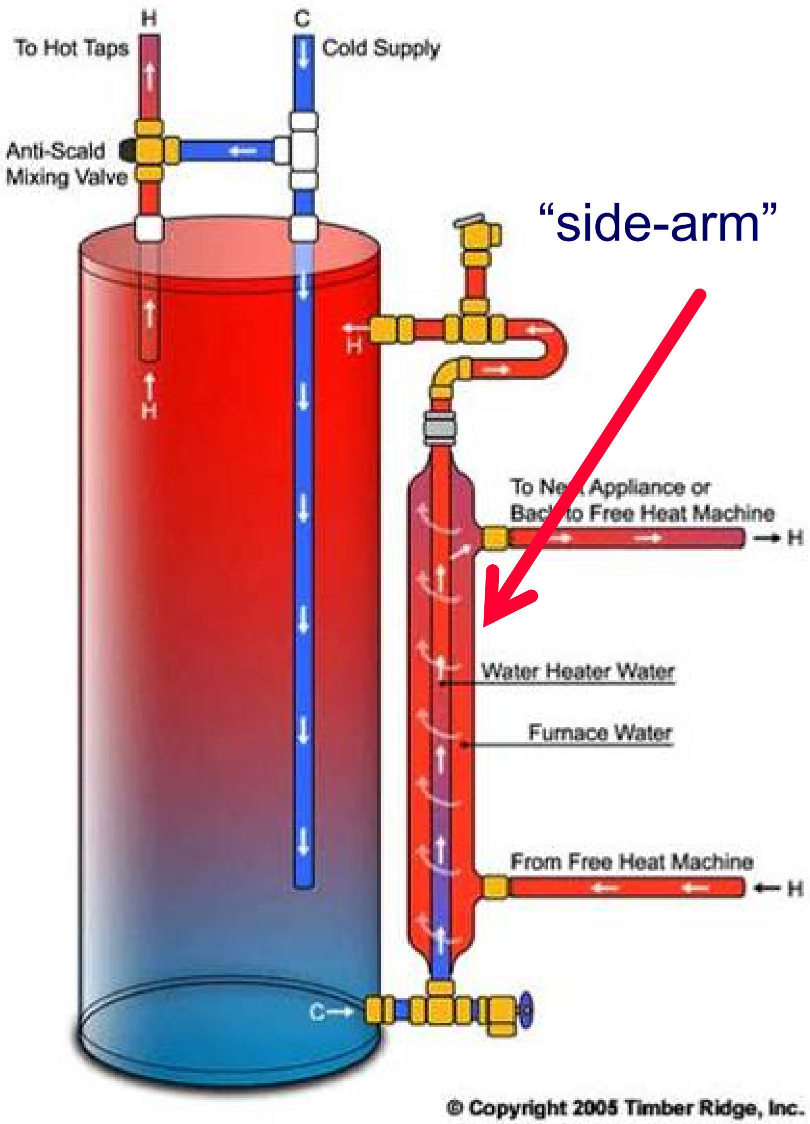
Often also has a drainback reservoir and a flow meter

Storage Tanks

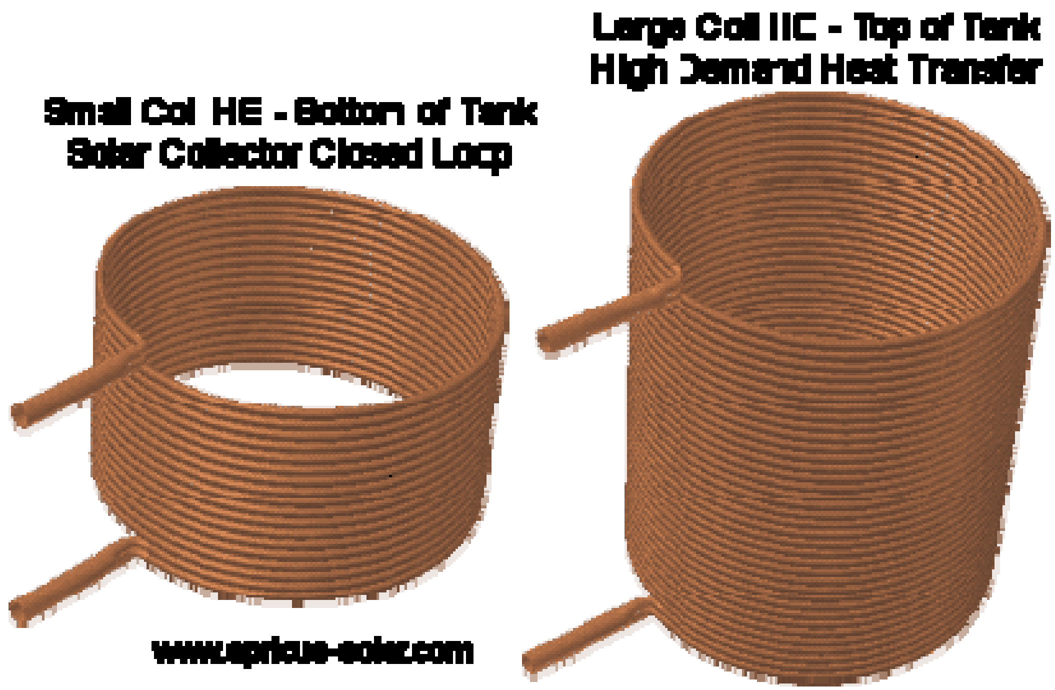
- Stores hot water so that it can be used at a later date.
- Used to transfer heat from solar piping to domestic water.
- Can contain heat exchangers.
- Can be:
  - pressurized or non-pressurized
  - made from metal, fiberglass or polymer materials
  - mounted above or below ground level
- Various sizes from 50 litres to 5000 litres or larger.

Heat Exchangers

- Transfers heat from one fluid "flow" or loop to another
  - Solar loop to storage loop
  - Solar fluid to drinking water
- Protects drinkable water from glycol and stale water



Coil inside the tank

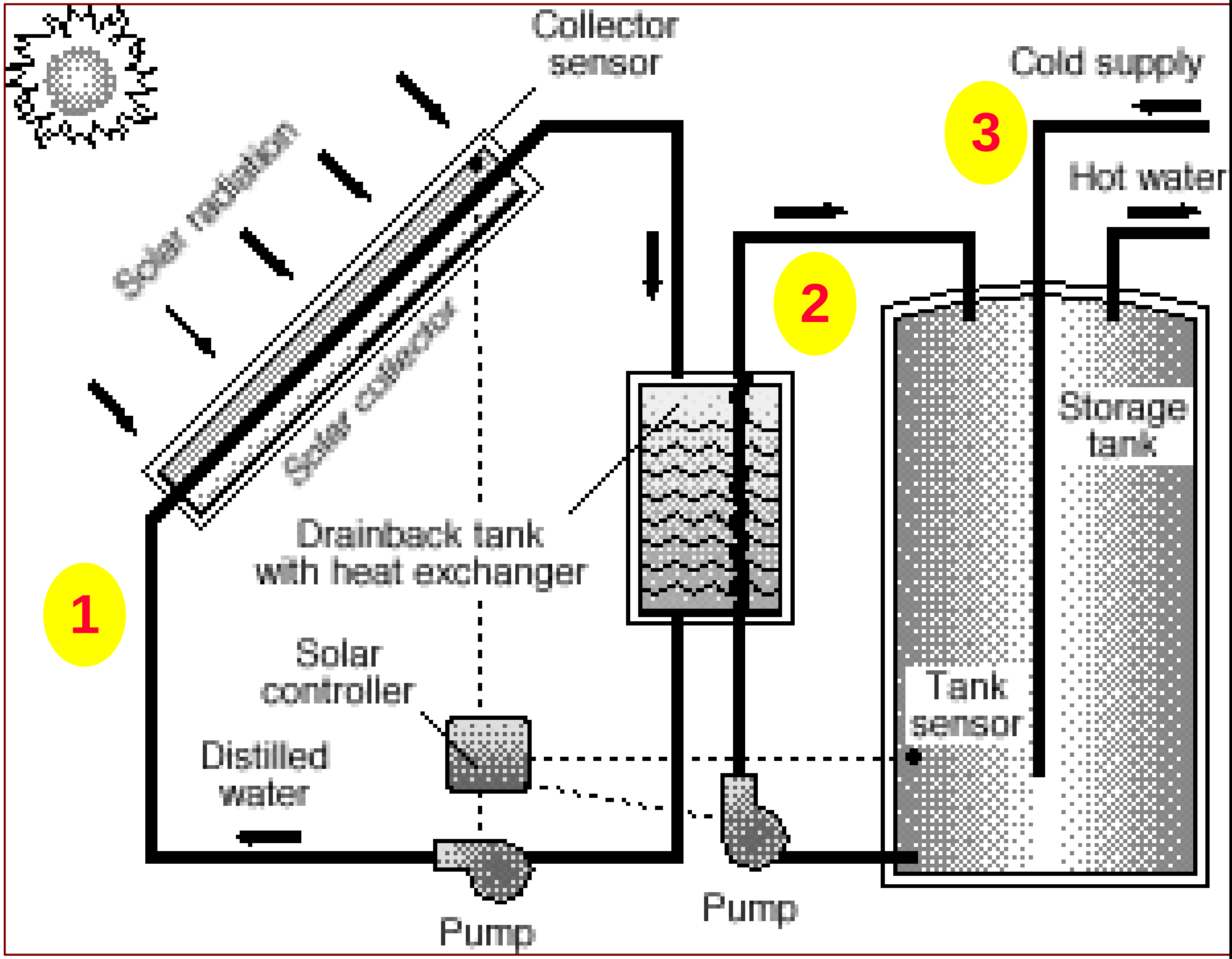


Text Credit: Trimline Design Centre

"Drainback" Water-Based Configuration

In a drainback system, water is only pumped up to the collectors when enough solar energy is available to heat it.

Otherwise, the collectors remain empty – such as at night and during freezing and stagnating conditions.



Drainback Configuration
– How is it different?

- Solar loop circulates water
  - from storage tank to solar collectors to be heated,
  - then to the drainback tank,
  - may need to use distilled water because there are no minerals in it. Some city water can make algae in the system in a year.

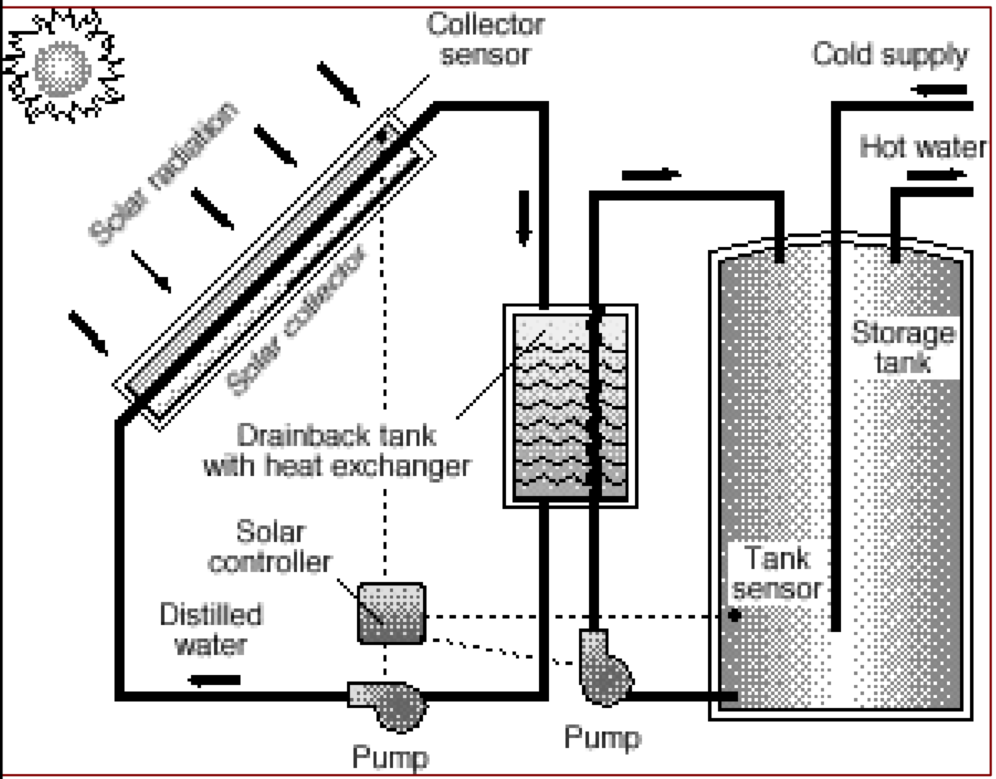
- Tank loop circulates water
  - from drainback tank,
  - to the storage tank, which stores the heat for future use.

- When storage tank is full of hot water, the pump stops and the water drains back to the drainback tank due to gravity.

- Drainback tank:
  - essential for a drainback system to work,
  - maintains an air buffer to allow the water in the collectors and piping to be displaced by air and drain back properly.

Text Credit: Trimline Design Centre

Drainback Configuration
– What does the drainback process do?



- Solar collectors and piping are empty when not operating.
- Provides failsafe protection against system damage due:
  - overheating in the summer,
  - freezing in the winter, or
  - electrical power outages.

Text Credit: Trimline Design Centre

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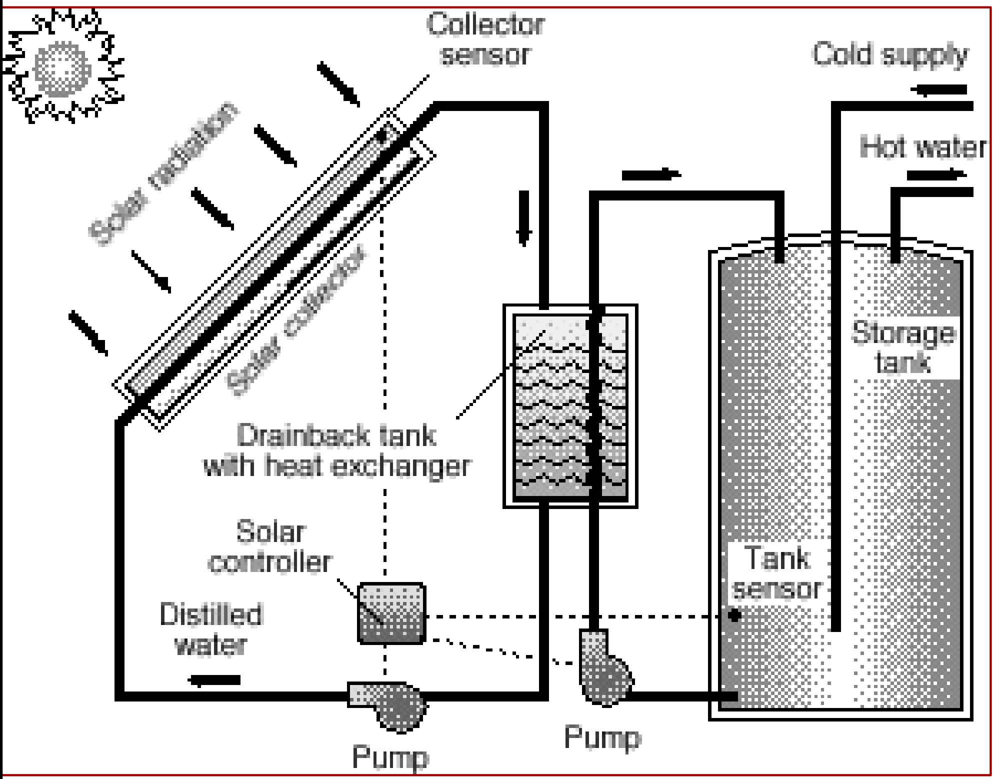
Drainback Configuration – Advantages

- Easiest 4-season system for a do-it-yourself person to install and maintain.
- Has the least maintenance of the 4-season systems.
- No concerns when going away on holidays or other periods of reduced hot water requirements.
- Solar collectors will last longer than in other systems.

Drainback Configuration – Advantages

- It can be stopped when the storage tank is full of hot water:
  - without degrading the water or causing major component failures due to collector stagnation.
  - without being concerned about boiling the storage tank or causing high system temperatures and pressures in the summer when the collectors are in stagnation mode (these would otherwise cause major system component failures).
- More collectors can be added to produce more heat in the winter:
  - without need to dissipate excess heat in the summer when it is not required.

Drainback Configuration
– Special Design Considerations



- Installation needs to be carefully done.
- Drainback needs to be certain:
  - all piping must be sloped,
  - collectors must be level, and
  - all water must drainback into a warmed space.
- Requires a larger pump than a glycol system due to the head pressure of the water in the piping.

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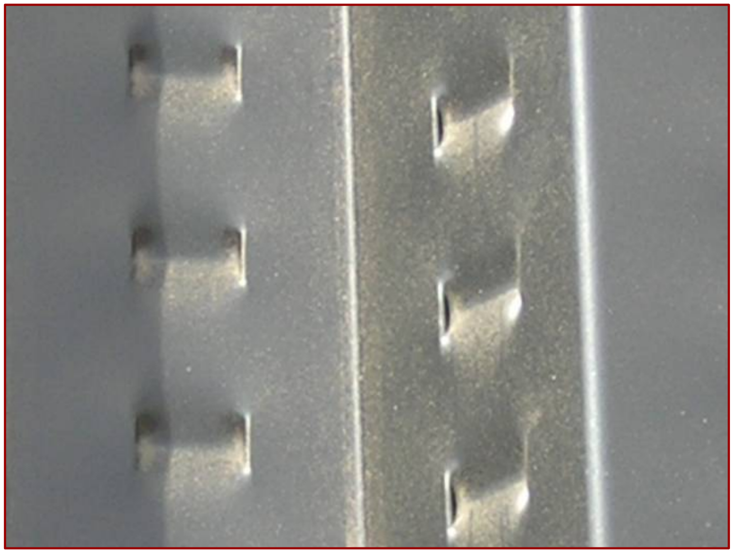
Operating Costs…

- Operating costs:
  - Solar PV powered pump: $0 per year
  - Glycol system: $10 per year in electricity
  - Drainback system: $15-$20 per year in electricity

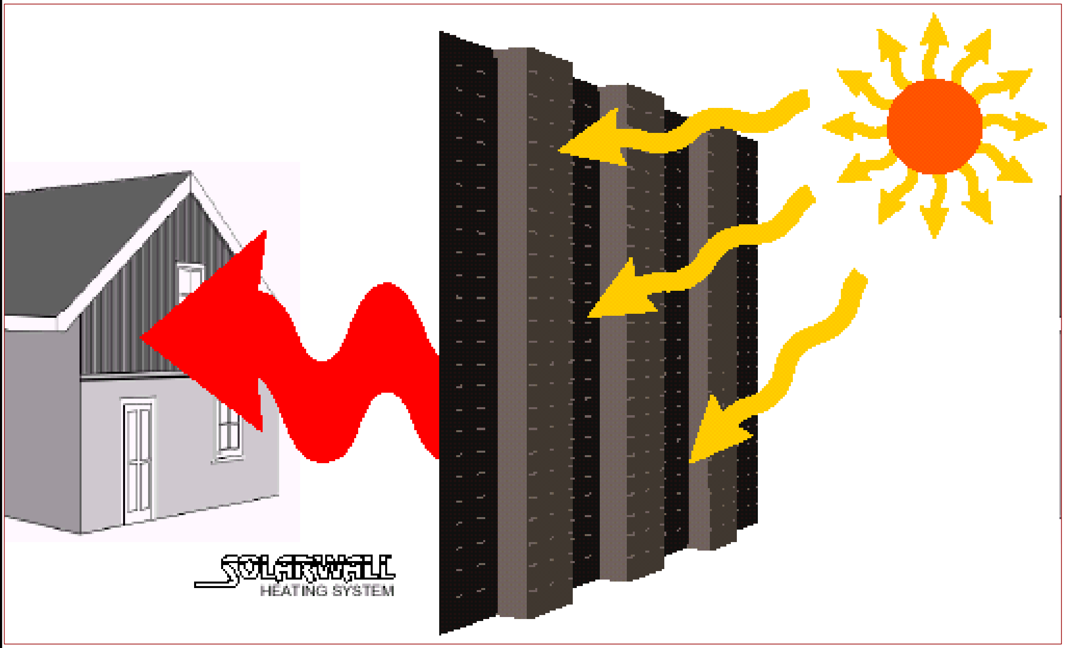
- Maintenance costs:
  - Glycol system: $20 per year for glycol?
  - Drainback system: $0 per year

Solar Air Heating
– Solarwall –



Unglazed perforated dark-coloured metal surface

Most dark colors have absorptivity of 0.80-0.95



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Residential-sized Solarwall

Avalon "Discovery II"
Net Zero Electricity Home
Red Deer, Alberta

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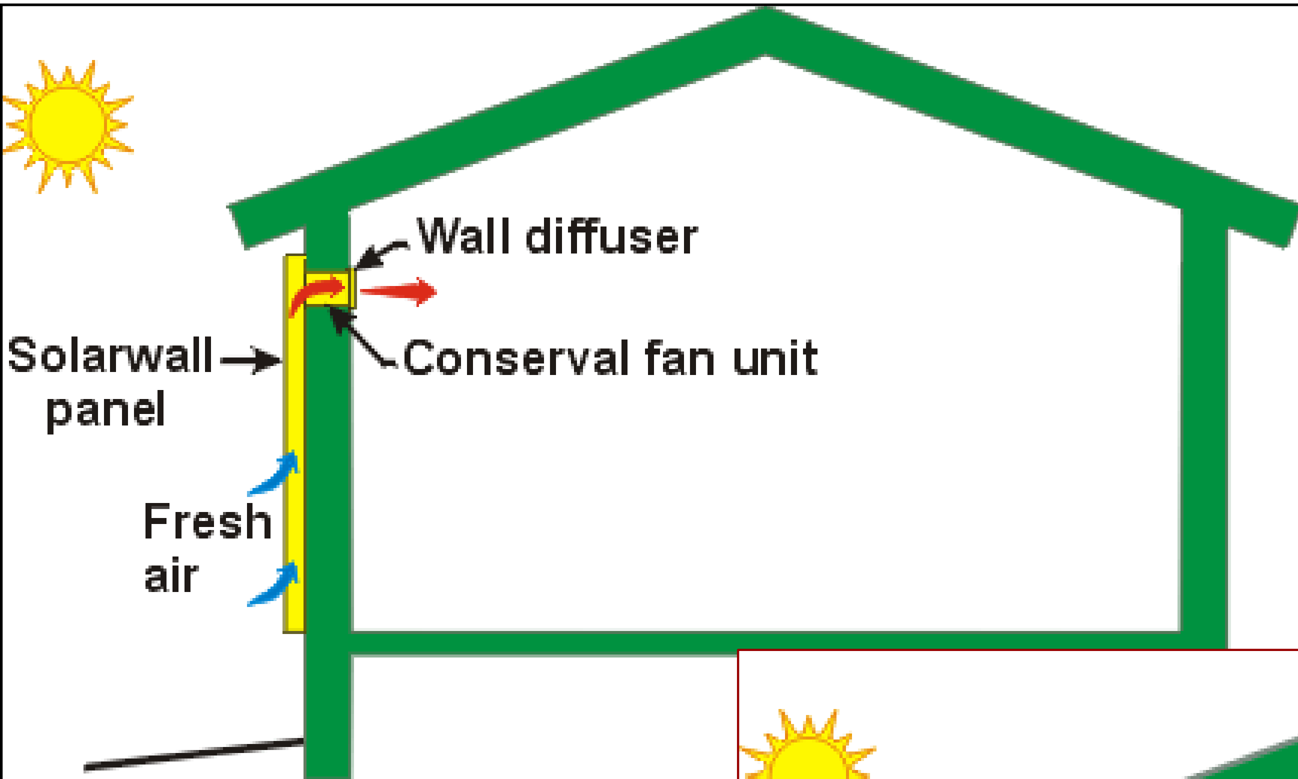
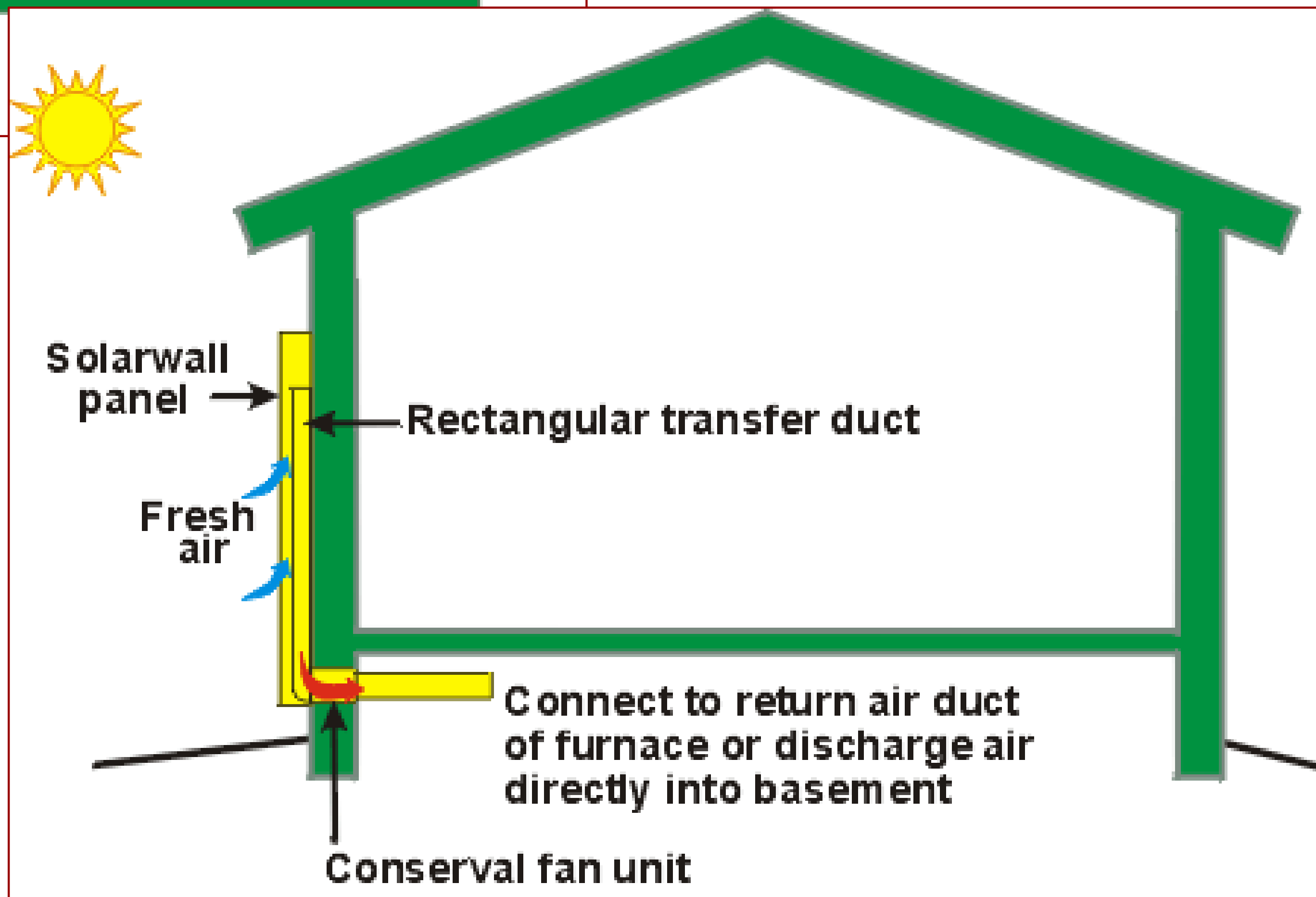
Solarwall Connection to Houses



Direct room discharge



Furnace connection

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Next… Some Technologies

1. Solar thermal for heating domestic water (DWH)
2. Geothermal heat pumps for space and DWH
3. Solar photovoltaic (PV) electricity

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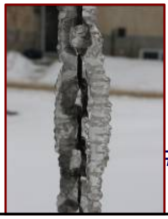
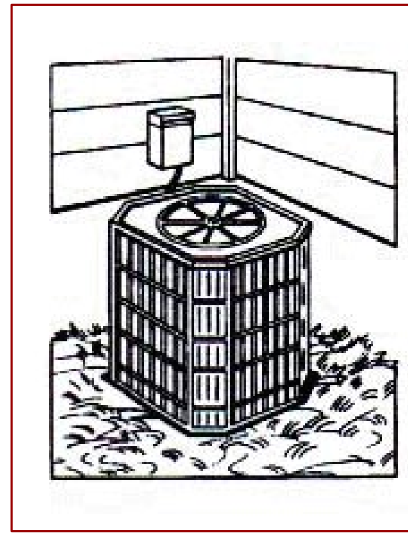


Geothermal == "Ground Heat"

- Lots of people are interested in this.
- Lots of companies are springing up.
- Lots of spinning of words and concepts as corporations vie for a unique position.
- Also called 'geo-exchange' by some companies.

Geothermal:
– What is a Heat Pump?



- A heat pump pumps heat from one place to another
  - From a hot place that we want to cool
  - (called an air conditioning system, fridge or freezer)

Electricity to run it → HP

fridge — **HP** → **room**

  - To a cold place that we want to heat up
  - (called a ground-source, water-source, or air-source heat pump)

Electricity to run it → HP

house ← **HP** — **ground, water, air**

- Its operation can be reversed

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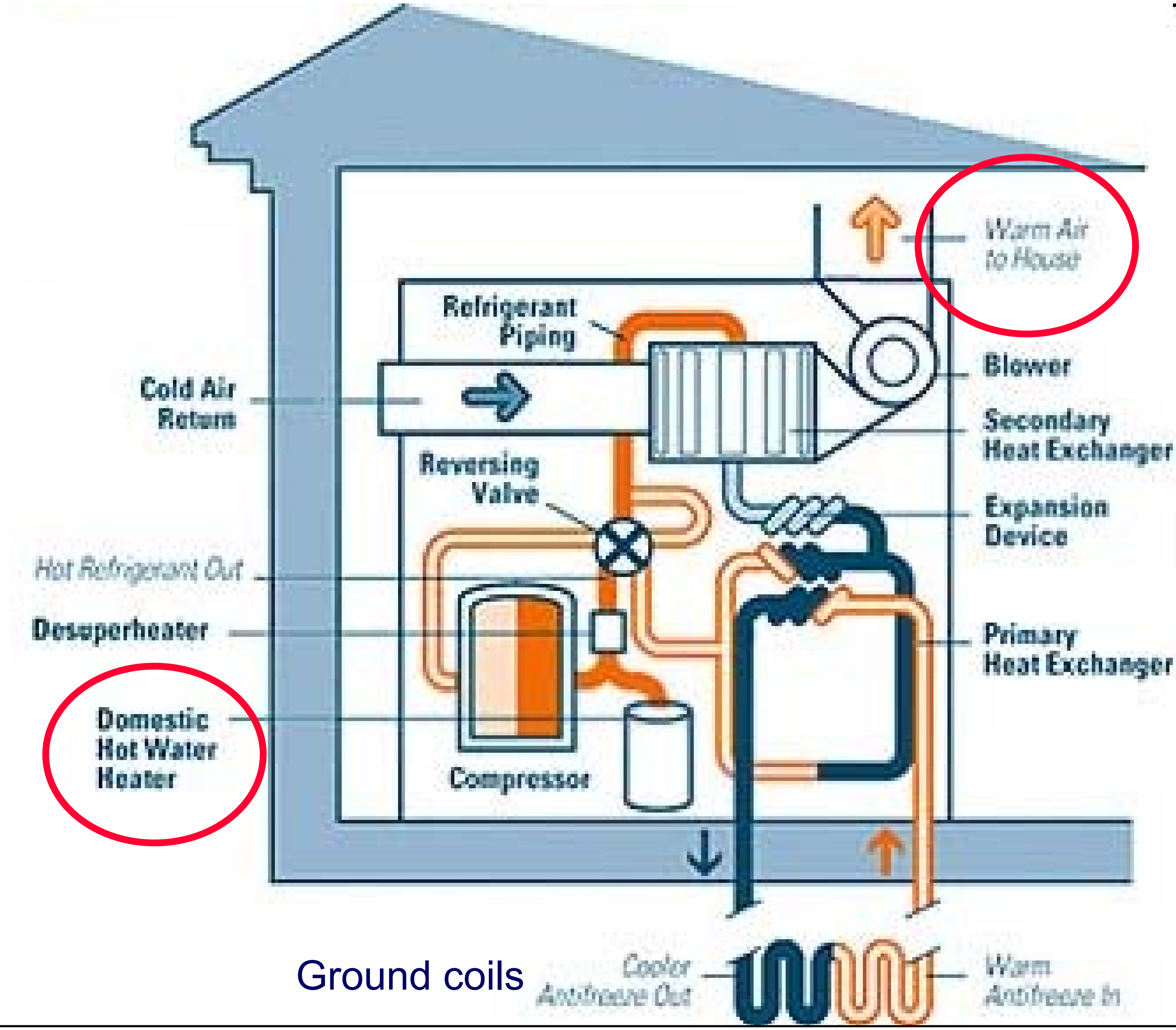
What does a GSHP do?

- Pumps heat from the ground to your home
  - Heats your home
  - Heats your domestic hot water
  - Cools the ground
- Pumps heat from your home to the ground
  - Cools your home
  - Heats the ground

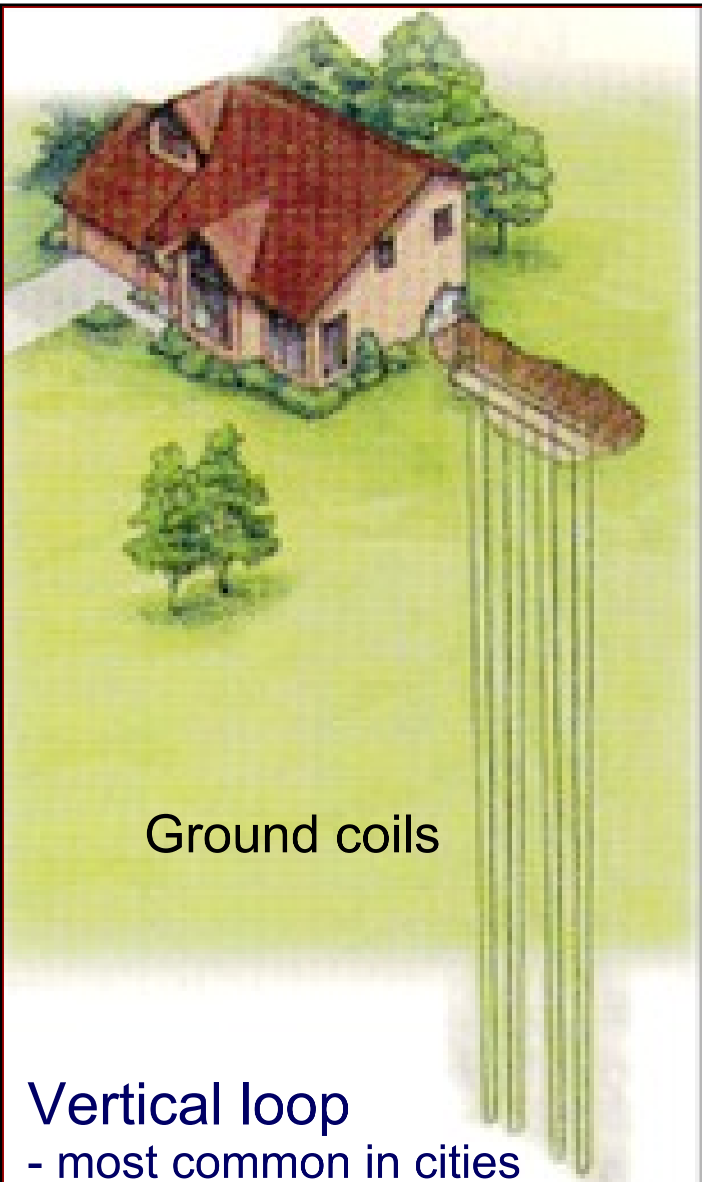
The Heat Pump



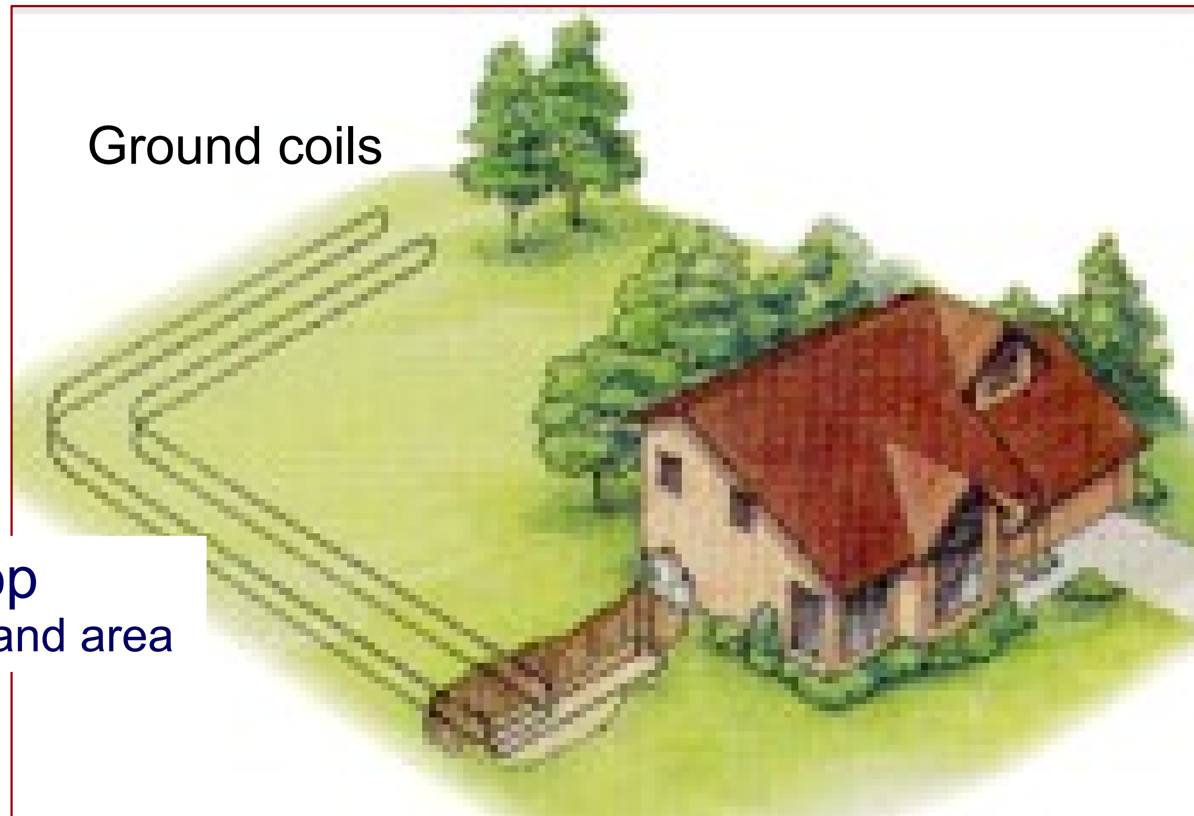
Ground coils

The Ground Coils

- remove solar-stored heat from the ground
- this is the top 150 m of the earth, <u>not</u> the core of the earth!!



Vertical loop
- most common in cities



Horizontal loop
- requires more land area

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What is Efficiency?

- Energy efficiency is always defined as:

$$\textbf{Efficiency} = \frac{\textbf{energy out}}{\textbf{energy in}}$$

  – but we don't like to see efficiencies of more than 100%!

What is COP?

- Coefficient Of Performance
- Shows the efficiency of a ground-source heat pump
- Identical to the efficiency equation:

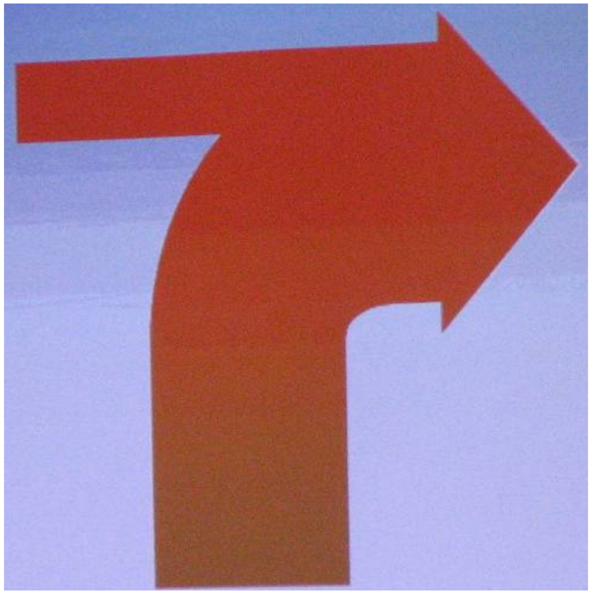
$$\text{COP} = \frac{\textbf{heat energy out}}{\textbf{electrical energy in}}$$

  - This number had better always be more than 1.
  - Typical advertised COPs are 3 to 4.5… actual COPs are… 2.5?
  - Which means that about
    - 1/3 of your heat comes from electricity (12 to 18 ¢/kWh)
    - 2/3 from the ground (for free, but with a large upfront equipment cost)

How COP is used with geothermal HPs

To heat your home,
a geothermal system delivers 100% of the electrical energy it uses plus it pumps 2 units of free energy from the earth.
You buy 1 unit of electrical energy
and get 3 units of heating energy out.

Use 1 unit of purchased electrical energy



Deliver 3 units of heat energy to the building

Pump 2 units of free energy from the earth

Next… Some Technologies

1. Solar thermal for heating domestic water (DWH)
2. Geothermal heat pumps for space and DWH
3. Solar photovoltaic (PV) electricity

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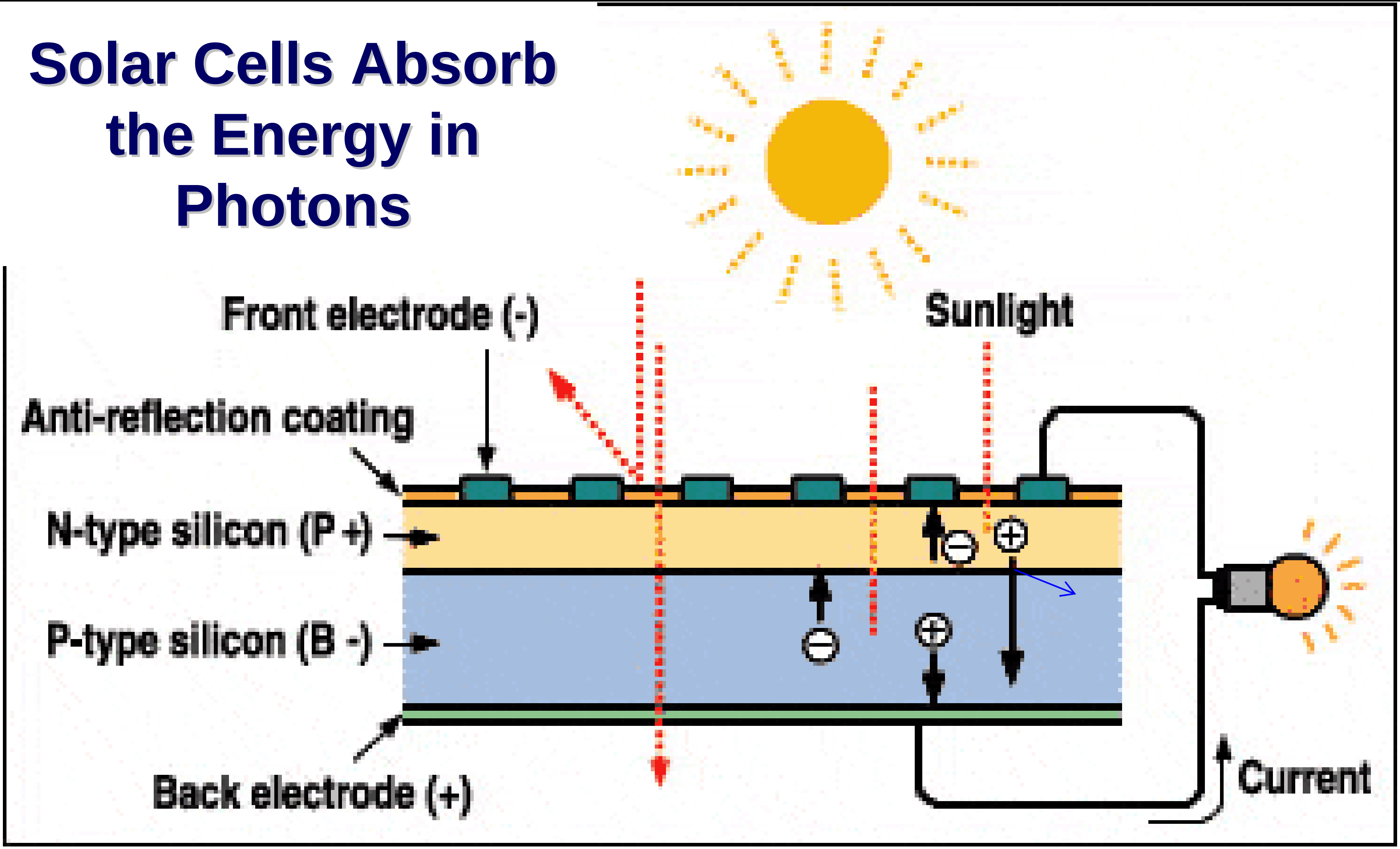
Solar Cells Absorb the Energy in Photons

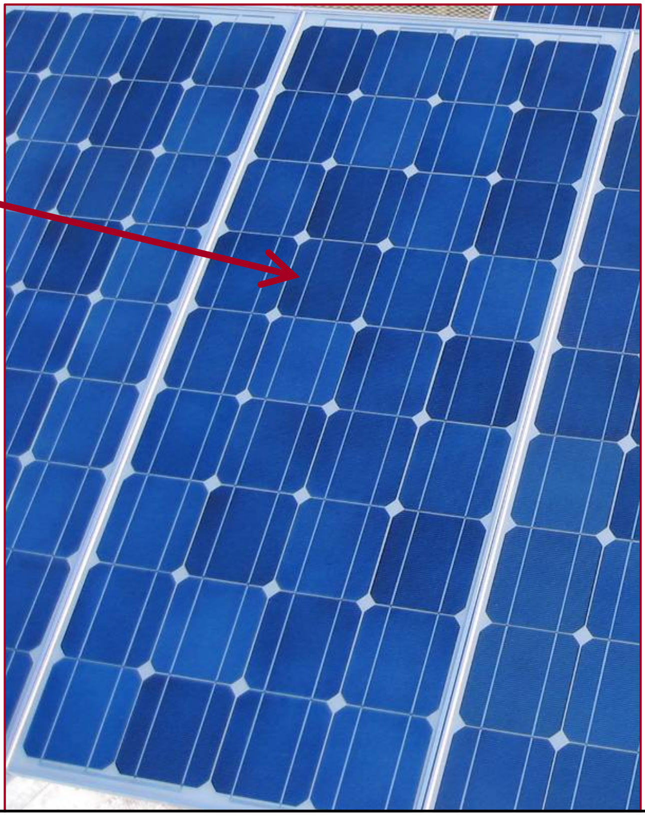


- The technology is called "photovoltaics", but we only call it "PV".
- The energy in the photons knocks electrons out of their orbital shell – 1 electron for 1 photon.
- The electric field generated by this turns the electrons into an electric current.
- Wires carry the current away.

What words do we use?

- Solar heating
  - thermal **collectors**

- Solar electricity
  - photovoltaic **modules**



- Solar panel – when several PV modules are attached on a rail.

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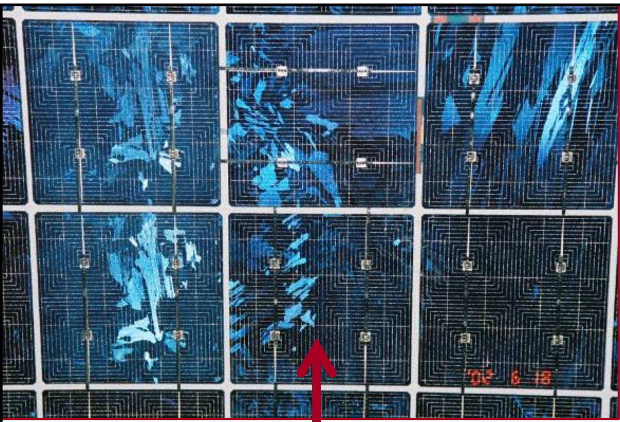
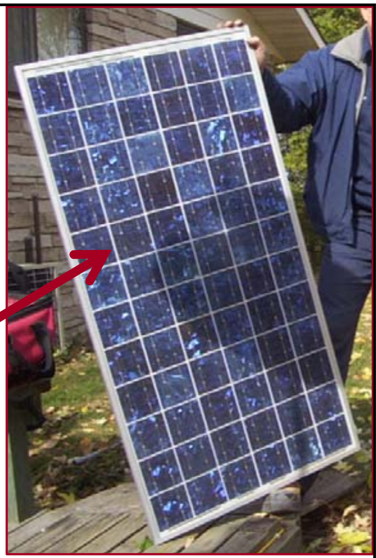
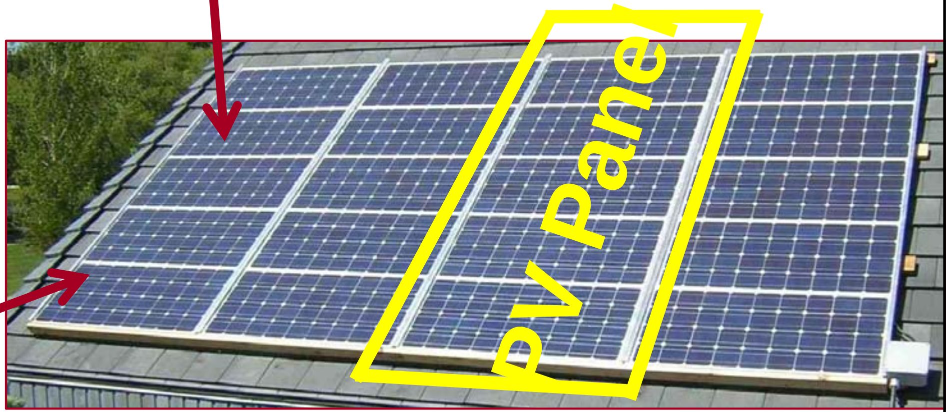


Solar Electricity



Solar PV Cell

Solar PV Module



PV can generate any amount of electricity.

Large PV systems = more PV modules.

Solar PV Array

5,000 modules
1000 kW

30,000 modules, 6000 kW

55,000 modules (200 W ea.)
11,000 kW PV array

Solar Electricity

Solar PV module

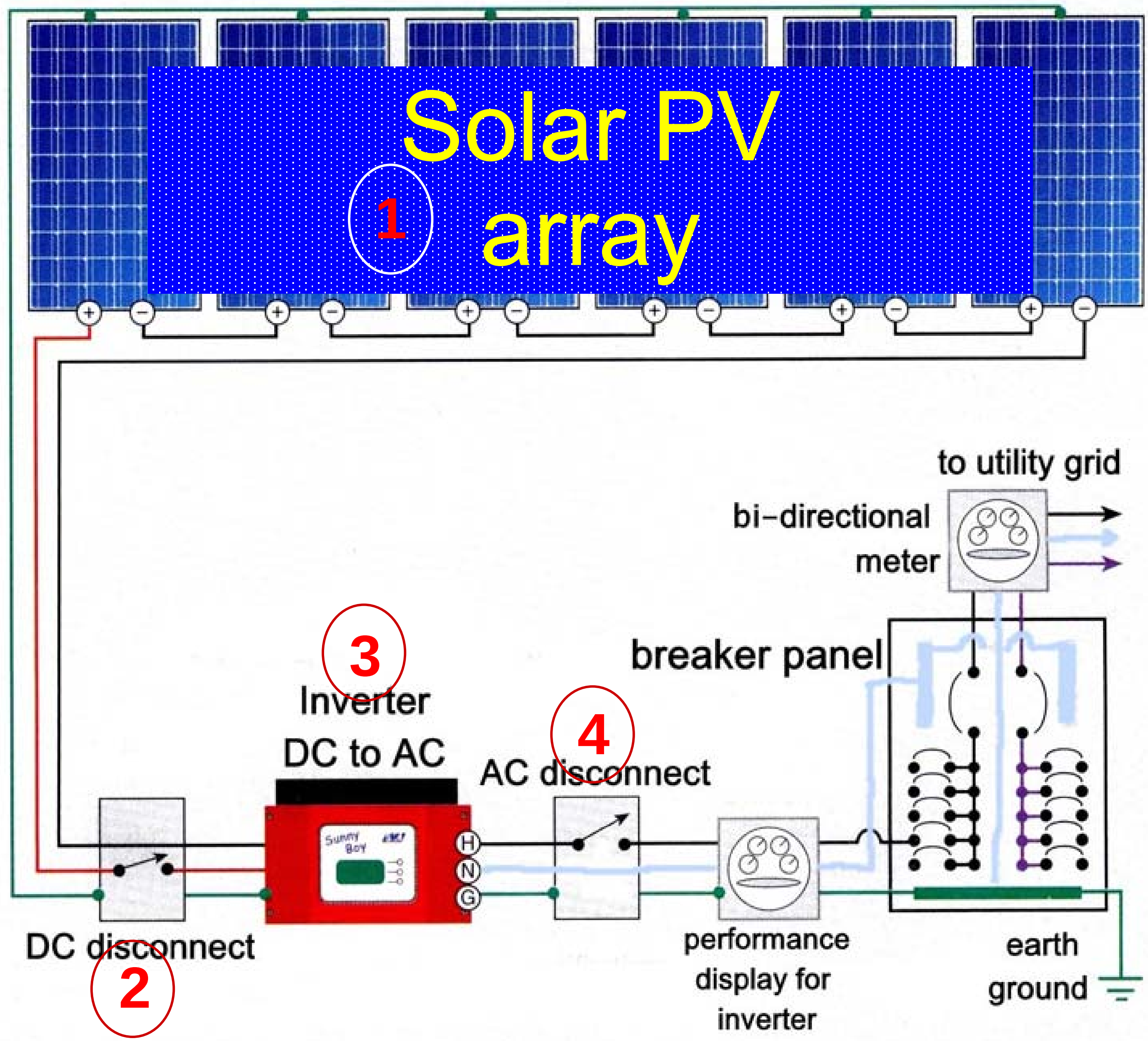
Solar battery

…maybe…

Solar inverter

Grid-dependent System

- 4 major components:
  - PV array
  - DC disconnect
  - Solar inverter
  - AC disconnect
- No energy storage
- Most common grid-connected configuration
- 1500 in Canada???
- 250 in Alberta?
- 5 million around the world…?

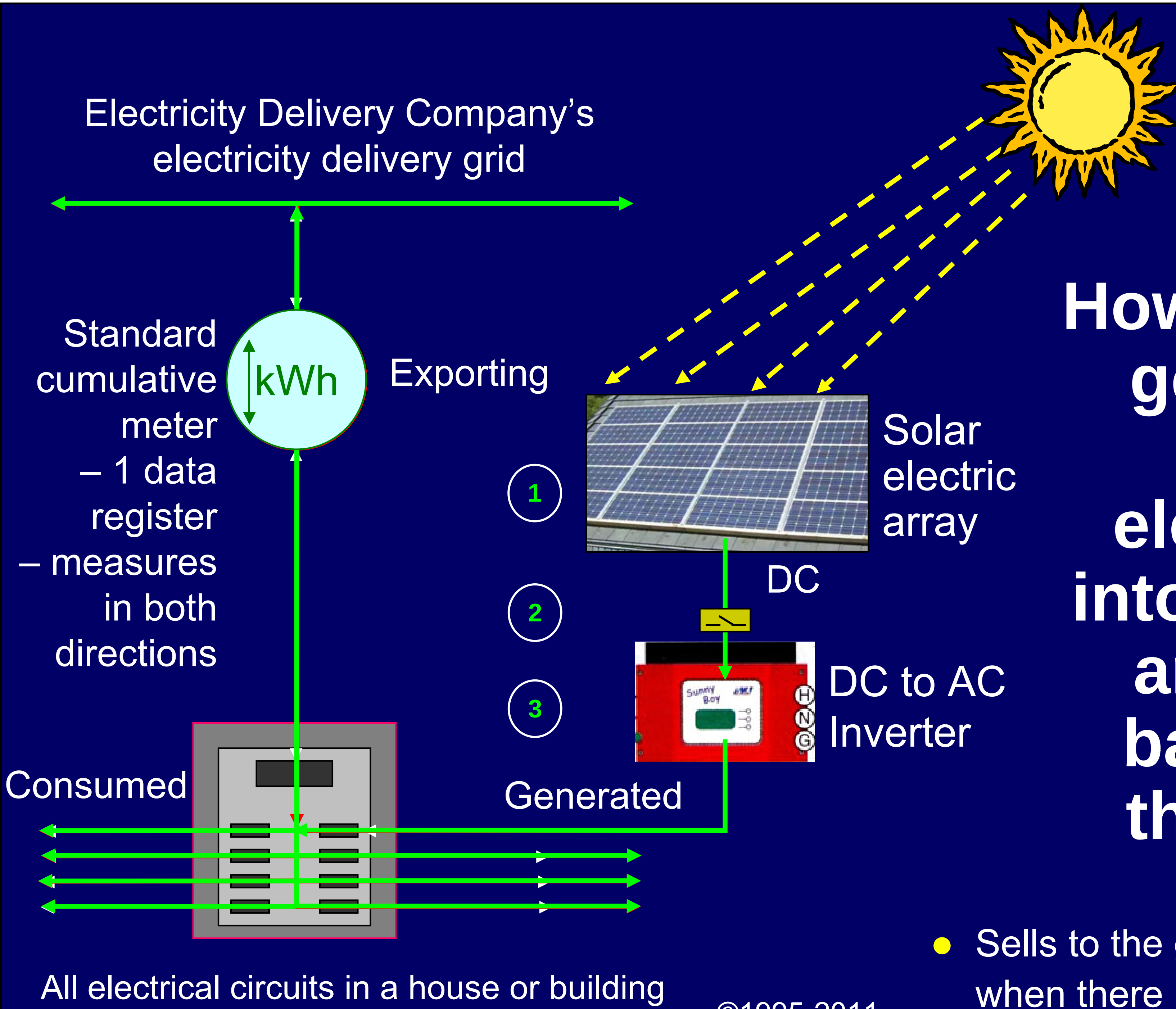


Connecting to the Grid – What really is it?

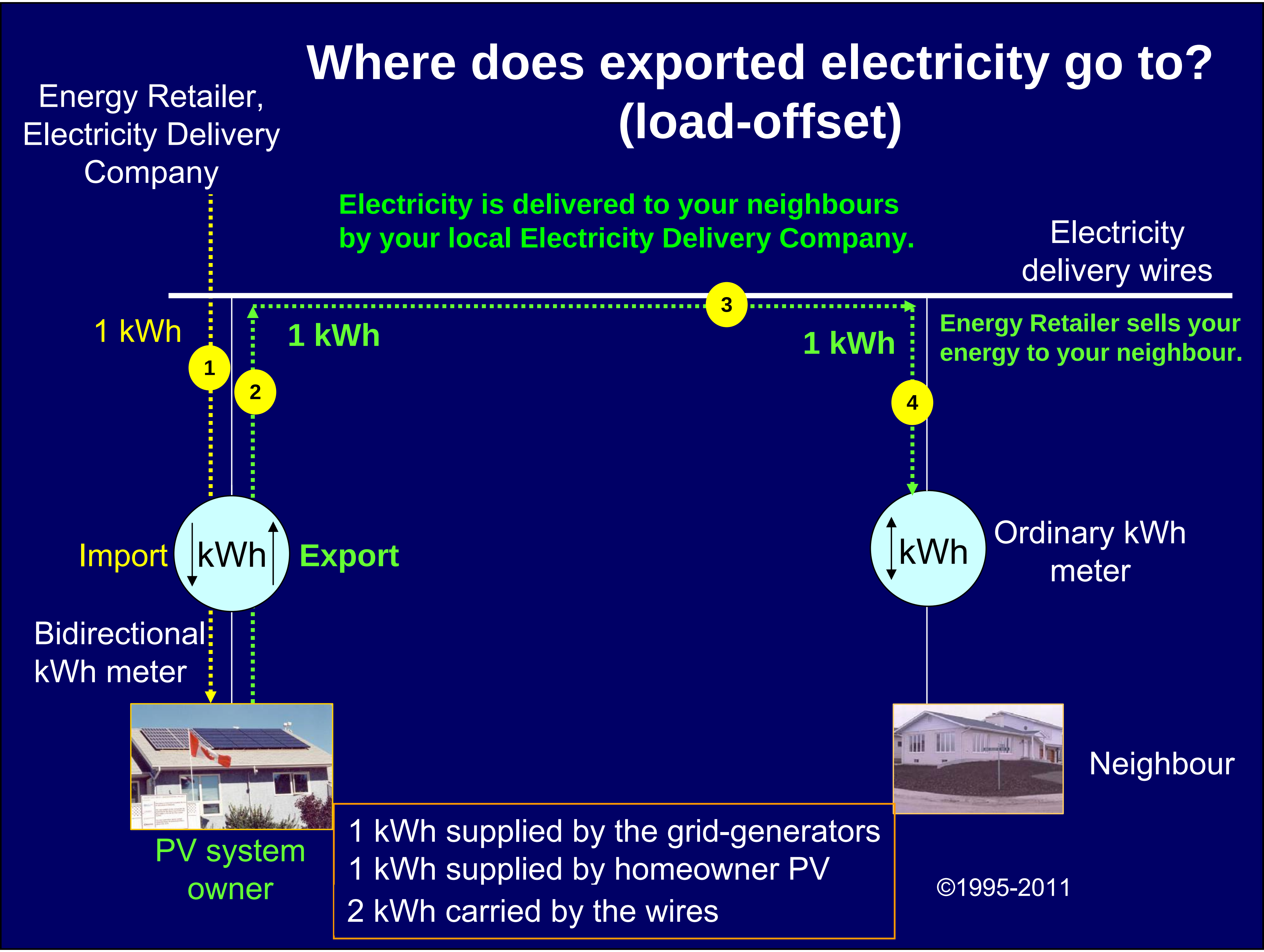
- Four **distinct** discussion **points** need to be kept completely separate:

Function	Term
– Connecting the wires from the solar PV system to the building's breaker panel (which is not the grid)	connecting up to the grid
– Exporting energy (not power) to the grid	back feeding to the grid
– Metering of the exported energy	metering
– Getting paid for the exported energy	billing

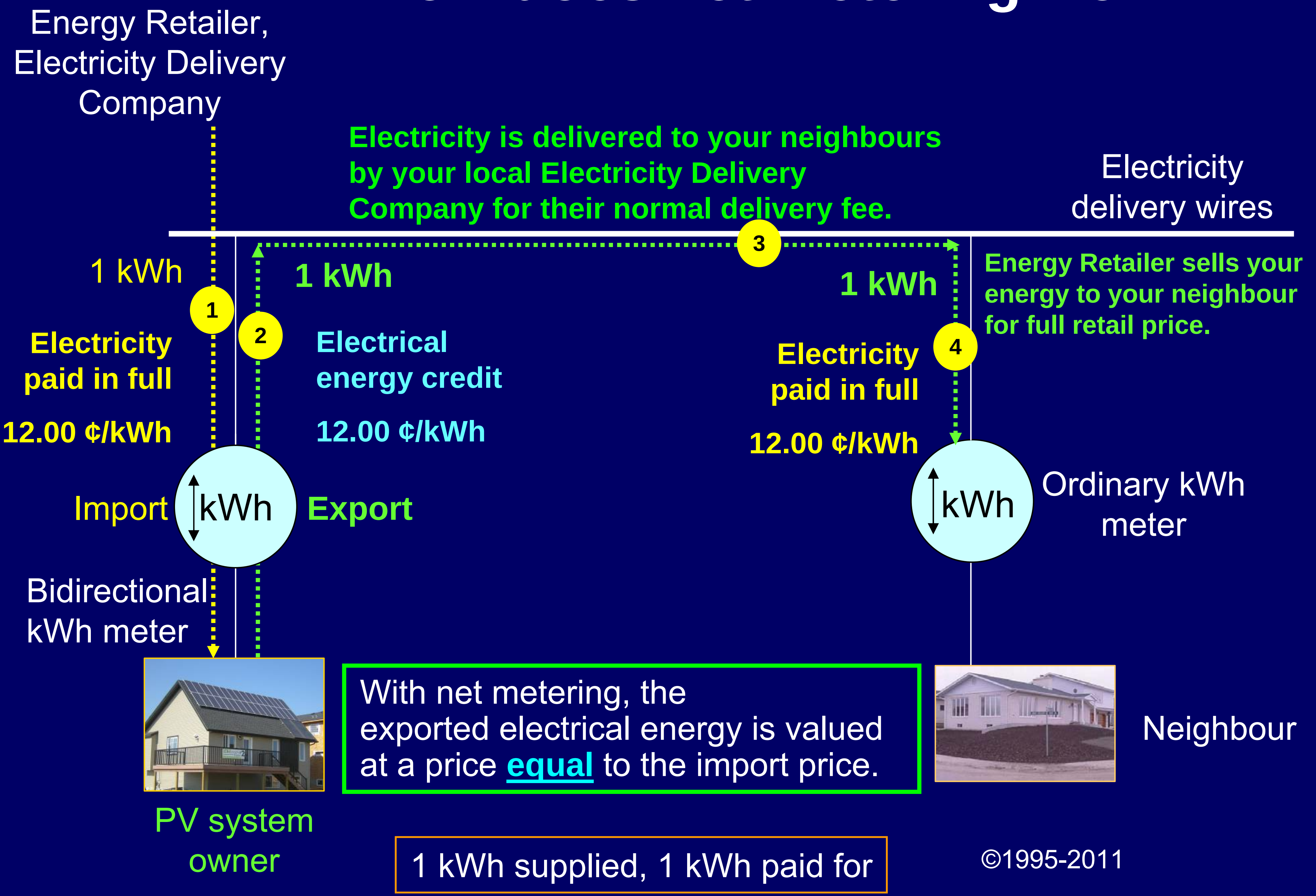
How can you generate solar electricity into a house and also back into the grid?



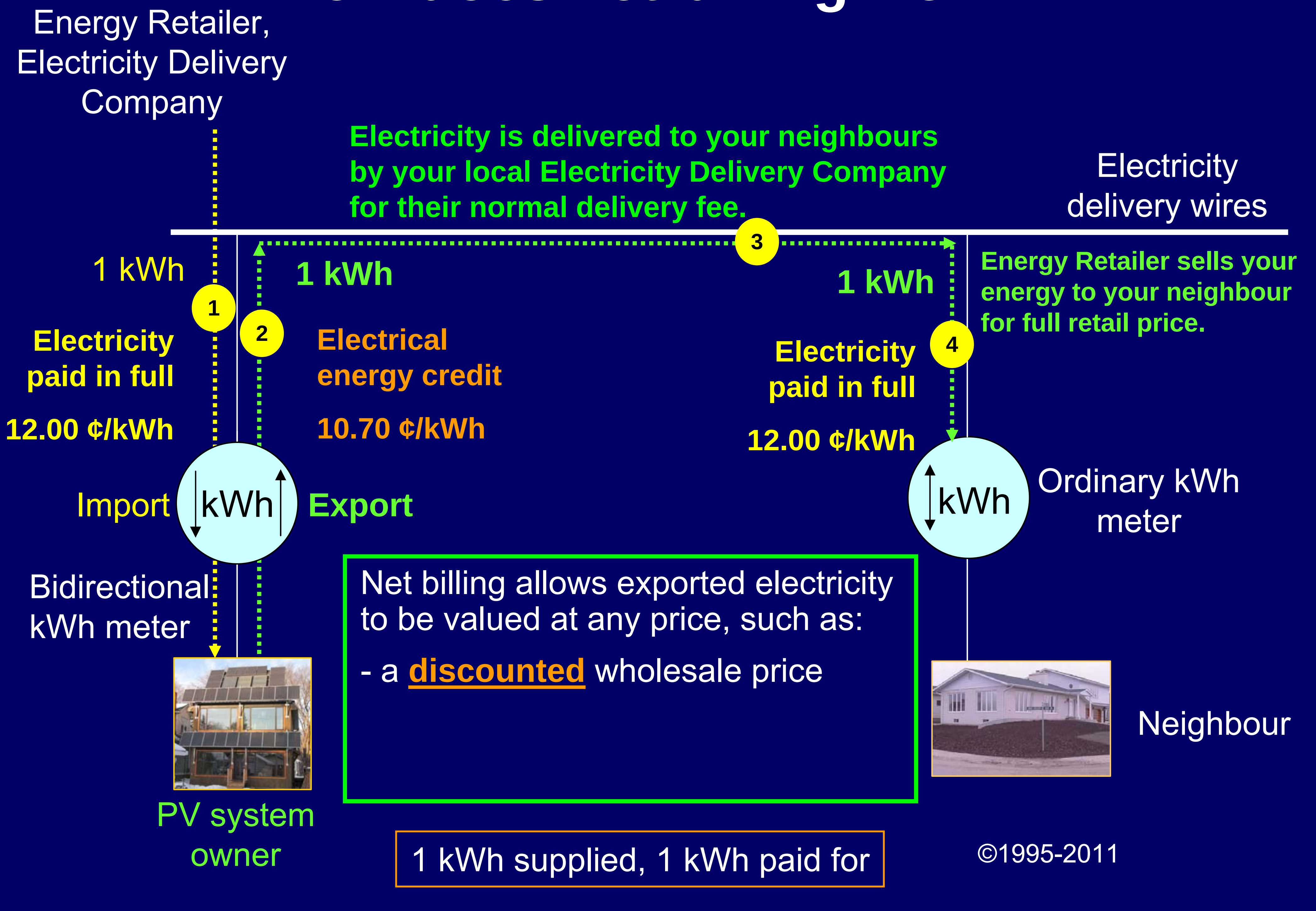
- Sells to the grid when there is a site surplus.
- Buys from the grid when there is a site shortage.


Where does exported electricity go to?
(load-offset)
Energy Retailer, Electricity Delivery Company
Electricity is delivered to your neighbours by your local Electricity Delivery Company.
Electricity delivery wires
1 kWh
1
2
1 kWh
3
1 kWh
Energy Retailer sells your energy to your neighbour.
4
Import
kWh
Export
Bidirectional kWh meter
kWh
Ordinary kWh meter
PV system owner
Neighbour
1 kWh supplied by the grid-generators
1 kWh supplied by homeowner PV
2 kWh carried by the wires
©1995-2011

How does net metering work?

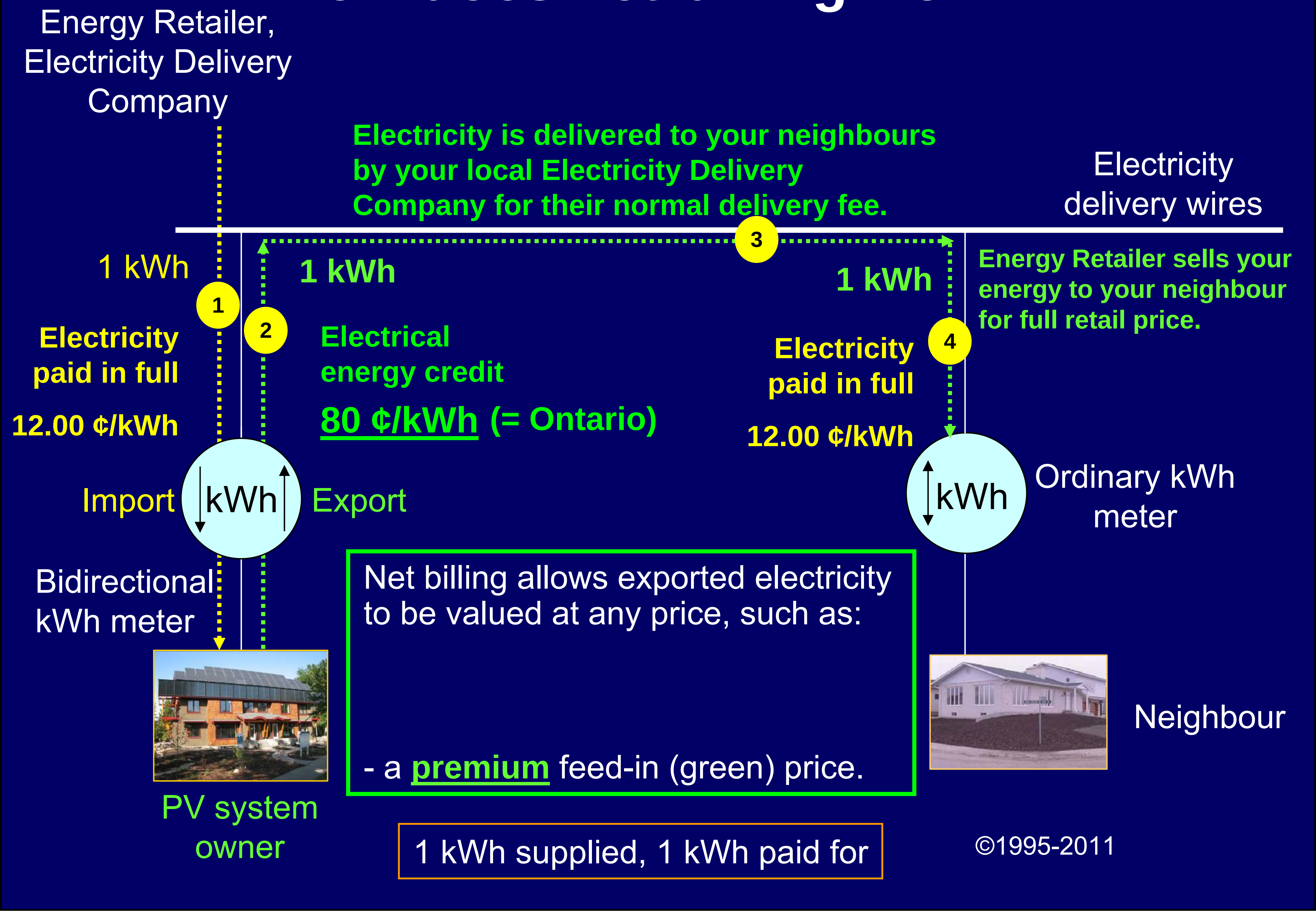


How does net billing work?

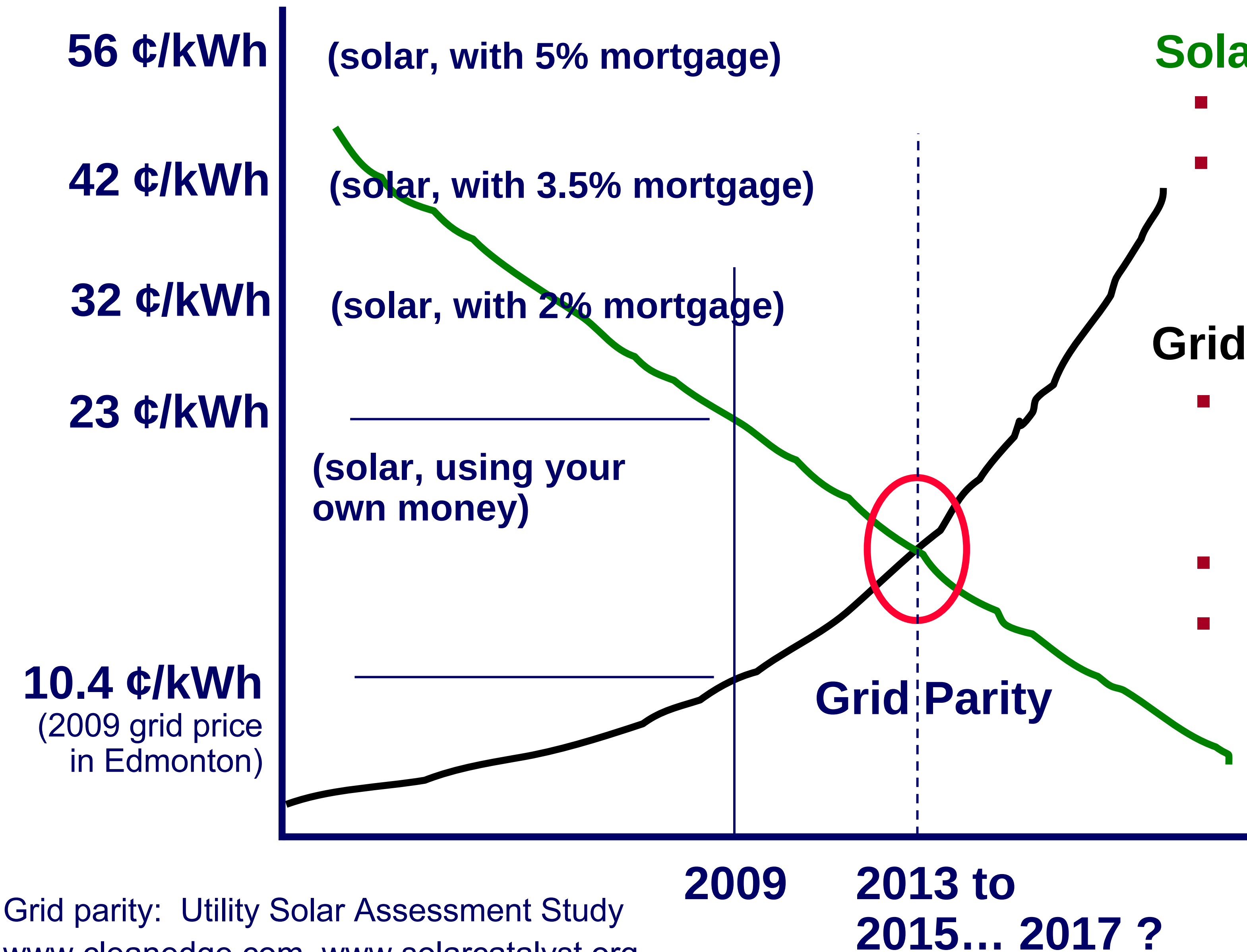


How does net billing work?

How does net billing work?



Declining Solar PV Prices, Increasing Grid Prices



Solar Electricity Price

- unsubsidized
- no environmental side-effects

Grid-Electricity Price

- huge environmental effects
- highly subsidized
- fossil fuelled electricity does not pay for the damage it causes to the environment and to our health care budgets

Grid parity: Utility Solar Assessment Study
www.cleanedge.com, www.solarcatalyst.org

Next…

1. Energy Performance Modelling
2. Design Choices
3. Expected House Performance
4. Costs and economics
5. What we’ve learned…

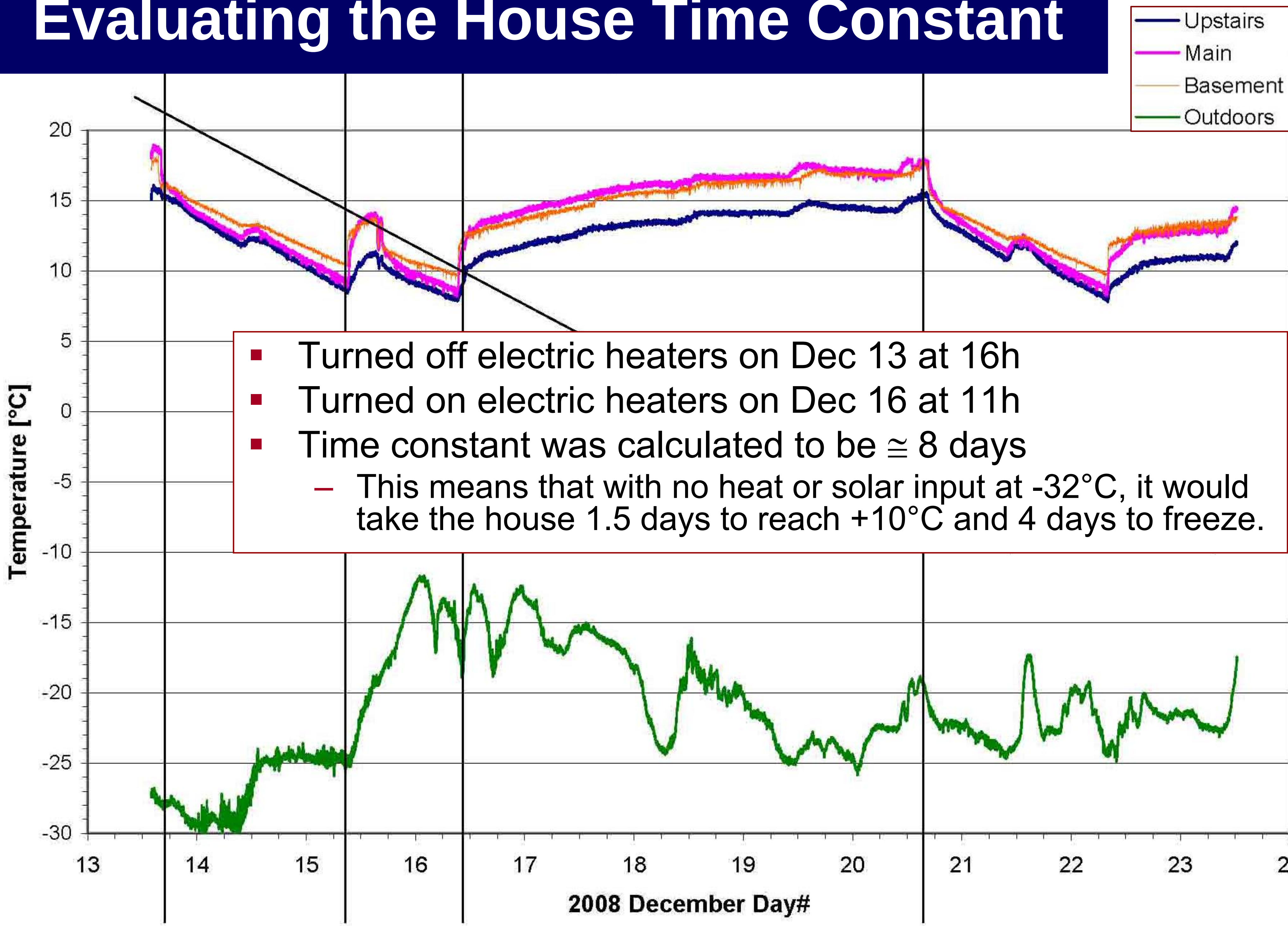
You must skate to where the puck is going
not to where it is now.

Wayne Gretzky

House Time Constants

- The "**time constant**" of a house is the amount of time that the house's air temperature take to respond to 63% of a change in the outdoor air temperature. It is an important measure of the energy security of a house.
- Its value depends on the amount of **heat stored** by the house structure (its thermal mass) and the **heat loss rate** of the house envelope (walls, ceiling, floor, windows, doors, and air leakage).
- Overall time constants in houses comprise a number of time constants for the air and the structure in the house. The air temperature responds more quickly than the house structure.
- In the winter of 2008/09, the house was heated with one 1500 W portable electric heater (equal to 1.5 hair dryers) (and two heaters when it got cold).
- An informal time constant test was conducted in 2008 December using 4 thermocouples – mounted near the ceilings in the upper floor, main floor, basement and outdoors under a bush.

Evaluating the House Time Constant



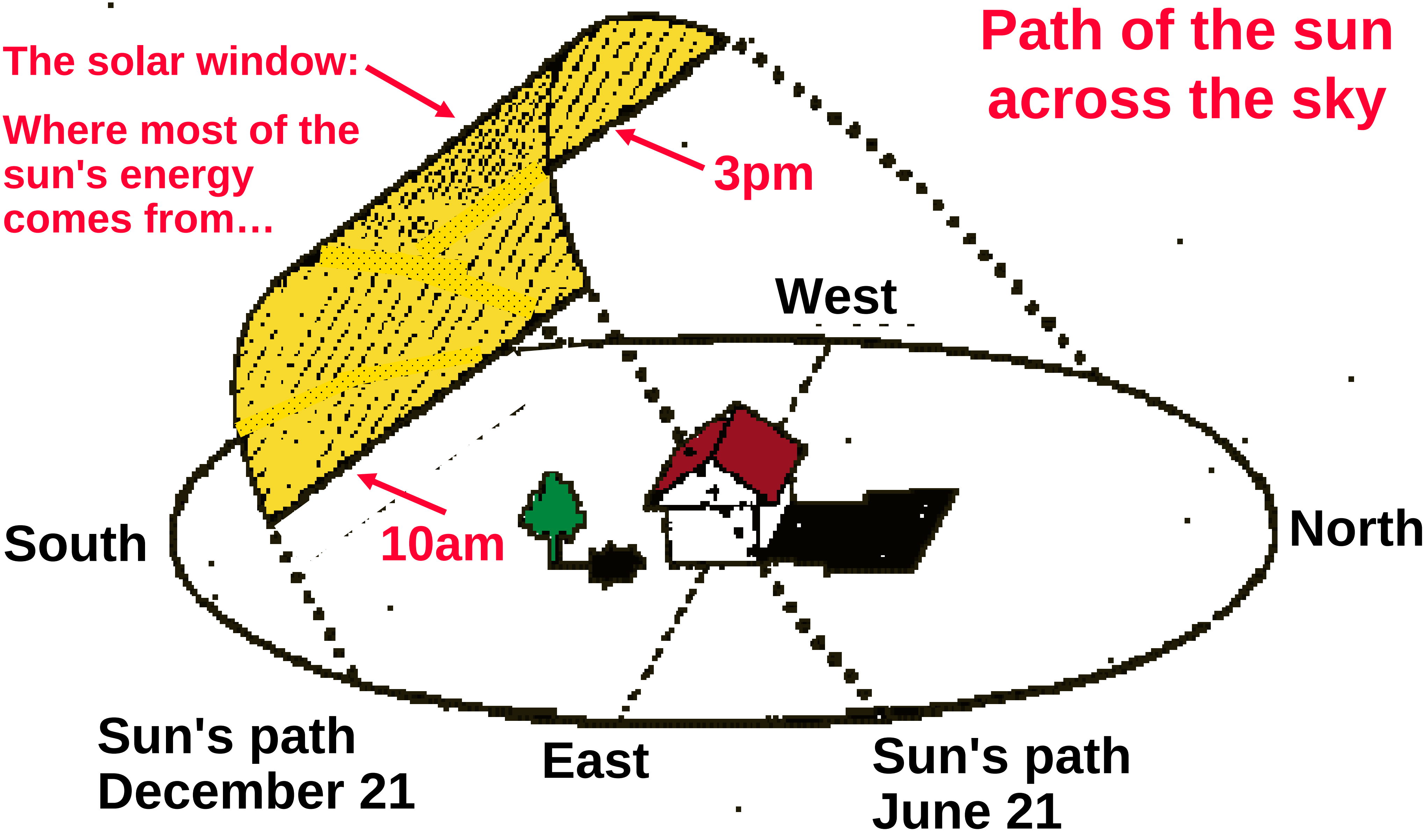
- Turned off electric heaters on Dec 13 at 16h
- Turned on electric heaters on Dec 16 at 11h
- Time constant was calculated to be ≅ 8 days
  - This means that with no heat or solar input at -32°C, it would take the house 1.5 days to reach +10°C and 4 days to freeze.

2008 December 30, -20°C

Once in a while solar doesn't work

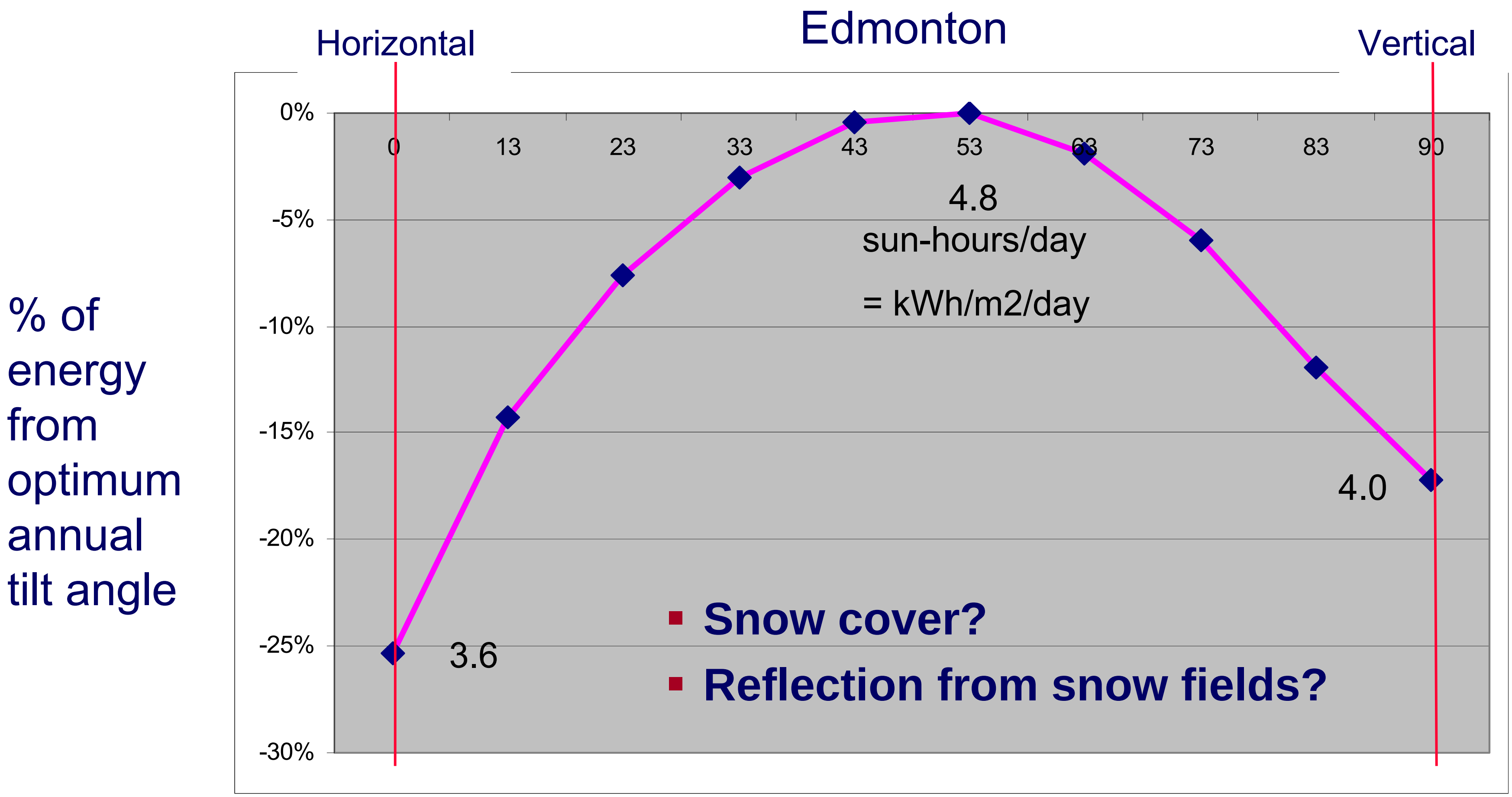
2008 November 20, 19:26

- Of course, when the big light in the sky turns off, the solar production systems don't work – passive solar, active solar and solar PV – so instead we draw electricity from the electric grid.



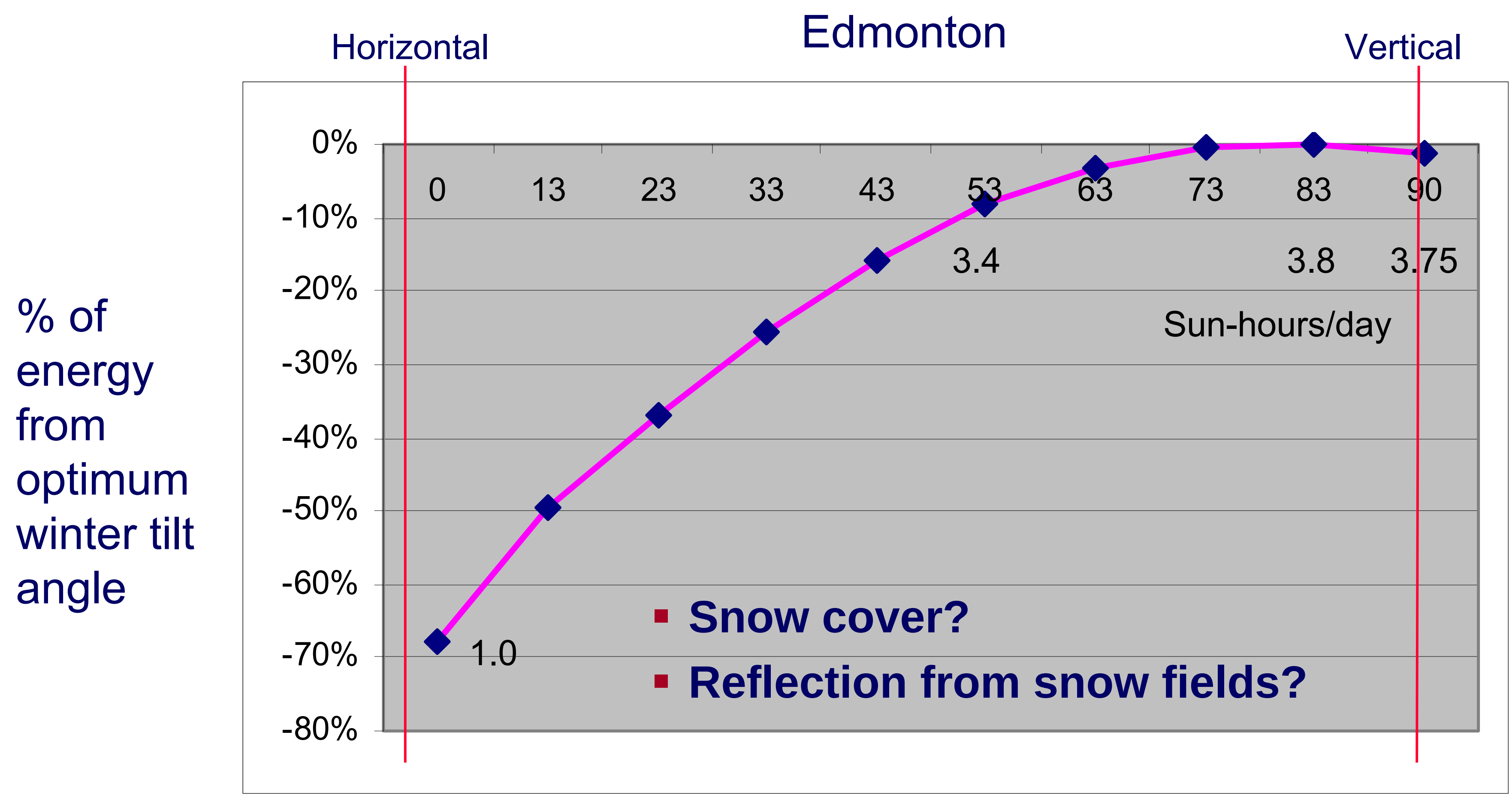
Path of the sun across the sky

Optimum Annual Solar Tilt Angle



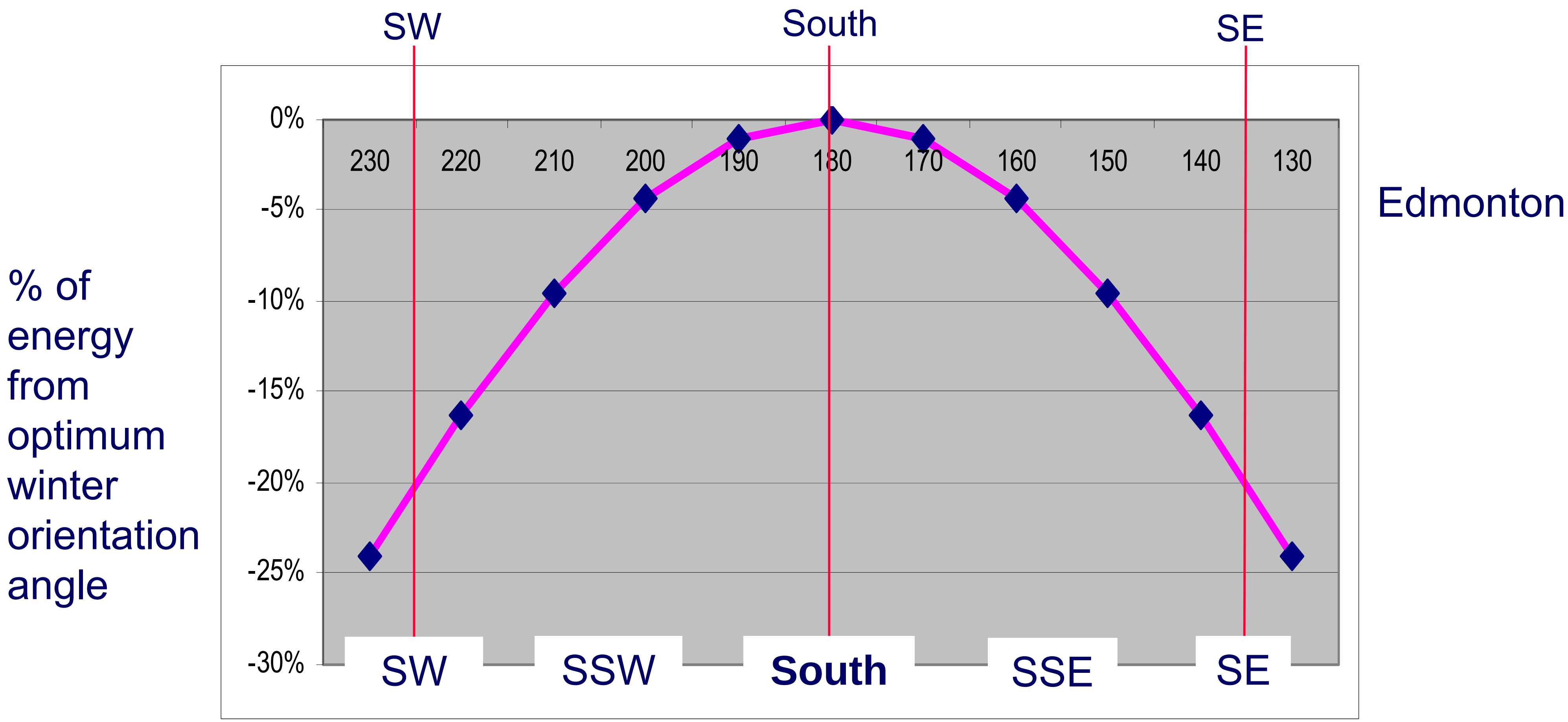
- The maximum annual solar energy production occurs around a 53° tilt for grid-connected solar PV and 64° tilt for solar thermal.
- Edmonton tilt angle's can be from 18° to 80° and still be within 10% of the maximum.

Optimum Winter Solar Tilt Angle



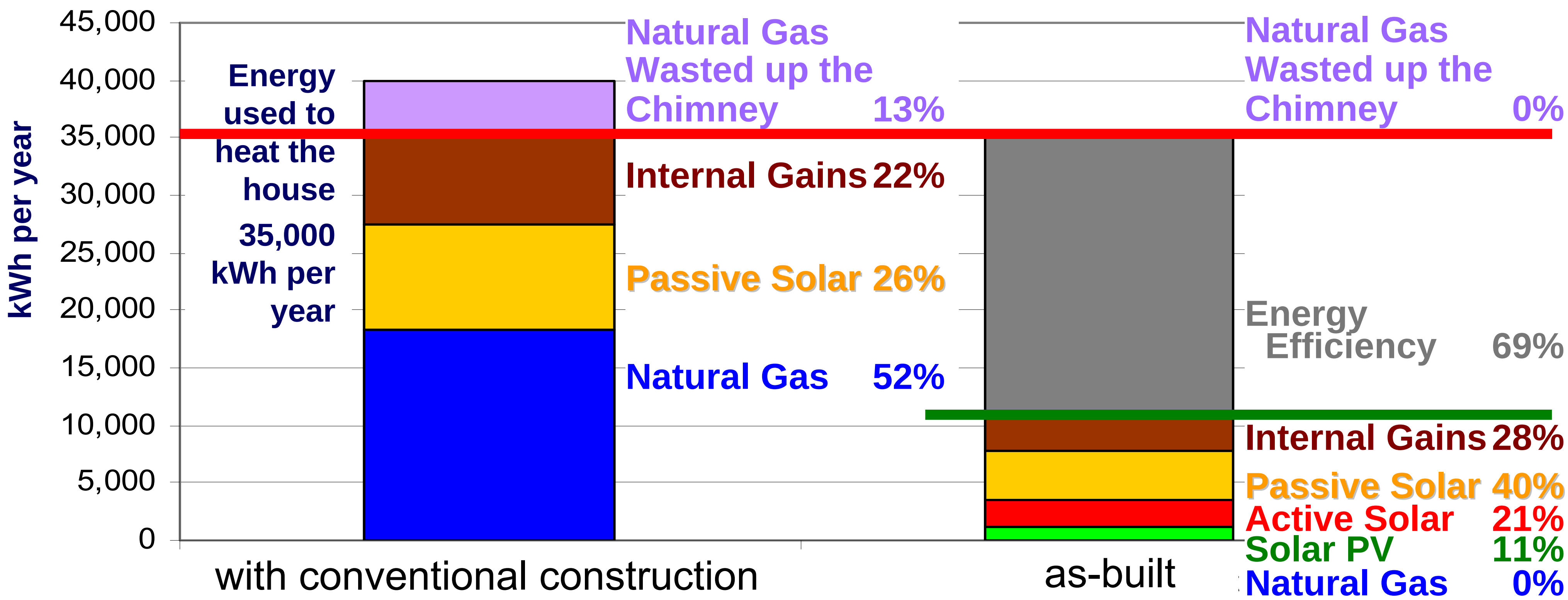
- The maximum winter solar energy production occurs at around a 83° tilt.
- Edmonton's tilt angle can be from 50° to 90° and still be within 10% of the maximum.

Optimum Winter Solar Orientation Angle



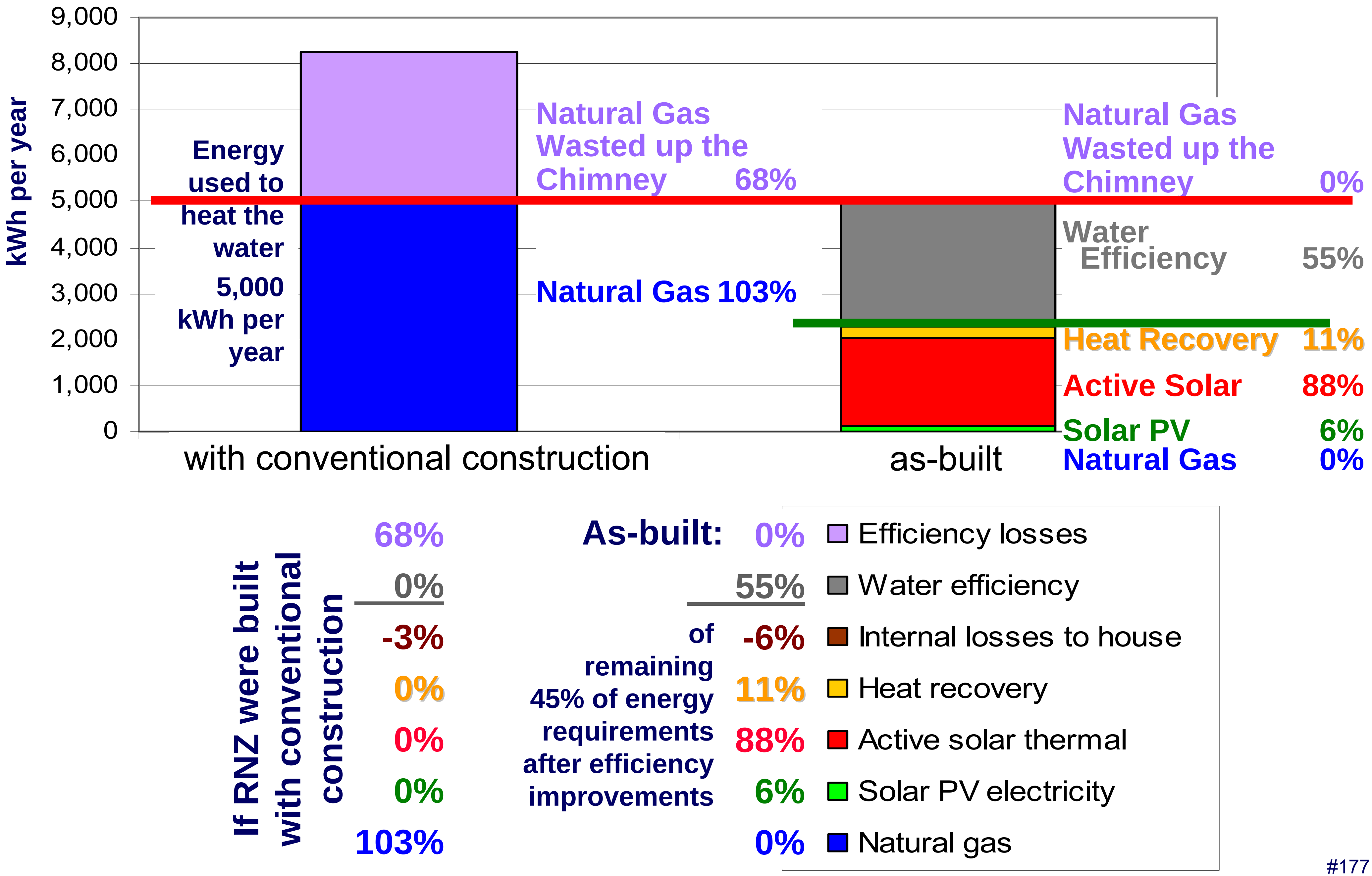
If the goal is to maximise the winter energy production, which occurs at a due-south orientation angle, you can locate the orientation 30° either side of south and still be within 10% of the maximum.

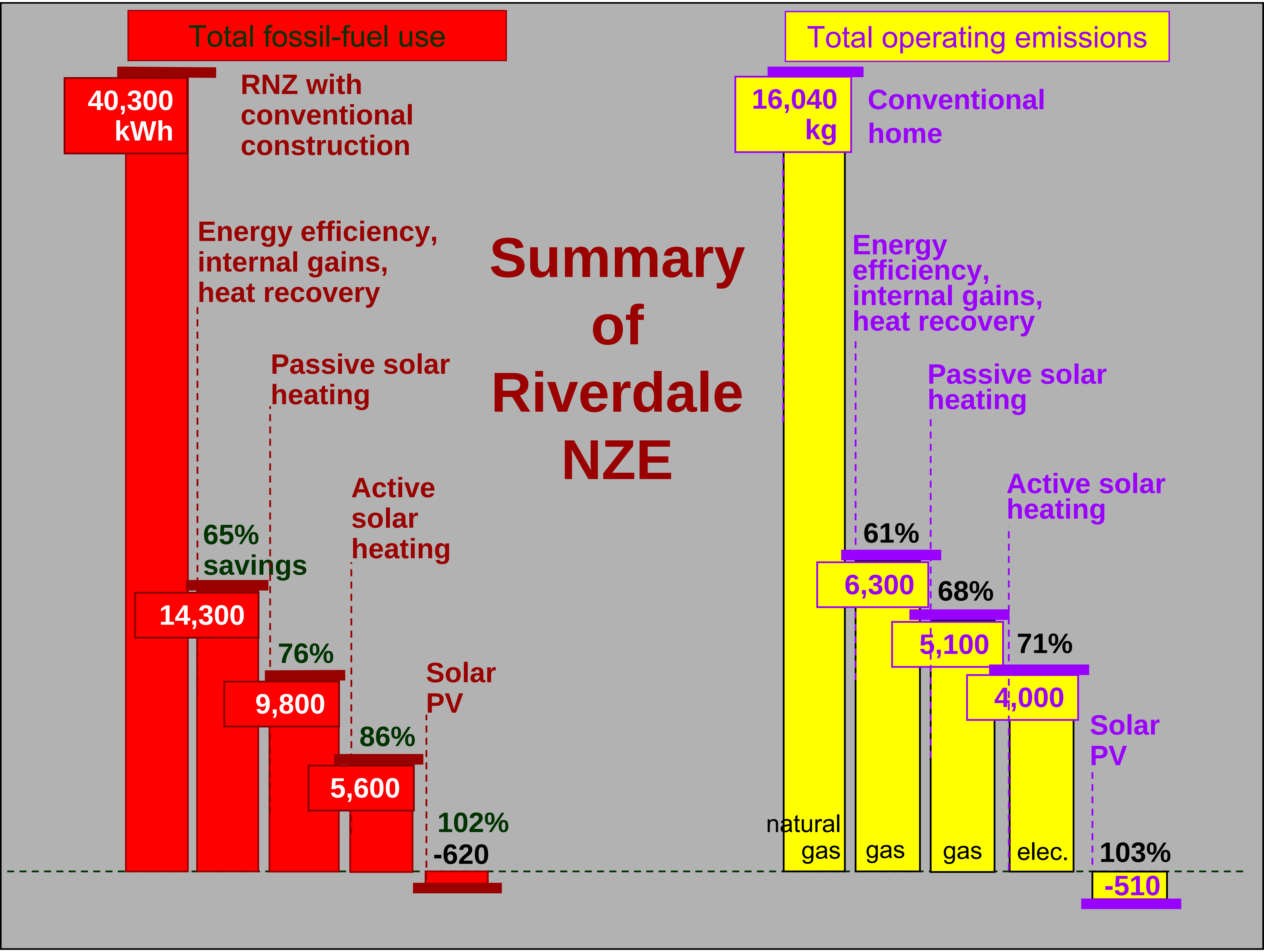
Source of Energy – Space Heating (at RNZ)



If RNZ were built with conventional construction	As-built:		
13%		0%	Efficiency losses
0%		69%	Building envelope energy efficiency
22%	portion of remaining 31% of energy requirements after efficiency improvements	28%	Internal gains from DWH, people, electricity
26%		40%	Passive solar through south windows
0%		21%	Active solar thermal
0%		11%	Solar PV electricity
52%		0%	Natural gas

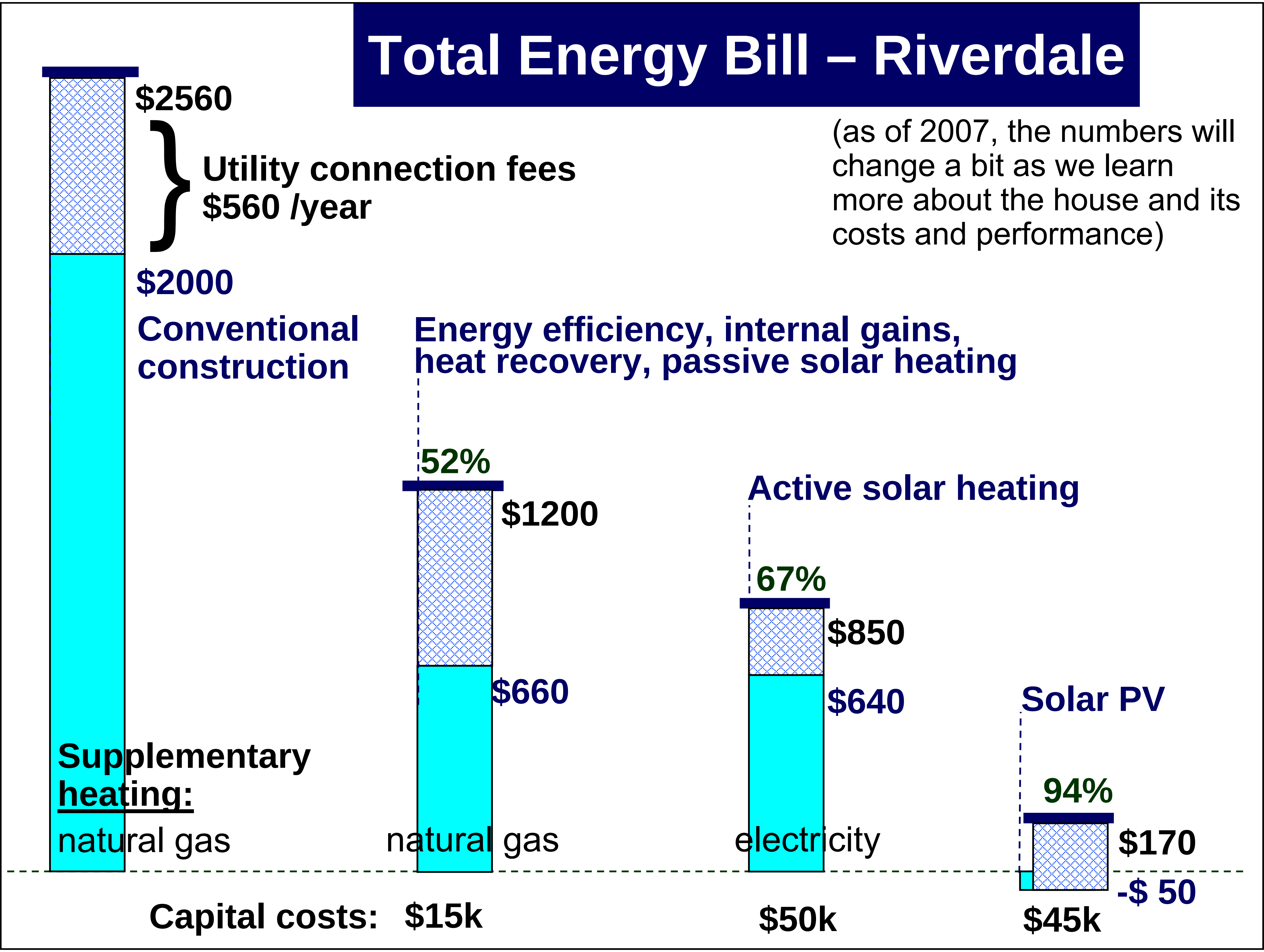
Source of Energy – Water Heating (at RNZ)




Total fossil-fuel use
Total operating emissions
Summary of Riverdale NZE
40,300 kWh
RNZ with conventional construction
Energy efficiency, internal gains, heat recovery
65% savings
14,300
Passive solar heating
76%
9,800
Active solar heating
86%
5,600
Solar PV
102%
-620
16,040 kg
Conventional home
Energy efficiency, internal gains, heat recovery
61%
6,300
Passive solar heating
68%
5,100
Active solar heating
71%
4,000
Solar PV
103%
-510
natural gas
gas
gas
elec.

Next…

1. Energy Performance Modelling
2. Design Choices
3. Expected House Performance
4. Costs and economics
5. What we've learned…


Total Energy Bill – Riverdale
(as of 2007, the numbers will change a bit as we learn more about the house and its costs and performance)
$2560
Utility connection fees $560 /year
$2000
Conventional construction
Energy efficiency, internal gains, heat recovery, passive solar heating
52%
$1200
$660
Active solar heating
67%
$850
$640
Solar PV
94%
$170
-$ 50
Supplementary heating:
natural gas
natural gas
electricity
Capital costs:
$15k
$50k
$45k

Results: Annual RNZ Home Energy Bills

▪ Natural gas bill:	$0	no gas line needed, also saves $520 per year in connection fees (in 2010)
▪ Electricity costs:	surplus ~$40	ranging from $150 surplus to $100 deficit per year depending on homeowner electricity consumption choices
▪ plus standard electricity grid connection fees of	$245	(in 2010)

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Riverdale NZE House Component Economics

	Upgrade Cost	Savings $/year	Energy price (simple analysis)		Return on investment
Electricity efficiency	$1,800	$550	1.6 ¢/kWh	$4.50 /GJ	30% /year
Water efficiency	$1,750	$260	1.1	$3.10	15% /year
Building envelope efficiency	$12,000	$1000	0.9	$2.60	9% /year
Passive solar space heating	$2,400	$185	▪ difficult to determine as a separate item…		…from the building envelope
Active solar space & water heating	$36,700	$582	26	$71	1.6% /year
Solar PV	$54,000	~$700	27	$76	1.7% /year
Overall house	$109,000	~$3000	9	$25	* 2.7% to 12%

plus 18,000 kg GHG savings

* depending on government policies on fossil-fuel subsidies, environmental emissions and green loans

Financial Challenges

- **House cost**
  - some $70k to $110k extra to build because of NZE features

- **Energy bill savings**
  - around $3000 per year (increasing every year)

- **Return on investment** (simple analysis)
  - Perceived to be 2.7% to 4.3% per year (23 to 37 year payback)
  - Not including mortgage costs
  - But at 4% interest, this is $2800 to $4000 per year in loan payments

- **Government regulatory polices** regarding
  - Selling house electricity into the grid (participant costs, low value)
  - Lack of policies and value placed on the environmental sustainability
  - Subsides of fossil fuels (implicit and explicit)
  - Mortgage costs
    - Reduce the savings and benefits of energy efficiency and solar energy
    - Increase the operating costs for the house
  - Result in a **minus 4%** per year ROI (payback is never).

Policy Solutions

- **If government regulatory polices**
  - **Allowed** full cost recovery of all electricity fed into the grid (no fixed fees, provided equal import and export prices)
  - **Removed** fossil fuel subsides (such as natural gas rebates)
  - **Required** fossil fuels to pay for their environmental damage (air pollution and health care budgets)
  - **Provided** ultra-low interest green loans (< 1%)

- **Then…**
  - The energy operating cost of the house would be **zero**
  - The benefits of energy efficiency and solar energy would be **fully valued**
  - Would result in a **+5.2%** per year ROI (18 year payback).

- The changes to achieve this relate to how we want to **organise** ourselves, they are not technical.

Incremental Costs to NZE – Coming Down

Riverdale ~$110,000
(per unit)

- Envelope ~$15,000
- Solar thermal ~$50,000
- Solar PV ~$45,000

(updated costs)

Mill Creek ~$67,000

- Envelope ~$16,000
- Solar thermal ~$9,000
- Solar PV ~$50,000
- Deduct avoided costs ~$8000

Belgravia ~$58,000

- Envelope ~$16,000
- Solar thermal $0
- Solar PV ~$50,000
- Deduct avoided costs ~$8000

(minus Alberta's $10k incentive for an EnerGuide 86 house)

Costs will continue to decline as solar PV prices drop
and as we discover better ways to utilise solar heating

Next…

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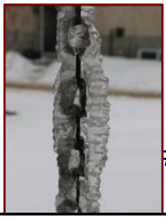
Money talks, and until it starts telling the truth about the consequences of fossil fuels, we're kidding ourselves that we can make any significant headway against climate change.



Some of what we've learned…

- **Keep it simple**
  active solar thermal space heating
  can get very complex very quickly

- Look for systems
  that can provide **more than one service**

- Challenge:
  need better **builder-friendly** modelling software

Design Challenges

- Amount of roof and wall **space available**…

  is there enough unobstructed area available for all the
  - **solar-thermal liquid collectors**?
  - **solar-thermal air collectors**?
  - **solar PV modules**?

  and
  - **view windows**? (**which also provide passive solar heating**)

- **Budget**
  - always a restriction
  - how can we make it **simpler** and **cheaper**?

Other Technologies Not Used …/1

- There are several strategies and technologies to get to the net zero energy goal…

- **Radiant Floor Heating**
  - did not consider
  - more expensive than low-speed forced air heating
  - do not see the advantage in a net zero energy house – don't have to distribute much heat around the house

- **Window Shutters** (inside or outside)
  - did strongly consider but the technology is not as well developed as we would like
  - concerns with:
    - condensation
    - air sealing
    - cost
    - rattling in the wind
    - effective R-value
    - durability
    - They are only effective when they are used… would they be used consistently?…

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Other Technologies …/2

- **Active solar air-thermal for space heating**
  - did not consider
  - didn't know much about it

- **Solar PV-thermal air for space heating**
  (recovery of heat by running air behind the back of a PV array)
  - did not consider
  - were not aware of modelling software or case studies to give us confidence to try this

Other Technologies …/3

- **Heat pump**
  - **Ground-source**: **(also called geothermal)**
    - – did consider it
    - – found it to be too expensive for the small additional amount of heating that we still needed
    - – could be good on a larger house or in the Arctic
    - – could be good if we did not have much passive solar heating or solar thermal space heating
    - – complicates and increases cost of the heating system compared to electric baseboards
  - **Air-source**: **(like an air-conditioning system)**
    - – did not consider
    - – we perceived that it would not work in winter in Edmonton
    - – It could be worth re-evaluating.
  - **Water-source**:
    - – did not consider for an urban house
  - **Solar-source**:
    - – could be used. We are not certain of its performance.

Other Technologies …/4

- **Evacuated Tube Solar Collectors** (ETC)
  - don't need the higher temperatures that it can provide
  - more expensive than flat-plate collectors at the time
  - concern about performance claims
  - concern about durability

- **Heating zones**
  - not needed in an ultra-efficient house
  - too complex
  - uses too much electrical energy to control it
  - the house responds too slowly to make this effective

- **Night set-back thermostat**
  - likely not enough energy could be saved in a net zero house to make this worthwhile

    (instead, we use a manual thermostat)

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Steps to take to achieve NZE

The design steps are iterative:

- **First choice** is ultra-high levels of energy efficiency.
- **Include** as much **passive solar heating** as available.
- **Consider** **solar thermal** and **geothermal** (make sure you get reliable performance #s).
- **Solar electricity** is used to achieve the NZE goal.
- **If** solar electricity is too large or too expensive then increase the energy efficiency, solar thermal and geothermal, then recalculate solar PV.

Next…

1. Net Zero Energy in Juneau
2. Net Zero Energy in Fairbanks
3. Net Zero Energy in Wasilla
4. Net Zero Energy in Anchorage

Potential NZE House in Juneau -- PV only

- From HOT-2000 or any house modelling software, the house needed:
  - space heating: 5532 kWh
  - domestic water heating: 3022 kWh
  - domestic electricity: 3833 kWh
  - total energy deficit: 12,387 kWh

- **If** this total deficit were to be generated by solar PV, the PV system would be:
  - 13.9 kW, tilted at 43° optimum
  - using 14.2% efficient PV module: 98 m^2 (1050 ft^2), cost: $84k installed
  - issues: cost, roof area is only 75 m^2 (810 ft^2)
  - challenge: how can the size and cost of the PV system be reduced?
  - using 17.1% efficient PV module: 82 m^2 (880 ft^2), cost: $103k installed

NZE House in Juneau – add solar thermal

- Let's look at how we could reduce this with solar thermal DWH.
- From RETScreen, a 2-collector solar thermal DWH system at 43° tilt could produce:
  - domestic water heating: 1460 kWh
  - net energy deficit: 10,927 kWh
  - cost: $8k installed

- If this net deficit were generated by solar PV, the PV system would be:
  - 12.3 kW, tilted at 43° optimum
  - using 14.2% efficient PV module: 86 m^2 (930 ft^2), cost: $74k installed, total with solar thermal = $82k ($2k saving)
  - using 17.1% efficient PV module: 72 m^2 (780 ft^2), cost: $91k installed, total with solar thermal = $99k ($4k saving)

NZE House in Juneau – add geothermal

- Let's look at how we could reduce this with a geothermal heat pump.
- With just basic calculations about a GTHP performance:
  - Would need 2 to 3 boreholes (depending on the soil conductivity)
  - If the GTHP has a COP of 3, then it would provide 7100 kWh and use 2400 kWh
  - Net deficit of 6200 kWh
  - Cost of GTHP = $20k (???)

- If this net deficit were generated by solar PV, the PV system would be:
  - 7 kW, tilted at 43° optimum
  - using 14.2% efficient PV module: 49 m^2 (530 ft^2), cost: $45k installed, total with solar thermal + GTHP = $73k ($8k saving)
  - using 17.1% efficient PV module: 41 m^2 (441 ft^2), cost: $55k installed, total with solar thermal + GTHP = $83k ($16k saving)

Next…

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2. Net Zero Energy in Fairbanks
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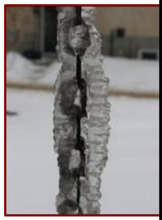
4. Net Zero Energy in Anchorage



Our self-interest is also the self-interest of the community & environment within which we operate.
We have no choice but environmental and social responsibility. Anonymous

Potential NZE House in Fairbanks -- PV only

- From HOT-2000 (or use any house modelling software), the house needed:
  - space heating: 12,799 kWh
  - domestic water heating: 3417 kWh
  - domestic electricity: 3833 kWh
  - total energy deficit: 20,049 kWh

- **If** this total energy deficit were to be generated by solar PV, the PV system would be:
  - 19.2 kW in capacity, tilted at 53° optimum
  - using 14.2% efficient PV module: 135 m^2 (1455 ft^2), cost: $115k installed
  - issues: cost, roof area is only 75 m^2 (810 ft^2)
  - challenge: how can the size and cost of the PV system be reduced?
  - using 17.1% efficient PV module: 113 m^2 (1213 ft^2), cost: $142k installed

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NZE House in Fairbanks – add solar thermal

- Let's look at how we could reduce this with solar thermal domestic water heating.
- From RETScreen, a 4-collector solar thermal domestic water heating system at 64° tilt could produce:
  - solar domestic water: 2712 kWh
  - net energy deficit: 17,337 kWh
  - cost: $9k installed

- If this net deficit were generated by solar PV, the PV system would be:
  - 16.6 kW, tilted at 53° optimum
  - using 14.2% efficient PV module: 117 m^2 (1258 ft^2),
    cost: $100k installed, total with solar thermal = $109k ($6k saving)
  - using 17.1% efficient PV module: 97 m^2 (1049 ft^2),
    cost: $123k installed, total with solar thermal = $132k ($10k saving)

NZE House in Fairbanks – add geothermal

- Let's look at how we could reduce this with a geothermal heat pump.
- With just basic calculations about a GTHP performance:
  - Would need 3 boreholes (depending on soil conductivity)
  - If the GTHP has a COP of 3, then it would provide 13,504 kWh of heat energy and use 4500 kWh of electrical energy
  - Net deficit of 8300 kWh
  - Cost of GTHP = $30k (???)

- If this net deficit were generated by solar PV, the PV system would be:
  - 8 kW, tilted at 53° optimum
  - using 14.2% efficient PV module: 56 m^2 (605 ft^2), cost: $52k installed, total with solar thermal + GTHP = $91k ($18k saving)
  - using 17.1% efficient PV module: 47 m^2 (504 ft^2), cost: $63k installed, total with solar thermal + GTHP = $102k ($30k saving)

Next…

1. Net Zero Energy in Juneau
2. Net Zero Energy in Fairbanks
3. Net Zero Energy in Wasilla
4. Net Zero Energy in Anchorage

Going to a junkyard is a sobering experience…
There you can see the ultimate destination of almost everything we desire. Roger von Oech

Potential NZE House in Wasilla -- PV only

- From HOT-2000 (or use any house modelling software), the house needed:
  - space heating: 5678 kWh
  - domestic water heating: 3192 kWh
  - domestic electricity: 3833 kWh
  - total energy deficit: 12,703 kWh

- **If** this total energy deficit were to be generated by solar PV, the PV system would be:
  - 11.2 kW in capacity, tilted at 53° optimum
  - using 14.2% efficient PV module: 79 m^2 (848 ft^2), cost: $67k installed
  - issues: cost, total roof area is 75 m^2 (810 ft^2)
  - challenge: how can the size and cost of the PV system be reduced?
  - using 17.1% efficient PV module: 66 m^2 (708 ft^2), cost: $83k installed

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NZE House in Wasilla – add solar thermal

- Let's look at how we could reduce this with solar thermal domestic water heating.
- From RETScreen, a 4-collector solar thermal domestic water heating system at 64° tilt could produce: (12 m^2, 130 ft^2)
  - solar domestic water: 2784 kWh
  - net energy deficit: 9919 kWh
  - cost: $11k installed

- If this net deficit were generated by solar PV, the PV system would be:
  - 8.8 kW, tilted at 53° optimum
  - using 14.2% efficient PV module: 62 m^2 (662 ft^2),
    cost: $53k installed,
    total with solar thermal = $64k ($4k saving) (still covering whole roof)
  - using 17.1% efficient PV module: 51 m^2 (553 ft^2),
    cost: $65k installed, total with solar thermal = $76k ($7k saving)

NZE House in Wasilla – add geothermal

- Let's look at how we could reduce this with a geothermal heat pump.
- With just basic calculations about a GTHP performance:
  - Would need 3 boreholes (depending on soil conductivity)
  - If the GTHP has a COP of 3, then it would provide 6090 kWh of heat energy and use 2030 kWh of electrical energy
  - Net deficit of 5860 kWh
  - Cost of GTHP = $20k+ (???)

- If this net deficit were generated by solar PV, the PV system would be:
  - 5.2 kW, tilted at 53° optimum
  - using 14.2% efficient PV module: 36 m^2 (390 ft^2), cost: $34k installed, total with solar thermal + GTHP = $65k ($1k MORE)
  - using 17.1% efficient PV module: 30 m^2 (330 ft^2), cost: $41k installed, total with solar thermal + GTHP = $72k ($4k saving)

Next…

1. Net Zero Energy in Juneau
2. Net Zero Energy in Fairbanks
3. Net Zero Energy in Wasilla
4. Net Zero Energy in Anchorage

You can never solve a problem on the level on which it was created,
[especially when] conventional wisdom wed to the status quo
[act as] powerful sedatives. ~ Albert Einstein, Ray Anderson

Potential NZE House in Anchorage – PV only

- From HOT-2000 (or use any house modelling software), the house needed:
  - space heating: 5678 kWh
  - domestic water heating: 3192 kWh
  - domestic electricity: 3833 kWh
  - total energy deficit: 12,703 kWh

- **If** this total energy deficit were to be generated by solar PV, the PV system would be:
  - 14.1 kW in capacity, tilted at 49° optimum
  - using 14.2% efficient PV module: 99 m^2 (1066 ft^2), cost: $84k installed
  - issues: cost, total roof area is 75 m^2 (810 ft^2)
  - challenge: how can the size and cost of the PV system be reduced?
  - using 17.1% efficient PV module: 83 m^2 (889 ft^2), cost: $104k installed

NZE House in Anchorage – add solar thermal

- Let's look at how we could reduce this with solar thermal domestic water heating.
- From RETScreen, a 4-collector solar thermal domestic water heating system at 63° tilt could produce: (12 m^2, 130 ft^2)
  - solar domestic water: 2264 kWh
  - net energy deficit: 10,439 kWh
  - cost: $11k installed, will deliver 71% of the domestic water heating

- If this net deficit were generated by solar PV, the PV system would be:
  - 11.6 kW, tilted at 49° optimum
  - using 14.2% efficient PV module: 81 m^2 (876 ft^2),
    cost: $69k installed,
    total with solar thermal = $80k ($4k saving) (still covering whole roof)
  - using 17.1% efficient PV module: 68 m^2 (730 ft^2),
    cost: $85k installed, total with solar thermal = $96k ($7k saving)

NZE House in Anchorage – add geothermal

- Let's look at how we could reduce this with a geothermal heat pump.
- With just basic calculations about a GTHP performance:
  - Would need 3 boreholes (depending on soil conductivity)
  - If the GTHP has a COP of 3, then it would provide 6606 kWh of heat energy and use 2202 kWh of electrical energy
  - Net deficit of 6030 kWh
  - Cost of GTHP = $20k (???)

- If this net deficit were generated by solar PV, the PV system would be:
  - 6.7 kW, tilted at 49° optimum
  - using 14.2% efficient PV module: 47 m^2 (506 ft^2), cost: $43k installed, total with solar thermal + GTHP = $74k ($6k saving)
  - using 17.1% efficient PV module: 39 m^2 (422 ft^2), cost: $53k installed, total with solar thermal + GTHP = $84k ($13k saving)

Potential NZE House – next steps

- **Challenge**:
  - These estimates do not include snow cover!
    Snow cover makes the solar PV system larger by about 10%
    but how do you obtain reasonable information on snow cover?

- **Next steps**:
  - Make the house even more energy efficient
  - Source out cheaper and more efficient solar PV modules
  - Get a cheaper geothermal heat pump
  - Use air-source heat pump ????
    (but where to buy it? How does it really work?)

Prepare for the near future…

1. Get ready for **high energy prices**
   (how else are we going to clean up our energy act?)

2. Get ready for **cheap solar electricity**:
   Make buildings "**solar PV-ready**".

3. Housing that is "**net-zero energy ready**"
   (which means ultra efficiency minus solar electricity)
   is likely the **cheapest cost option** in a house right now.

Please take care of the Earth,
its the only planet with chocolate!

Opportunity for "Net Zero Ready"…

- We are finding that "**net zero ready**"
  (ultra efficiency plus passive solar)
  is likely the cheapest-cost energy option
  for our new houses…
  - 73% energy reduction
  - 58% emission reduction
  - 54% utility bill reduction
  - yet only 4% of the costs of a new house…

- The infrastructure of "**net zero ready**" houses
  leaves homeowners and cities with a
  positive legacy
  instead of a future retrofit burden…

Ask not: what would it cost **me** to do this?
Ask rather: what would it cost **my grandchildren** if I did **not** do this?

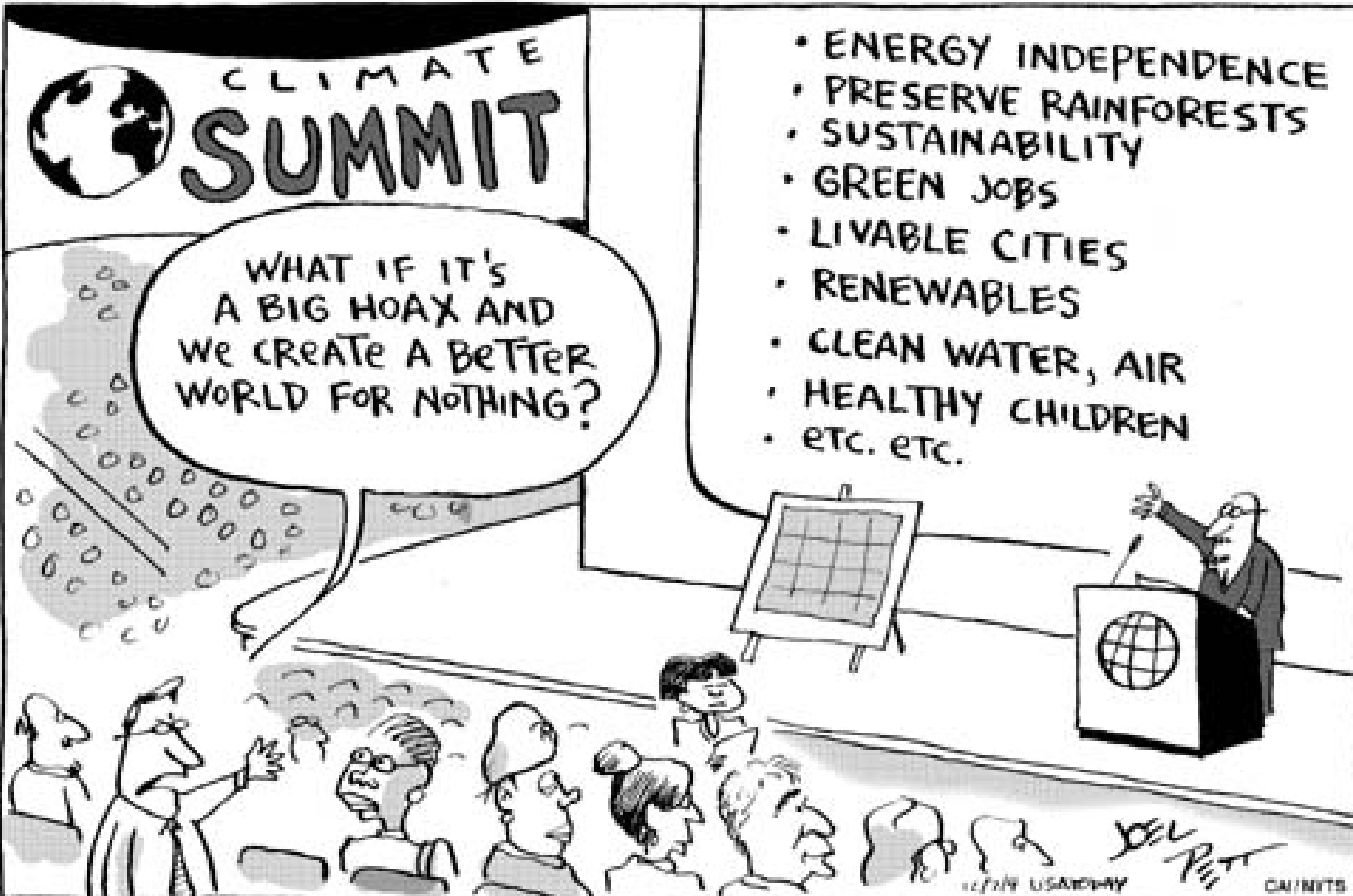
Bruce Karney

NetZero Ready on a House being Designed

- Make your house as energy efficient and solar friendly **as possible**!
- House orientation
  - roof lines from SW to SE
- Amount of solar collection area
  - Area of south windows, area of roof, roof tilt angle
- Landscaping
  - Well-placed trees, deciduous trees on the south
- Space from basement to attic
  - Conduit for electrical cables, "Chase" for 2 solar hot water pipes

If you don't like change, you're going to like irrelevance even less. General Eric Shinseki
Chief of Staff, American Army

JOEL PETT
USA TODAY



Where are we going…?

- **Socialism** collapsed
  because it did not allow the
  market to tell the economic truth.

- **Capitalism** is heading in the direction of collapsing
  because it does not allow the
  market to tell the ecological truth.

Quote Øystein Dahle
former VP, Exxon Norway

Is this the outcome we want
just because the market forces are not allowed to tell the truth?

Net Zero Energy Housing

… can we really afford anything less?

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www.riverdalenetzero.ca

www.greenedmonton.ca

www.habitat-studio.com

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Calvert Island north of Vancouver Island

Alberta Emerald Foundation

Gordon Howell, P.Eng.
Howell-Mayhew Engineering
Edmonton
Phone: +1 780 484 0476
E-mail: ghowell@hme.ca

We welcome any feedback, questions, suggestions, comments and challenges to anything we present.

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