Ultra-High Efficiency Heating Equipment

Skip Hayden
Advanced Combustion Technologies
Better Buildings by Design 2004
Burlington, VT
February 2004


RICE
RICE
RICE
RICE
TYPAR
TYPAR
TYPAR

Objectives

- Understand what makes heating systems efficient, learning the distinctions in appliance technologies and in energy sources
- Appreciate advantages & disadvantages of various “high efficiency” systems
- Be better able to choose or modify heating systems for high efficiency operation in new or existing housing

?

?

What are you looking for ?

?

? ?

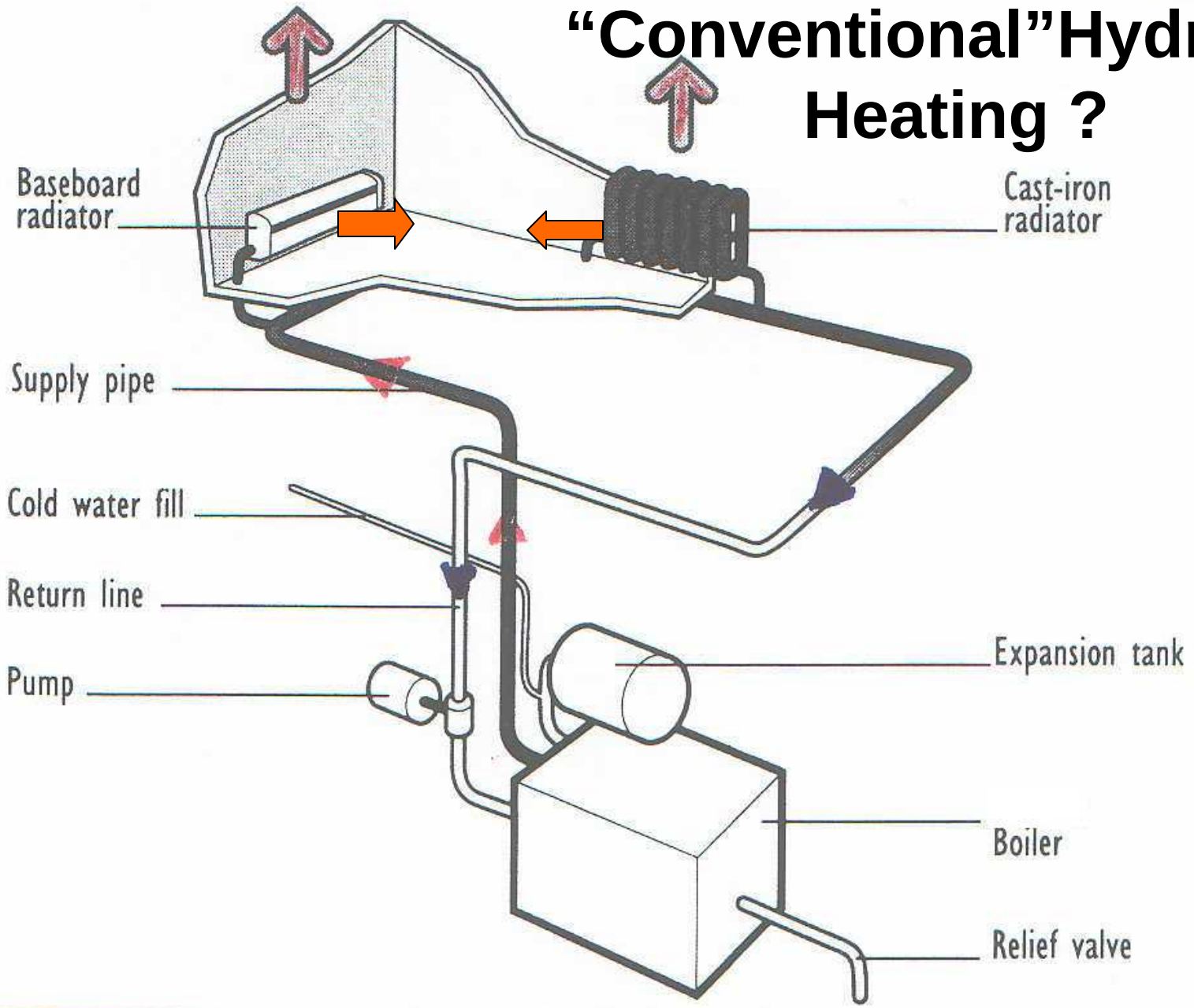
What is your prime energy choice ?

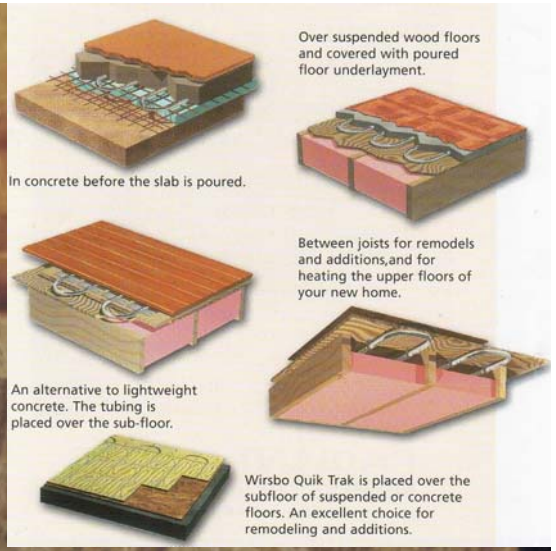
- natural gas
- oil
- propane
- wood
- electricity

Who also uses a supplementary/complemetary heating system?

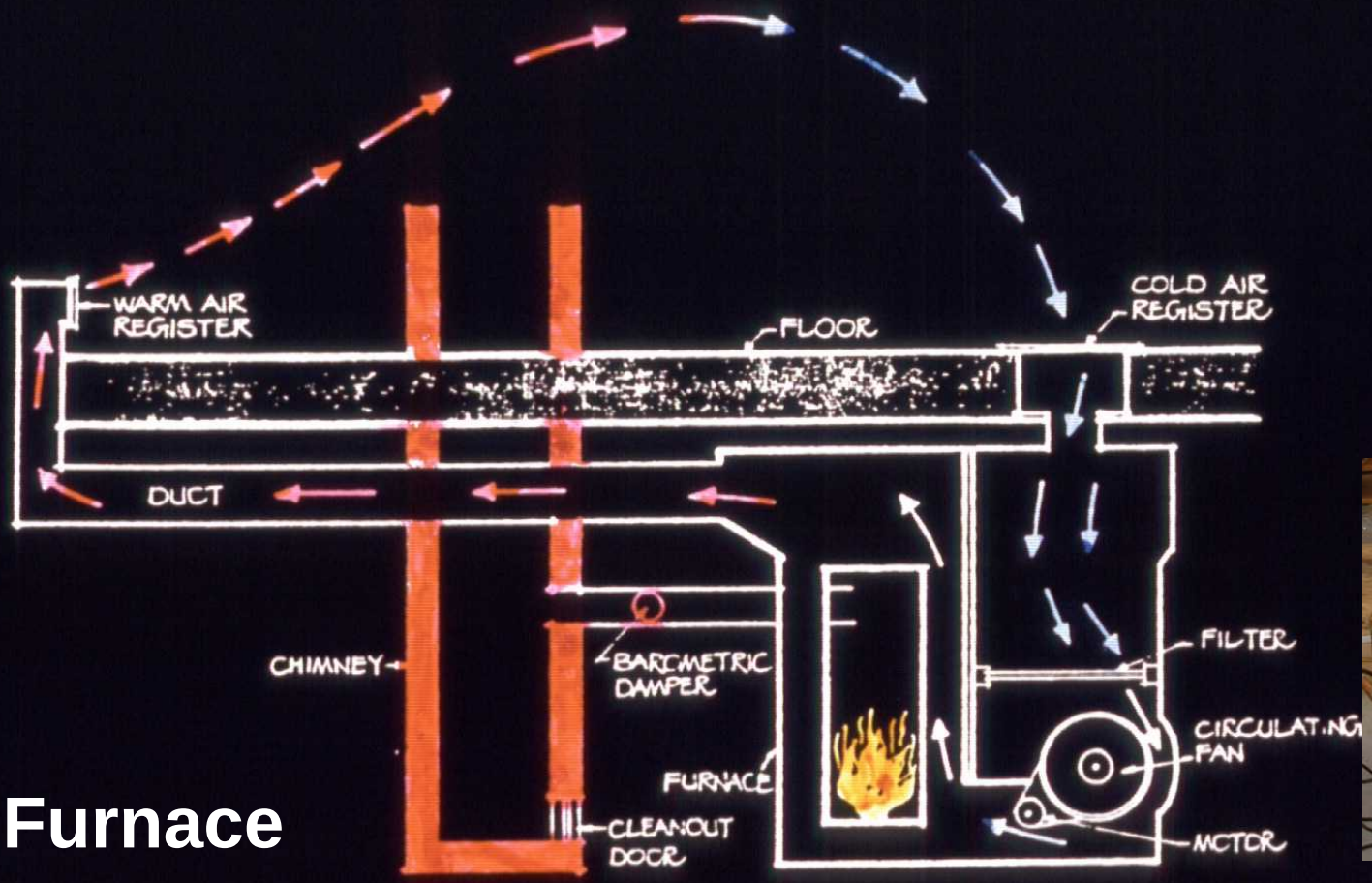
Heat Distribution ?

“Conventional”Hydronic Heating ?





Radiant Floor ?



Furnace

Fan Coil (Boiler)

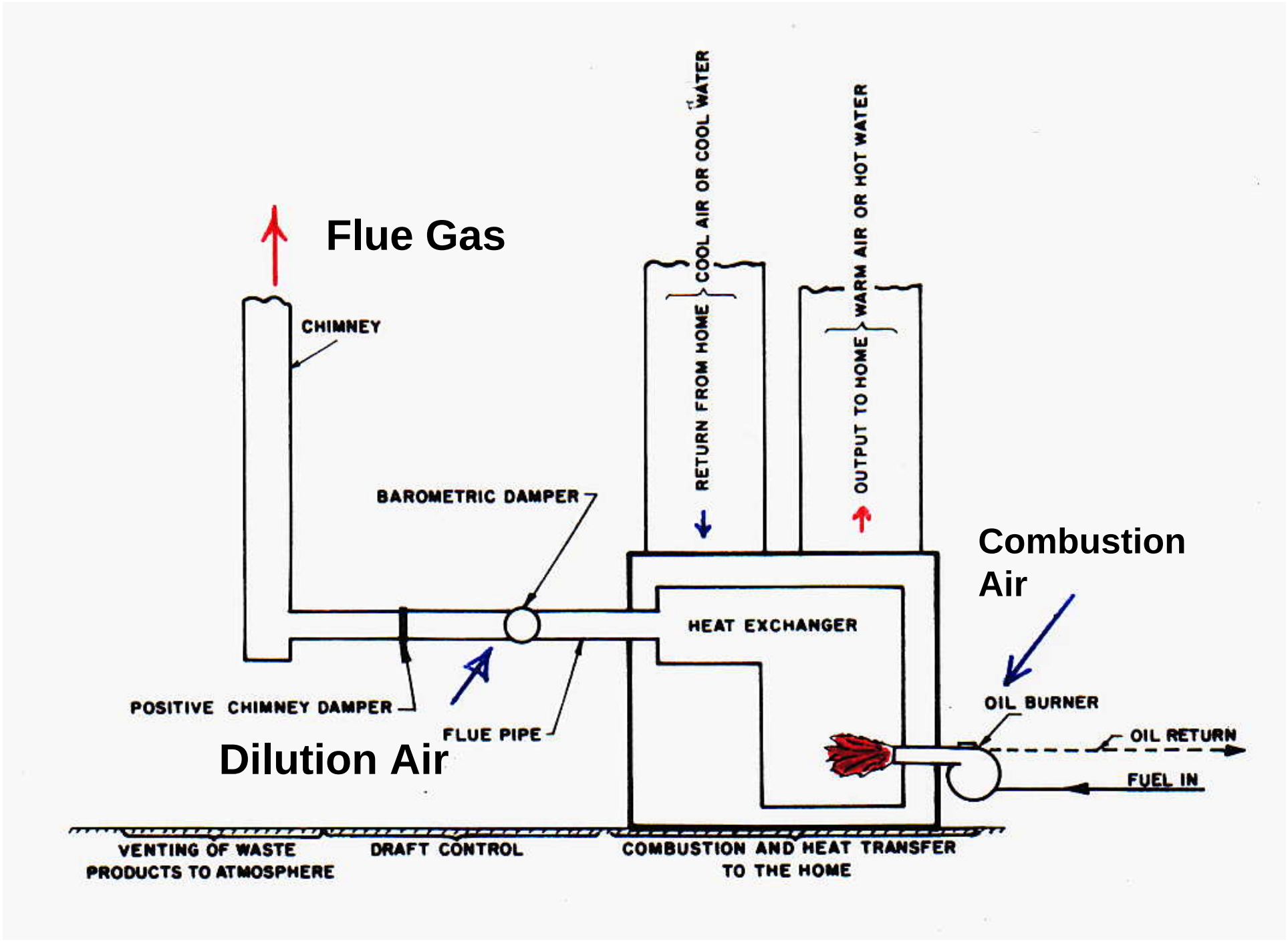
Warm Air System ?

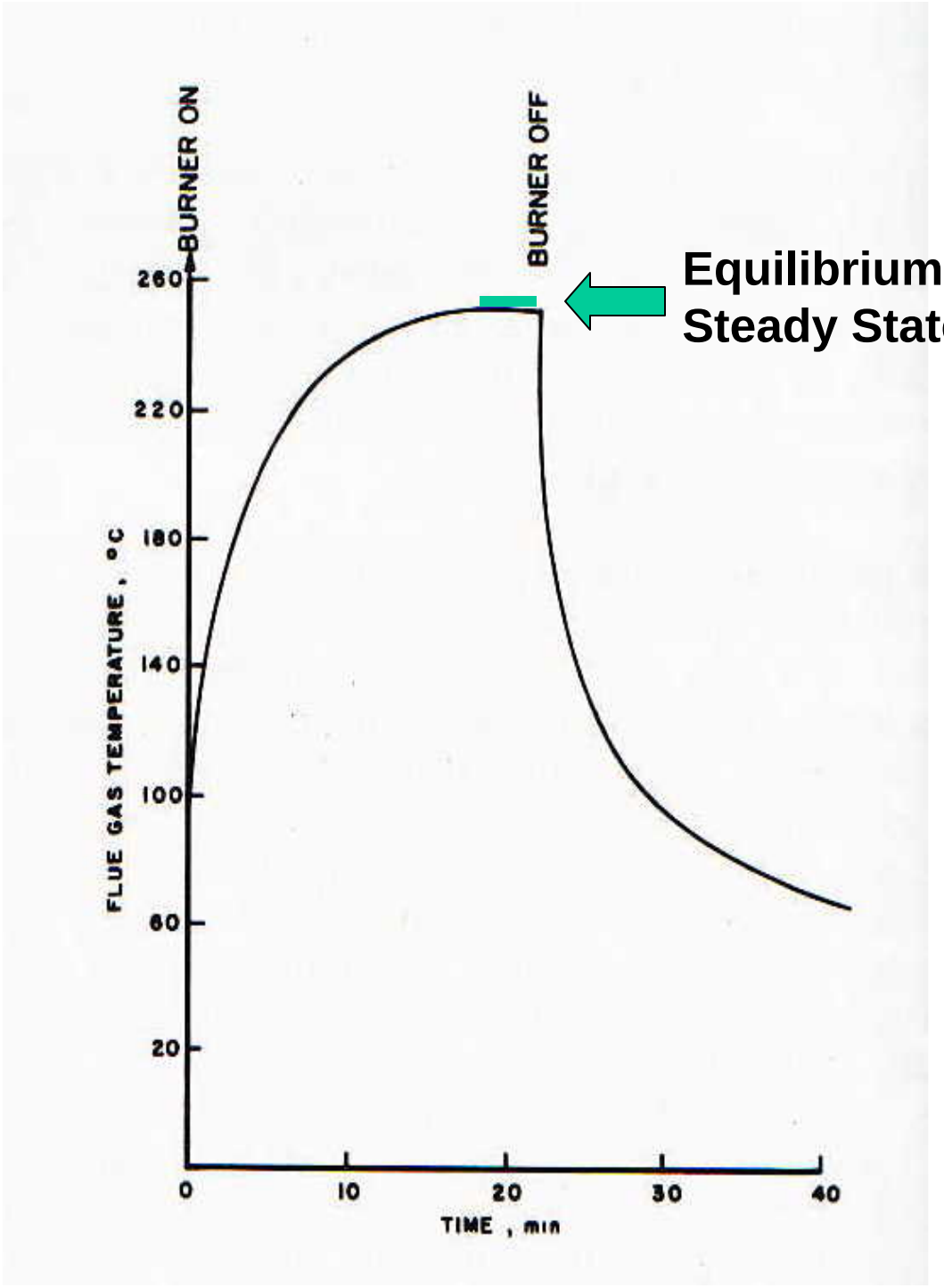

LOCAL
SPACE
HEATING ?

Energy Contents

Heating Oil	140 kBtu/gal
Natural Gas	1 007 Btu/ft^3
	100700 Btu/therm
Propane	92.7 kBtu/gal
Electricity	3413 Btu/kwh
Mixed Hardwood	26 Mbtu/fullcord
Wood Pellets	336 kBtu/bag or
	16.8 MBtu / ton
Coal	24 Mbtu / ton

Residential Heating System

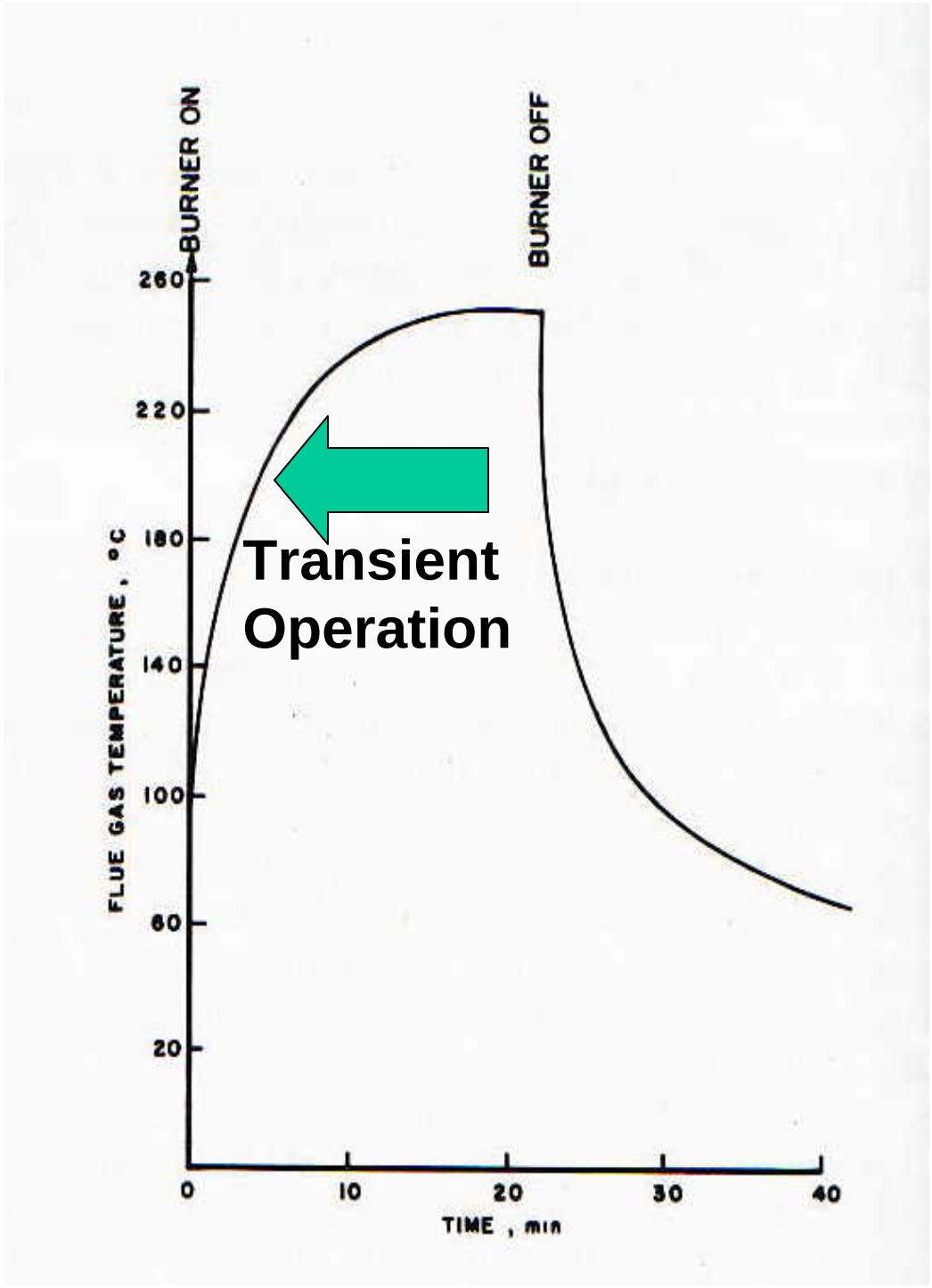

Flue Gas
CHIMNEY
BAROMETRIC DAMPER
RETURN FROM HOME
COOL AIR OR COOL WATER
OUTPUT TO HOME
WARM AIR OR HOT WATER
Combustion Air
HEAT EXCHANGER
POSITIVE CHIMNEY DAMPER
FLUE PIPE
Dilution Air
OIL BURNER
OIL RETURN
FUEL IN
VENTING OF WASTE PRODUCTS TO ATMOSPHERE
DRAFT CONTROL
COMBUSTION AND HEAT TRANSFER TO THE HOME



Equilibrium:
Steady State Operation

Steady State Efficiency

- Usually the most efficient point of operation
- Like cruising on the highway
- Many smaller systems (residential/commercial) rarely operate in steady state
- Gives a maximum point of reference and guides system readjustment to compensate for performance degradation


BURNER ON
BURNER OFF
260
220
180
140
100
60
20
FLUE GAS TEMPERATURE , °C
Transient
Operation
0
10
20
30
40
TIME , min

Transient or Cyclic Efficiency

Many combustion systems do not operate in steady state for most of their operation.

They cycle up and down, taking a significant time to reach equilibrium, if at all.

Usually the higher the mass of the system,the longer it takes to get to steady state

Nearly all transient systems are significantly less efficient than ones that operate in steady state.

Factors Affecting Overall Fuel Consumption

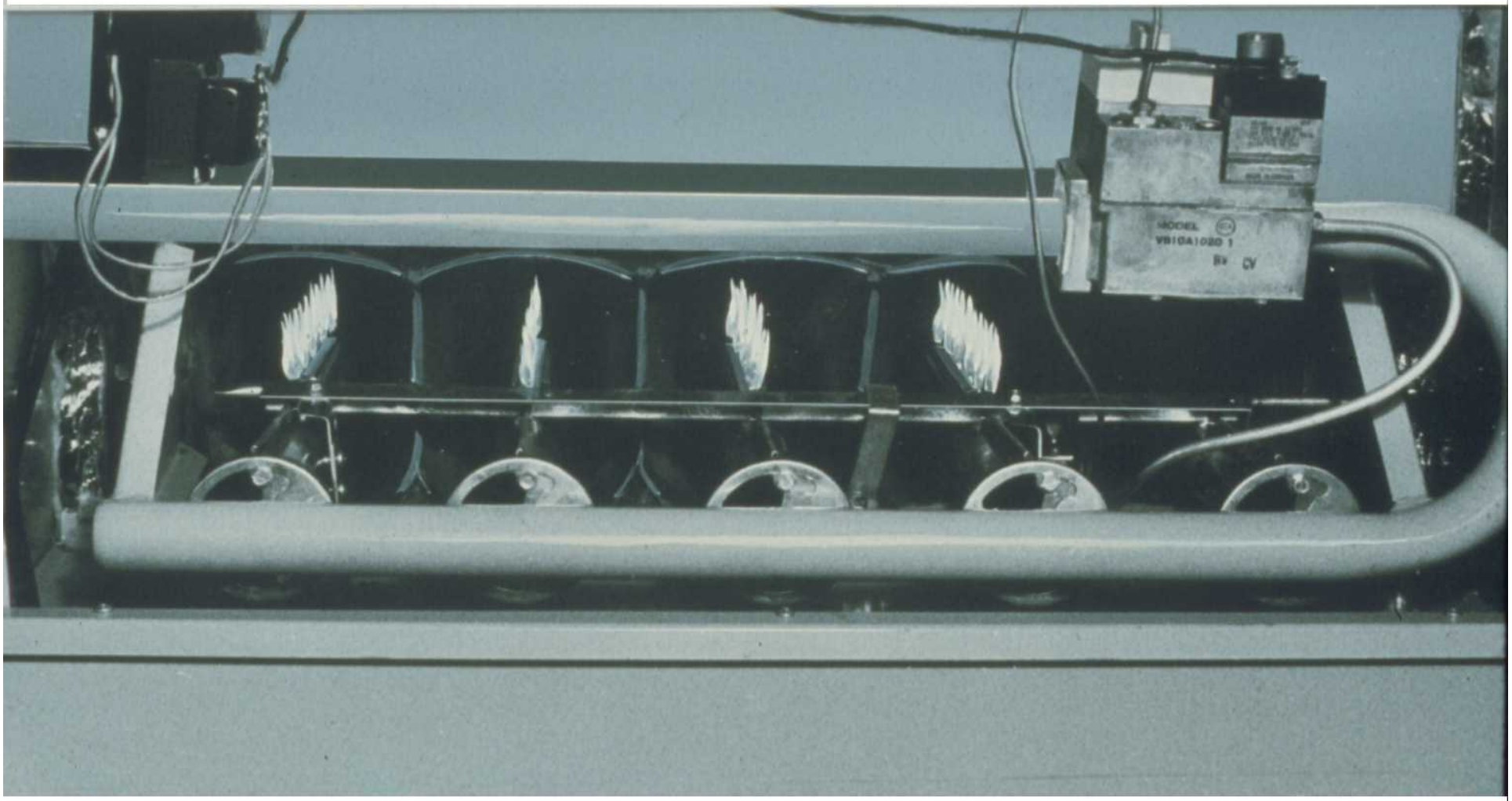
Demand		Supply
Heat Req'd	Heat Losses	
Outdoor Temp	Transmission	S.S. Efficiency
Thermostat (indoor)	Infiltration	Transient
	Off-Cycle (heat, air)	Dilution

Seasonal or Annual Fuel Utilization Efficiency (AFUE)

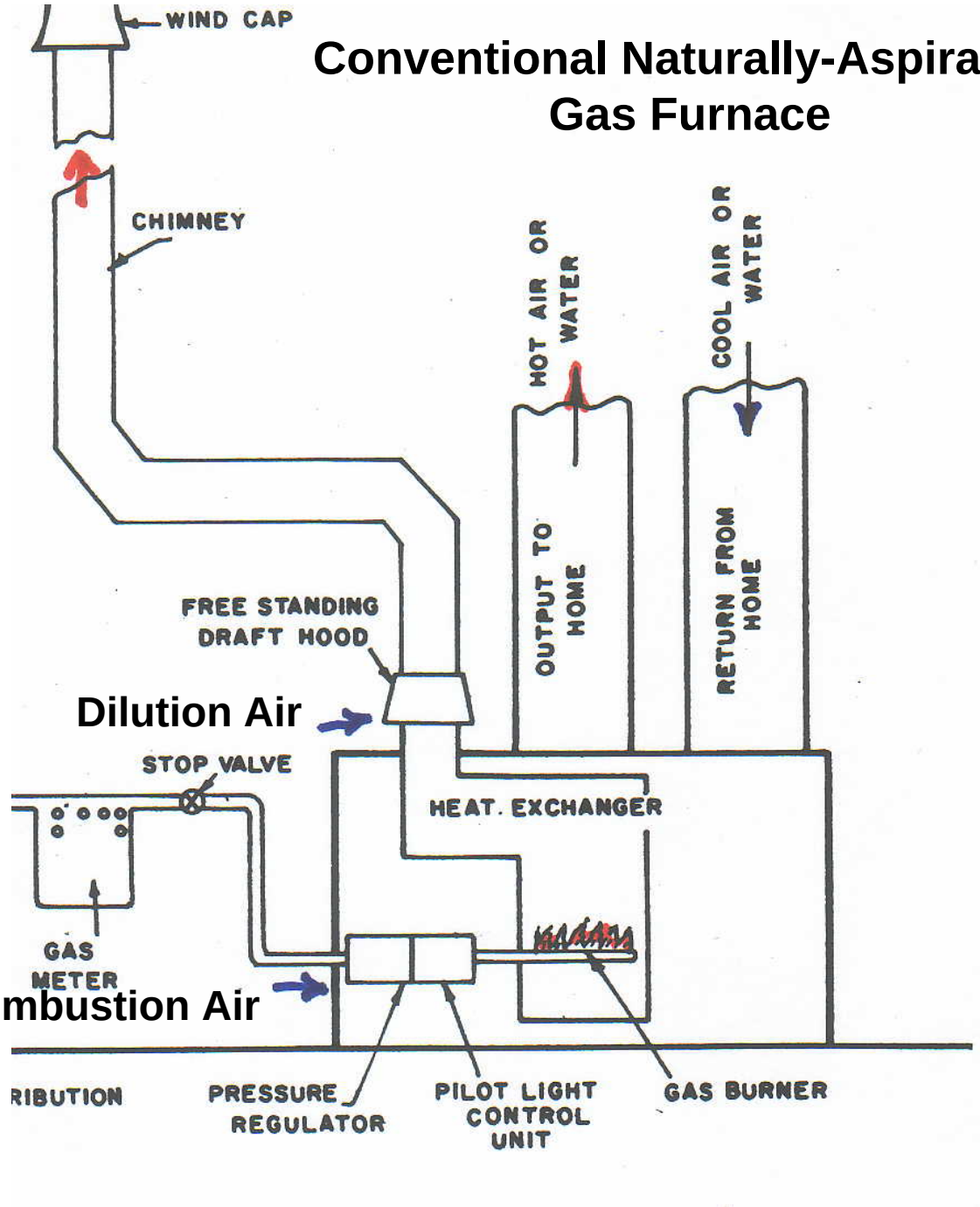
This is a cumulative (average) efficiency of a system over a year or other extended period in response to varying conditions

Gas-Fired Systems

Conventional Gas Furnace



Conventional Naturally-Aspirating Gas Furnace

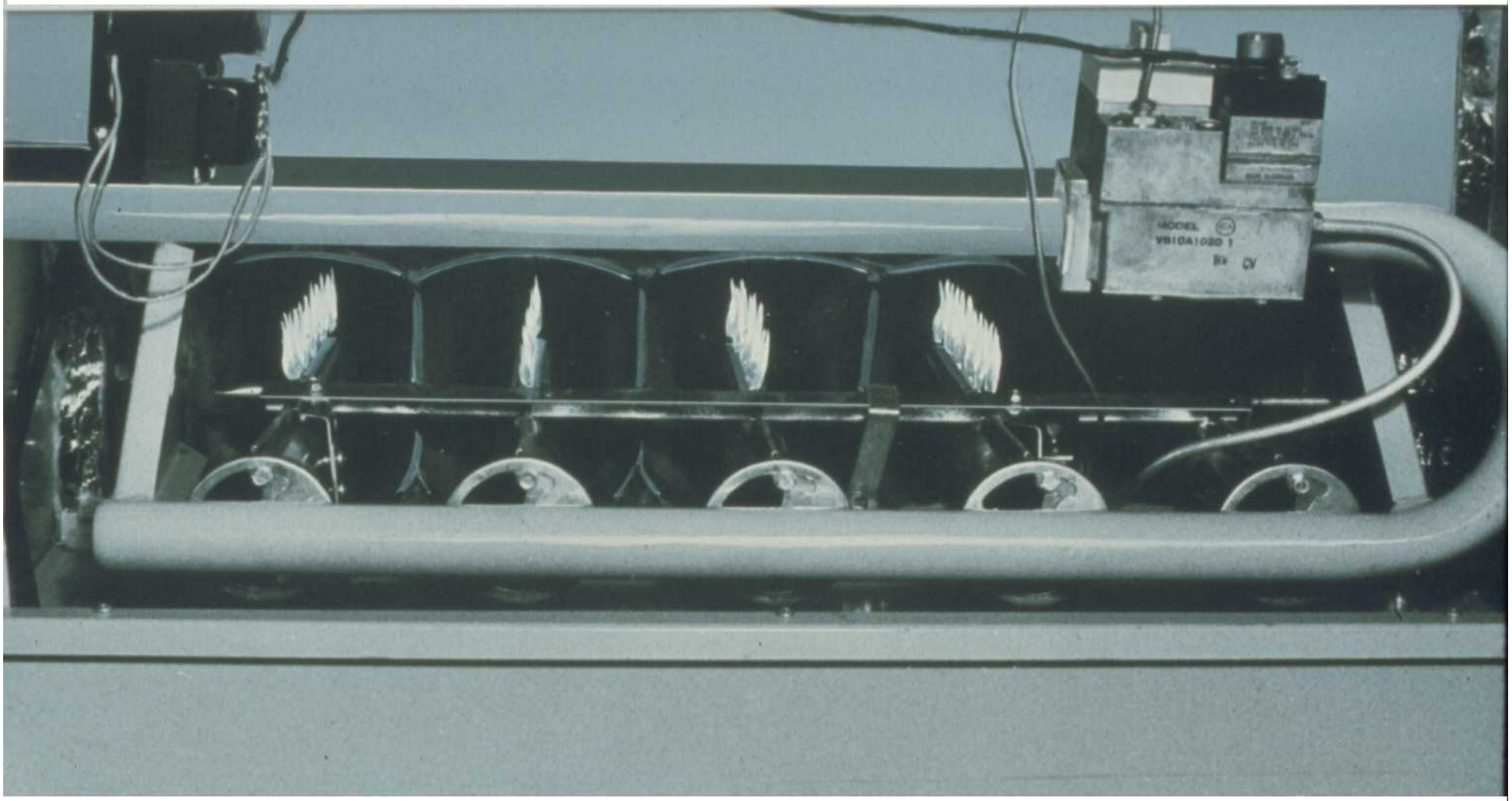


Conventional Gas Furnace

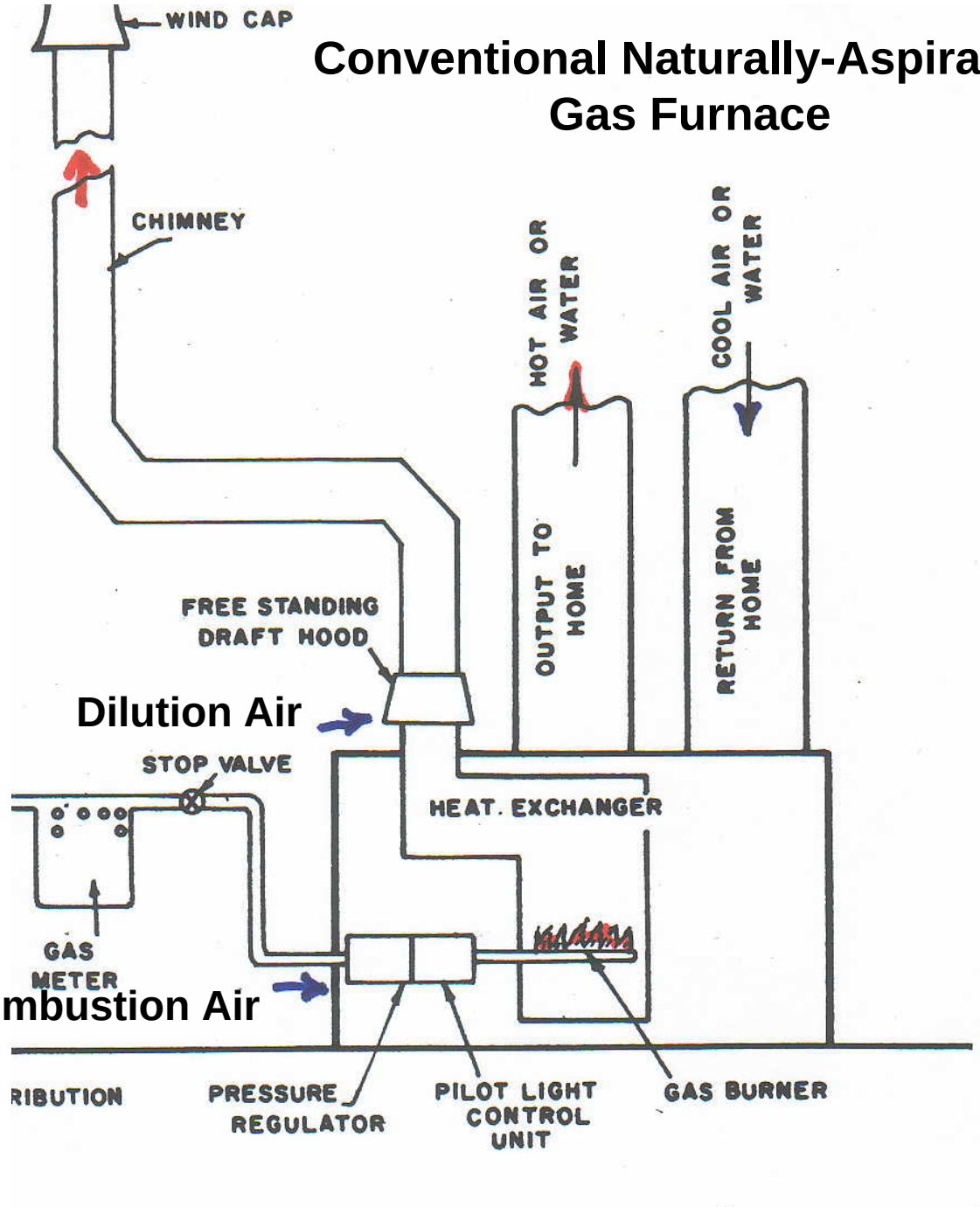
- Naturally aspirating
- Highly susceptible to depress & spillage
- Draft hood (extra heated air loss)
- Continuous pilot (energy waste)
- Large off-cycle loss
- Low seasonal efficiency (~ 60%)
- Now an “antique” !

Gas-Fired Systems

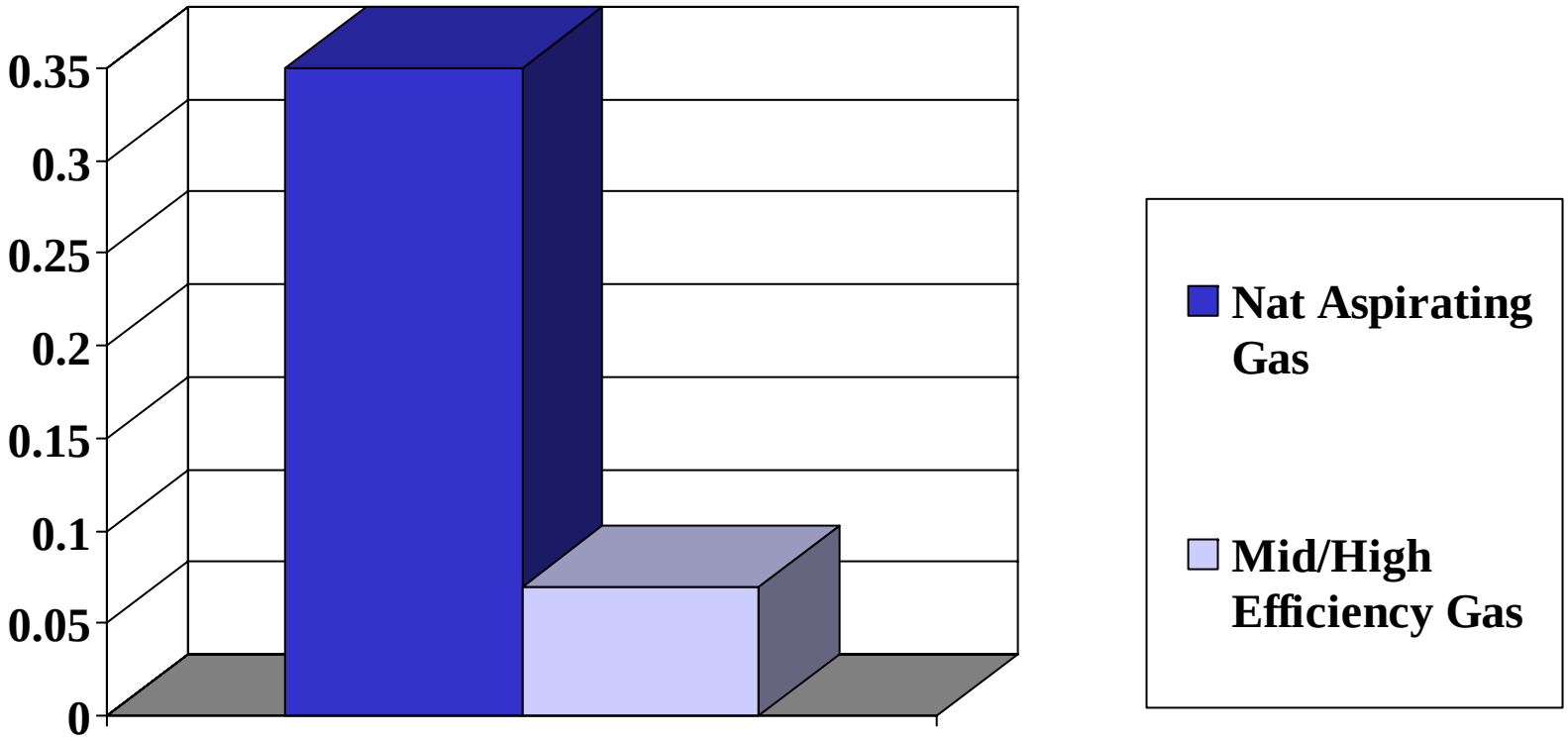
Conventional Gas Furnace



Conventional Naturally-Aspirating Gas Furnace



Air Requirements of Gas Furnaces



Conventional Gas Furnace

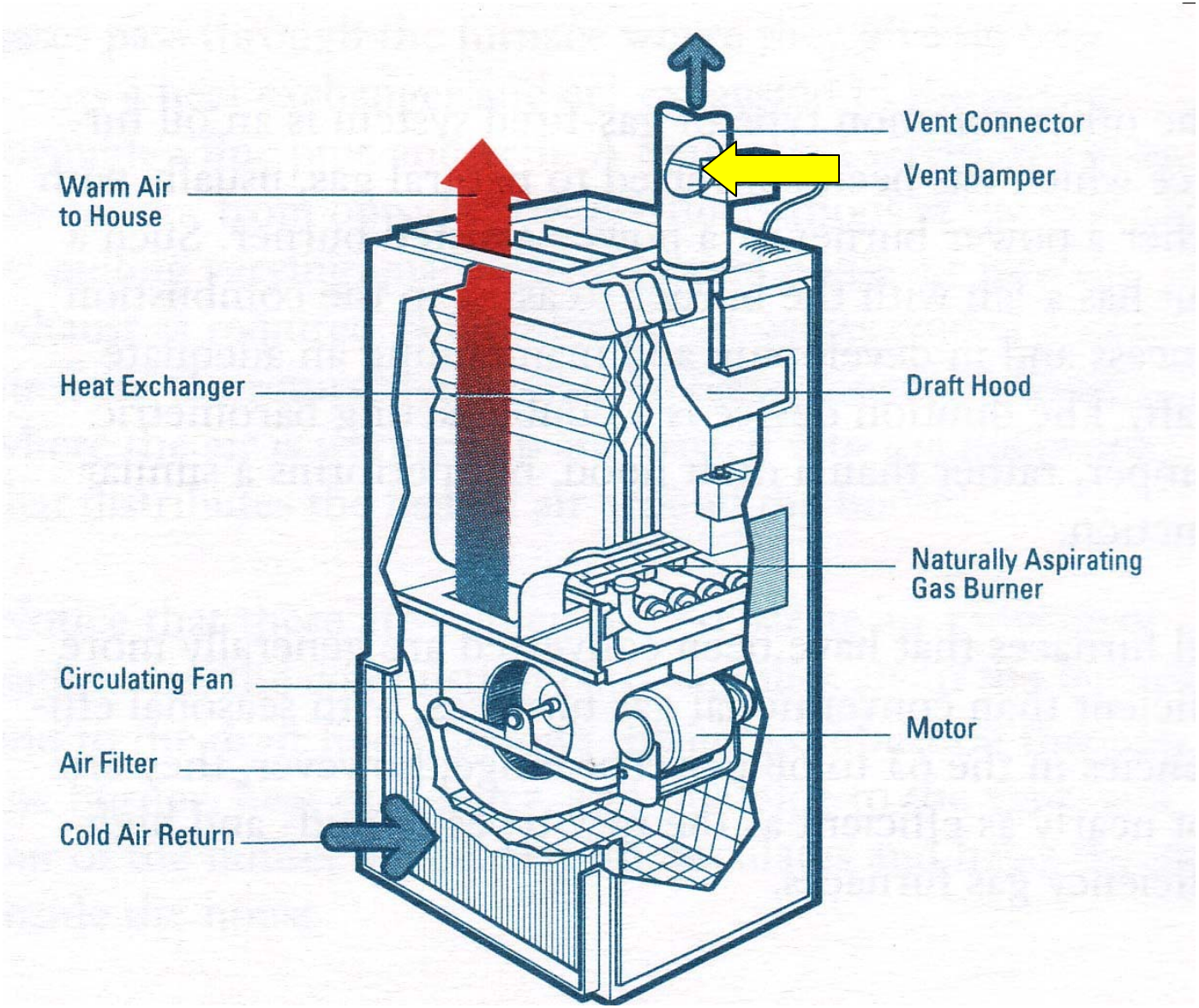
- Naturally aspirating
- Highly susceptible to depress & spillage
- Draft hood (extra heated air loss)
- Continuous pilot (energy waste)
- Large off-cycle loss
- Low seasonal efficiency (~ 60%)
- Now an “antique” !

Conventional Gas Boiler

Conventional Gas Boiler

- Naturally aspirating
- Highly susceptible to depress & spillage
- Draft hood (extra heated air loss)
- Continuous pilot (energy waste)
- Large off-cycle loss
- Can have low efficiency
- Should be an “antique” !

Vent-Dampered Naturally-Aspirating Gas Furnace

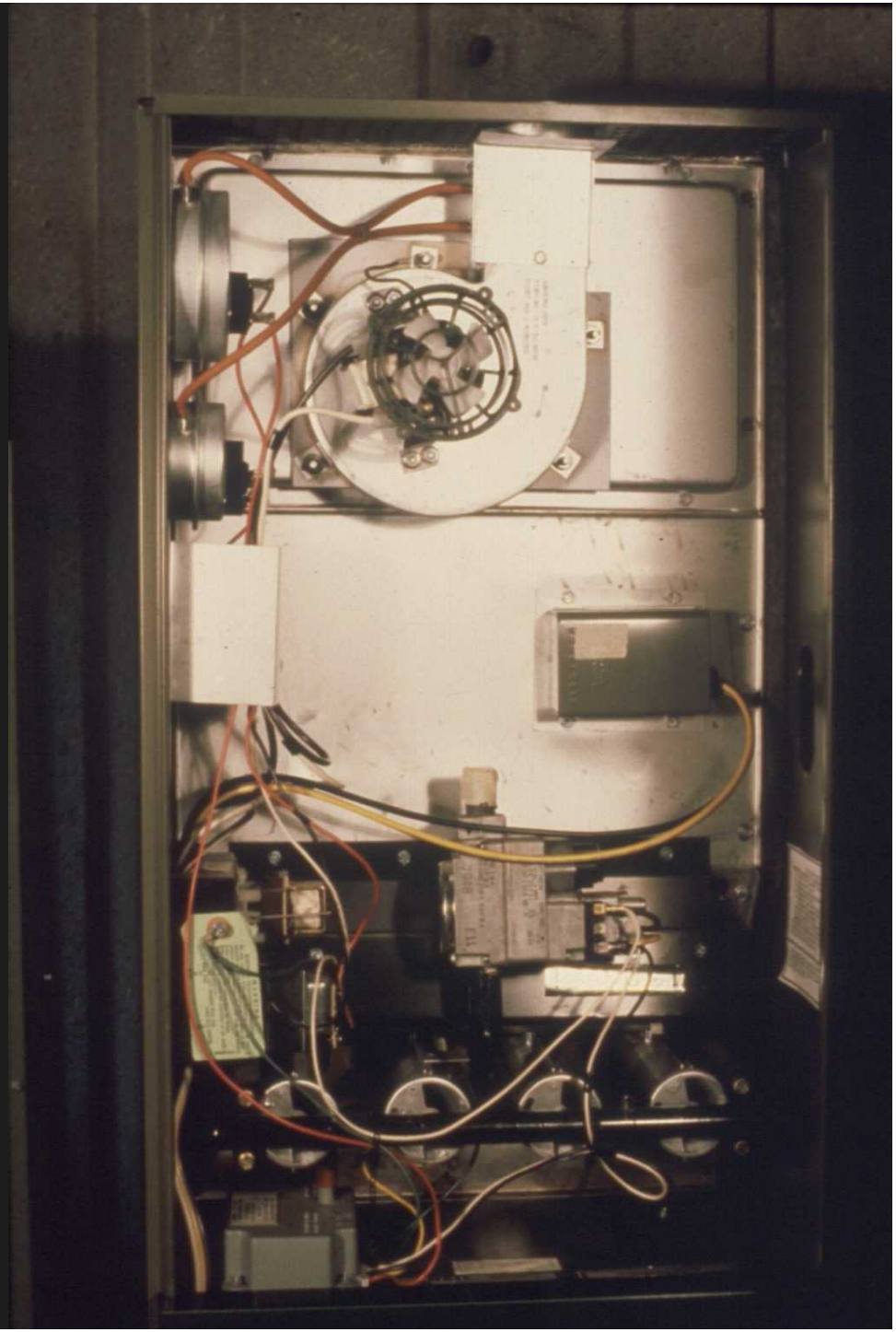


Vent-Dampered Furnaces and Boilers

Vent-Dampered Gas Boiler

- Naturally aspirating
- Highly susceptible to depress & spillage (more than conv. because stack cold)
- Draft hood (extra heated air loss)
- May or may not have Continuous pilot (energy waste)
- Lower off-cycle loss, but not rapid closing, so sig heat still lost
- Lower than “AFUE” efficiency
- Should be an “antique” !

Mid-Efficiency Gas Furnace

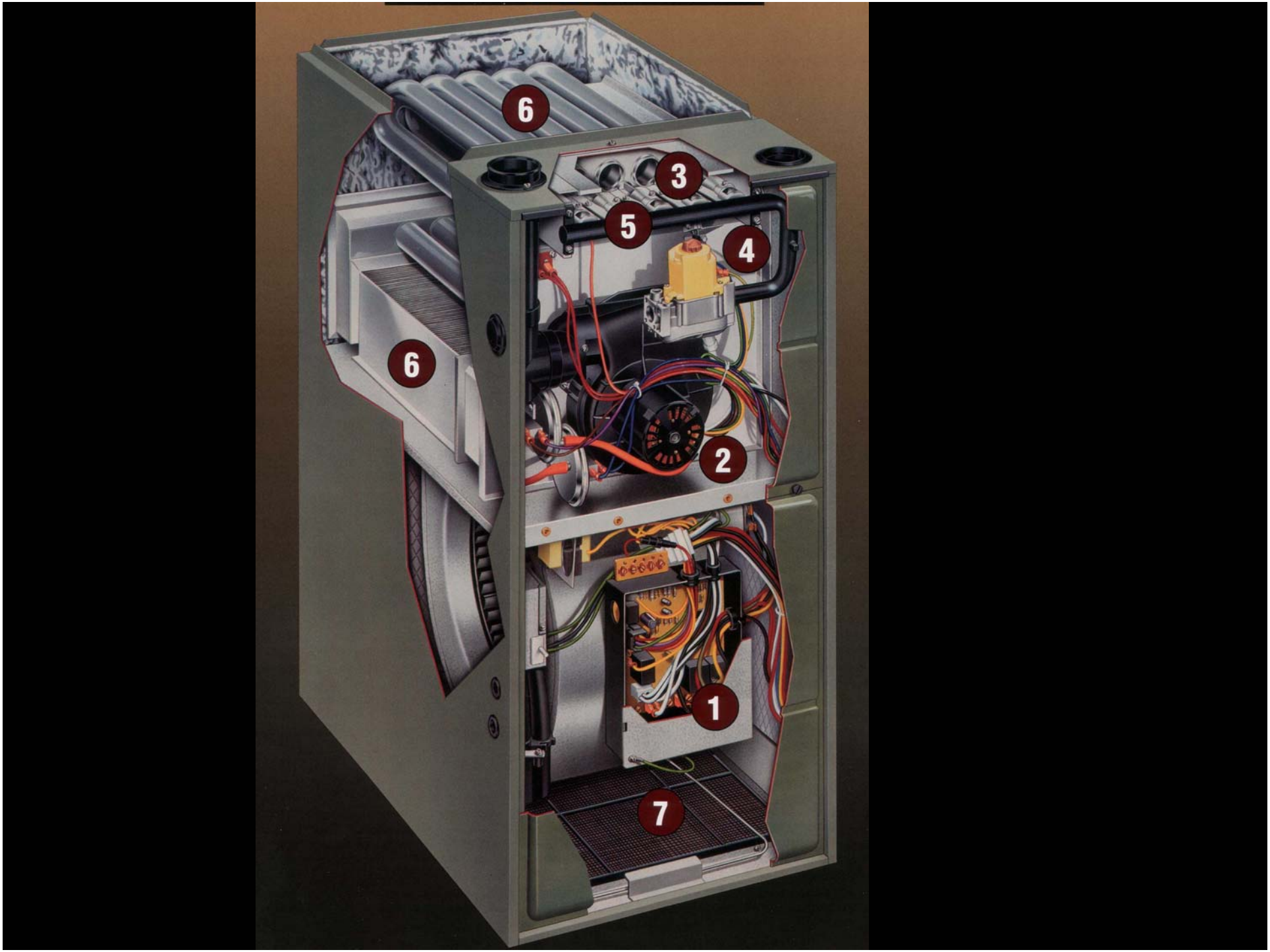


Mid-Efficiency Gas Furnace

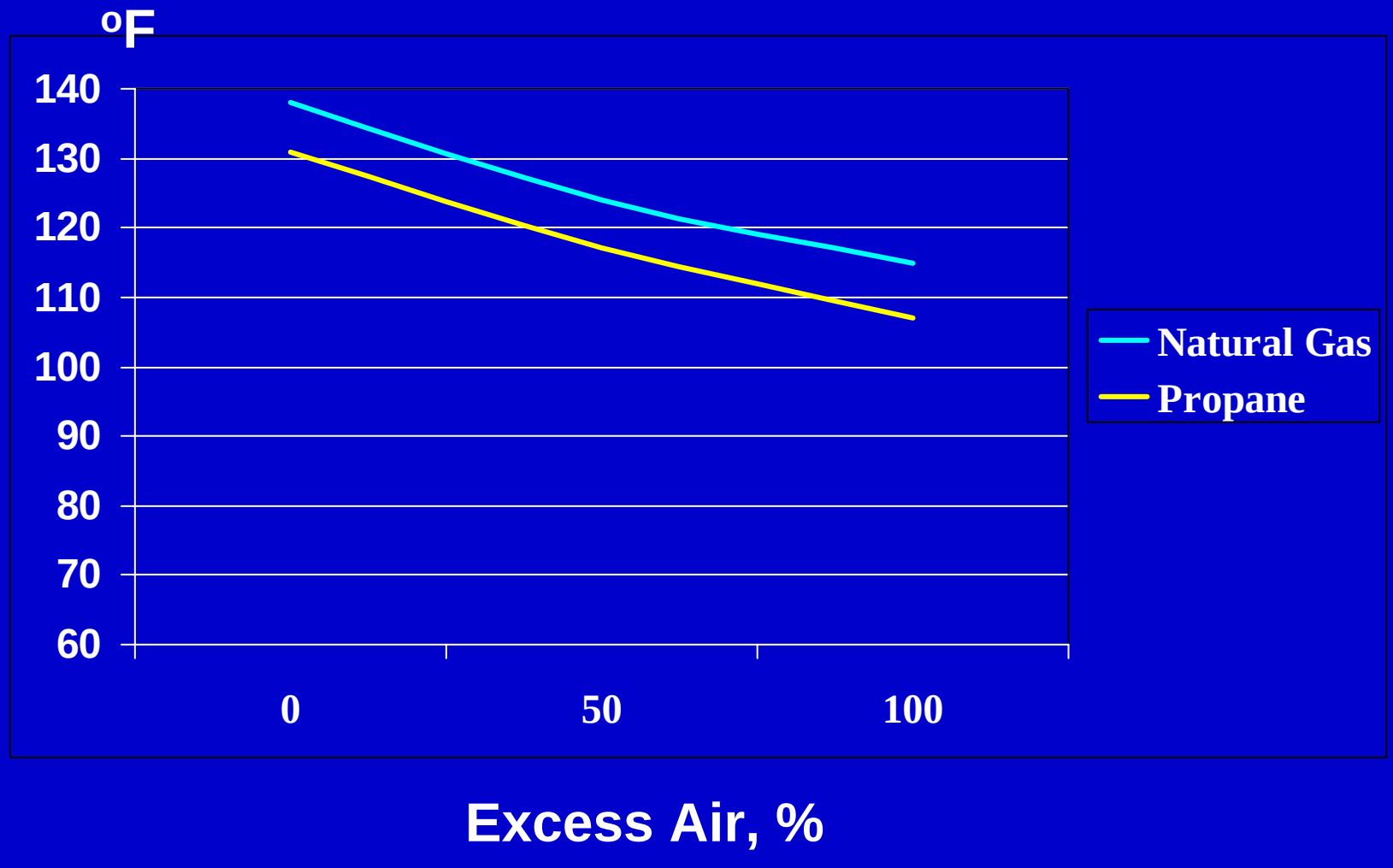
- **Powered exhaust**
- **Electronic ignition**
- **No dilution air**
- **So-so resistance to depressurization**
- **Probs with side-wall vent -No plastic!**
- **Should NOT be efficient (<81%)**
- **Oversizing loses efficiency and gives short-cycle condensation/corrosion problems with furnace or vent**

High Efficiency Condensing Furnace

*****


6
3
5
4
6
2
1
7

Dewpoints for Gaseous Fuels



Plastic pipe (PVC or ABS) and sidewall vent for Condensing Furnaces

Works great if continually sloped to appliance!!

Be wary of spiders, etc entering in summer

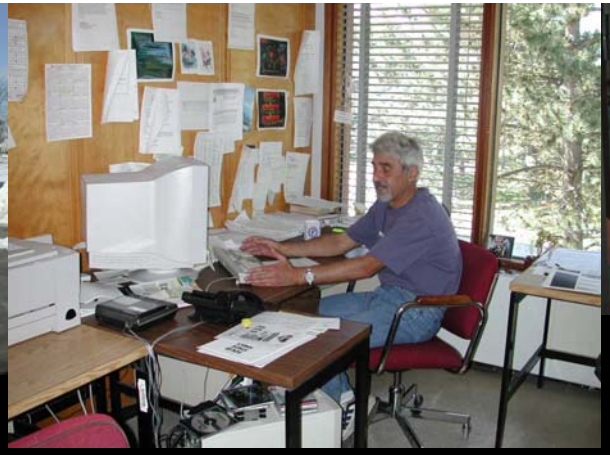
High-Efficiency Gas Furnace

- Powered exhaust
- Electronic ignition
- No dilution air
- High resistance to depressurization
- Excellent side-wall vent - plastic!
- Should be well above 90%
- Efficiency improves with slight oversizing

What about two-stage furnaces ?

Two-Stage or Modulating Furnaces

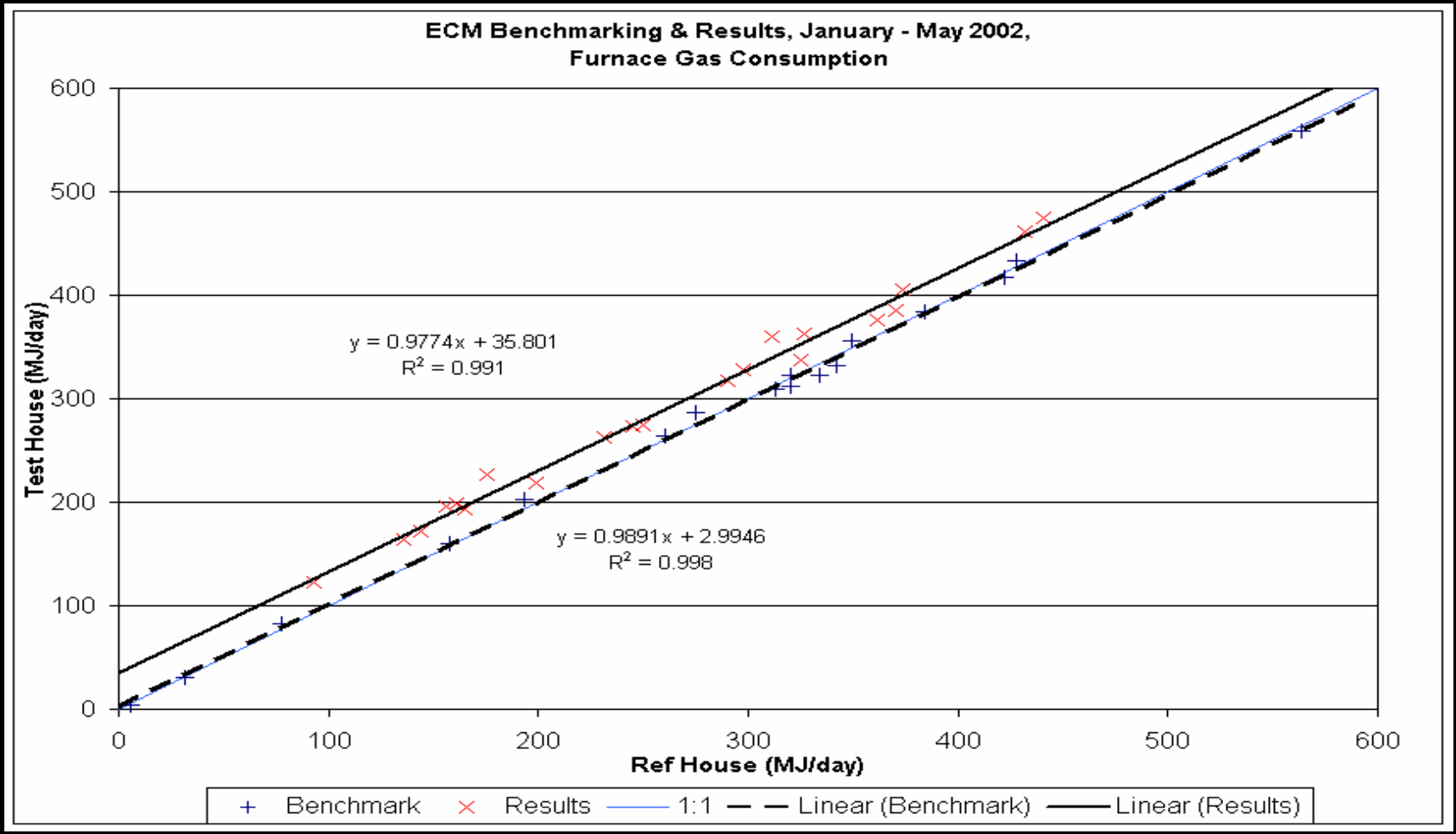
- If excess air not controlled on low fire, std efficiency will decrease, and
- dewpoint will fall, making it difficult to condense for hi-eff furnaces
- Increased electricity consumption due to longer circulating fan run-time may result in higher operating costs, esp if conventional motor
- If cycles fall significantly, constant-per-cycle post-purge losses could be lower
- Duct losses could outweigh savings

Electrical Use/Gas Consumption in Heat/Ventilation/Air Conditioning Distribution

- Sig increase in gas use & $$ electric saving with efficient electric motor (ECM) vs conventional PSC in warm air system
- $ saving and slight reduction in air conditioning requirement with efficient ECM motor

Gas Consumption with ECM & PSC Motors

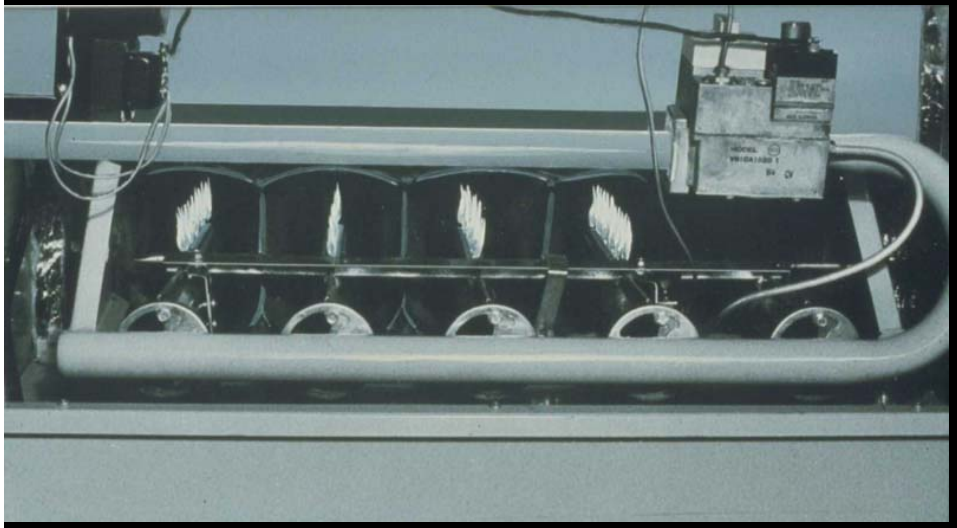


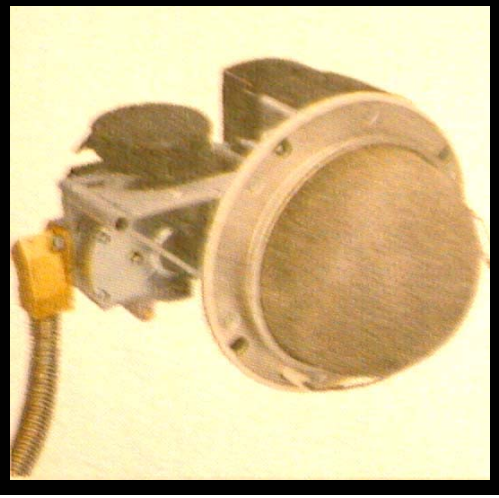
Electricity Consumption & Air Flows

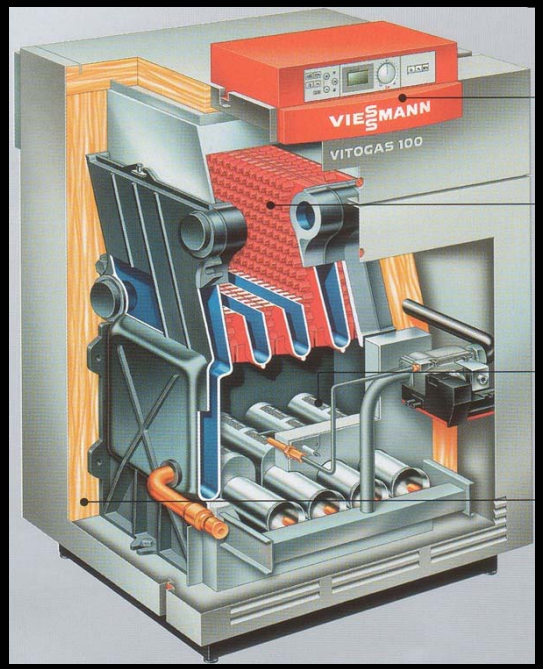
	Low Speed Circulation	High Speed Heating
ECM	16.5 w @	284 w @
	448 cfm	1215 cfm
	0.39PF	0.54PF **0.77 I**
PSC	350 w @	490 w @
	960 cfm	1317 cfm
	0.80PF	0.86PF

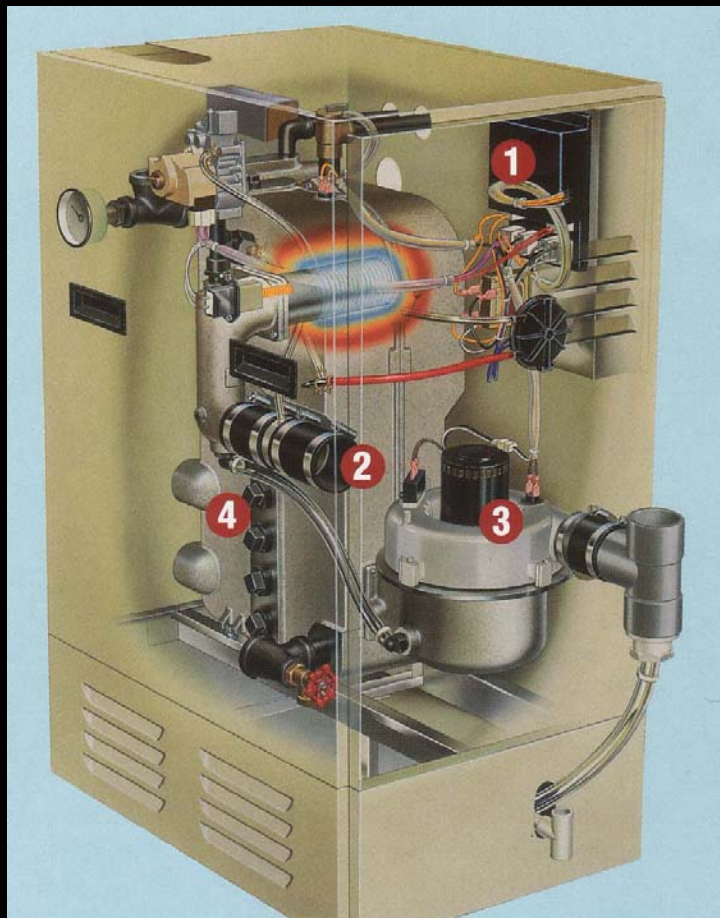
“Better” Gas Boilers

Major Advances in Gas Burners







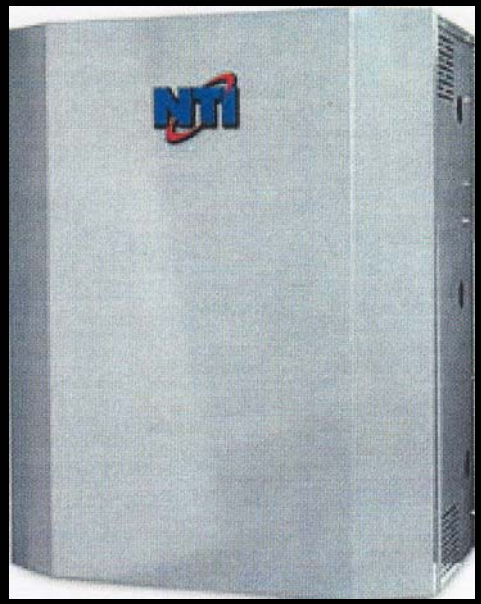


Newer Gas-Fired Boilers

Mid-Efficiency Gas Boiler

- Powered exhaust or power burner
- Electronic ignition
- No dilution air
- So-so resistance to depressurization
- Probs with side-wall vent -No plastic!
- If too efficient, or if long vertical or coaxial vent, risk of condensation/corrosion problems with furnace or vent
- Similar problems can occur on lower firing rates with modulating burners


MUNCHKIN

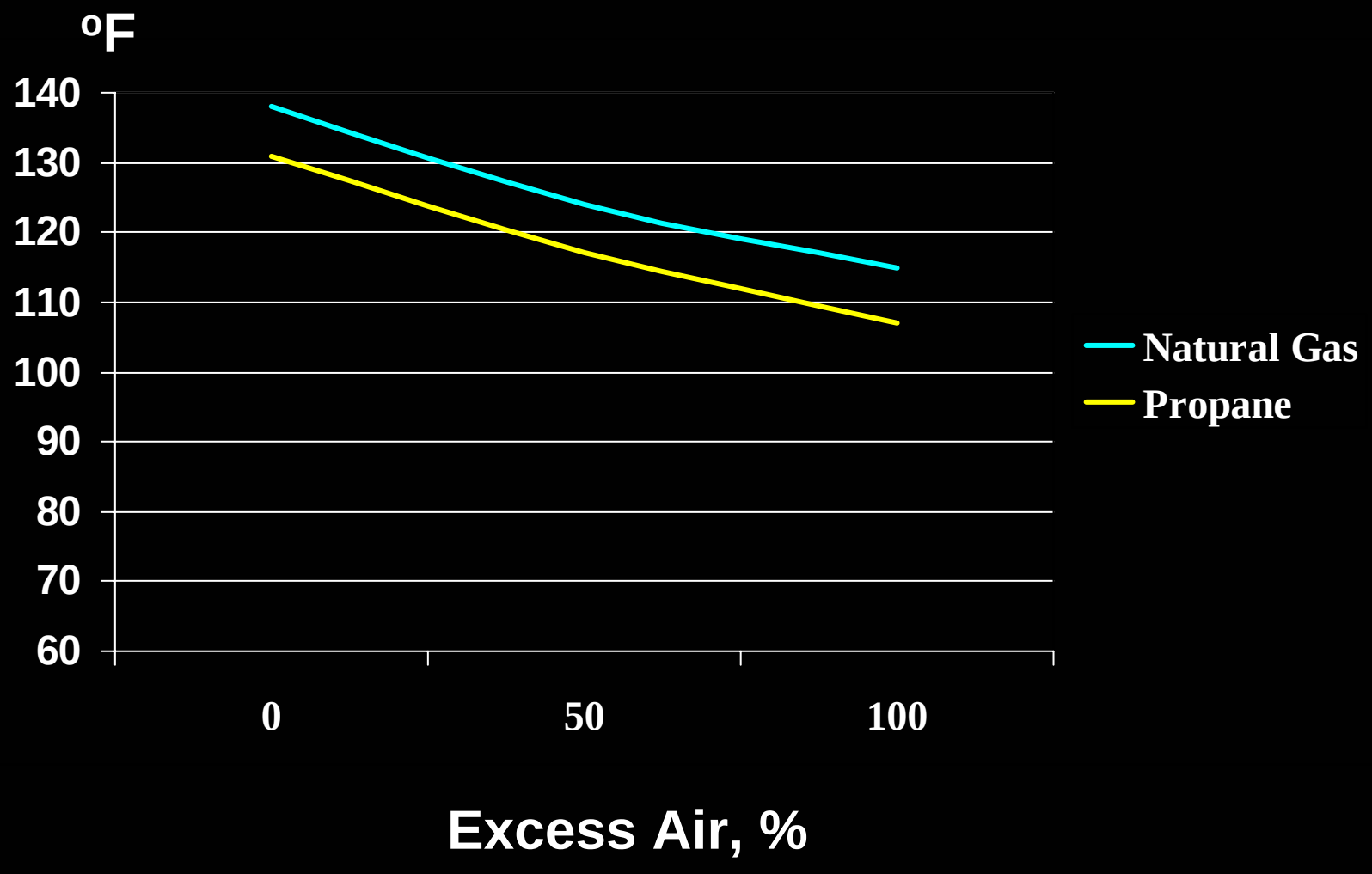

NTI

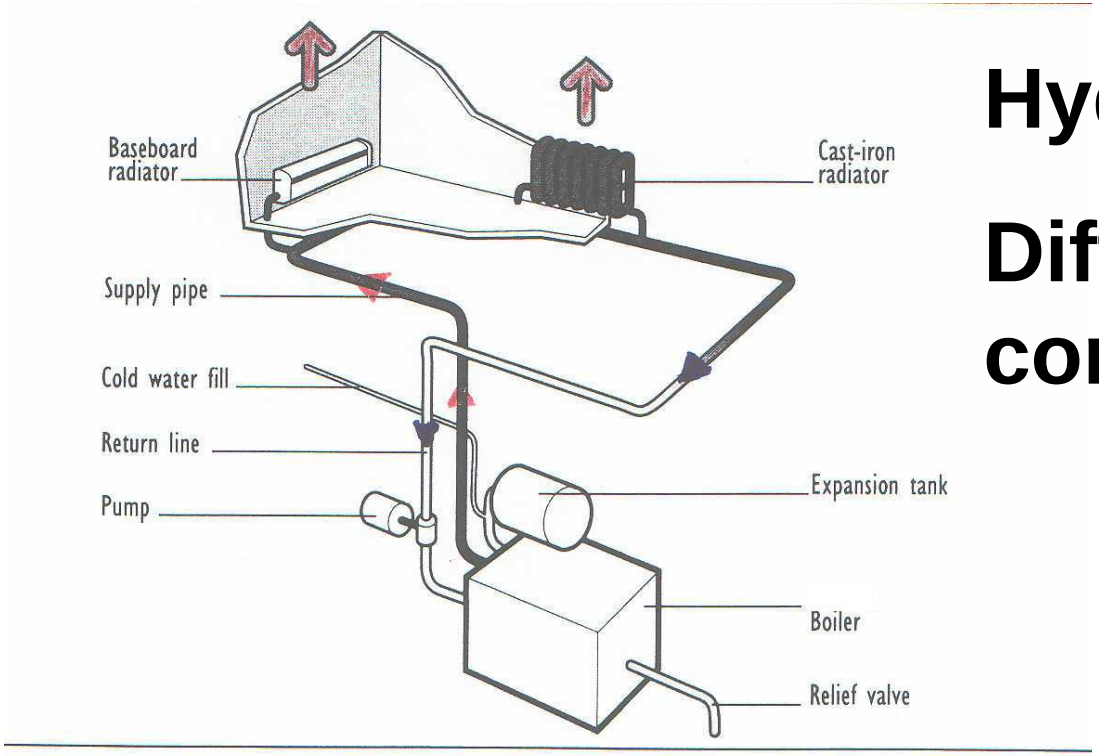
Condensing Gas Boiler

- Powered exhaust or power burner of different types
- Electronic ignition
- No dilution air
- High resistance to depressurization
- May have significant burner modulation
- Excellent side-wall vent - plastic!

Does a condensing boiler condense ?

Dewpoints for Gaseous Fuels





Hydronic:

Difficult to condense

Radiant Floors

Easy to condense

Condensing with Hydronic Heating Systems

- **Baseboard convectors or radiator: Return water temperature above dewpoint and condensing boilers rarely condense, outdoor reset can save energy**
- **Radiant floors: cool return can result in condensing truly occuring within system**
- **Fan coils: depending on fan coil sizing, circulating fan/pumps speeds, return may be below dewpoint, without discomfort**

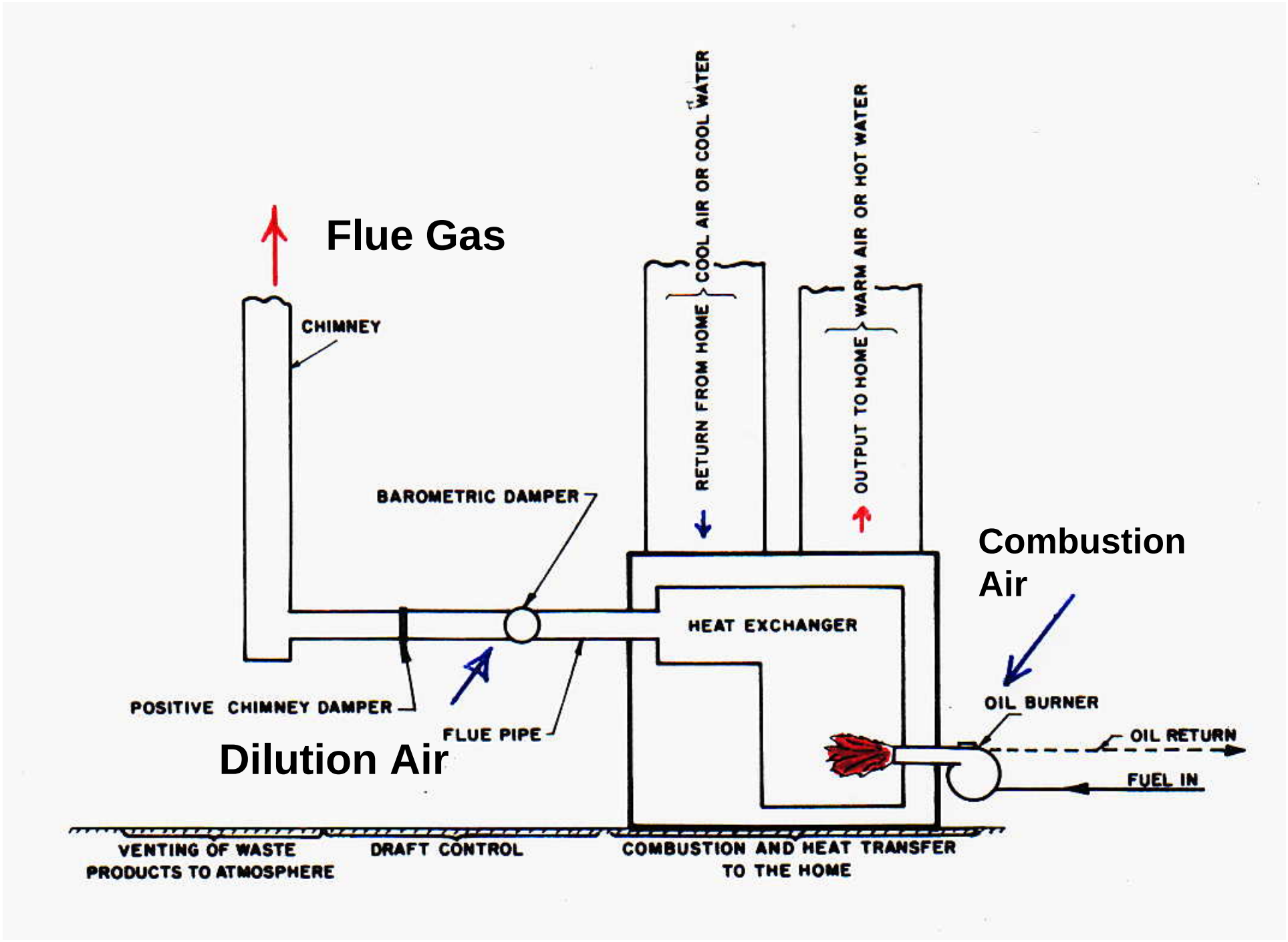
Gas-Fired Boilers

- **Mid-Efficiency in range of 82-86%, with power burner or powered exhaust**
- **Condensing may often in range of 84% or less, because return water is too hot to cause flue gas condensation**
- **Thus, if you have a hot water heating system, get a good mid-efficiency blr or find means to reduce return water temperature (radiant floor, outdoor reset, tap water, etc)**

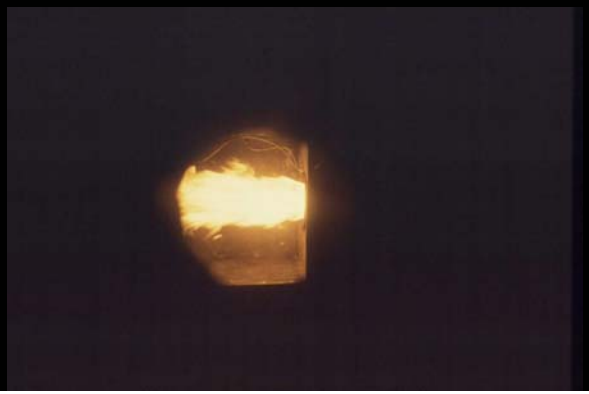
Natural Gas vs Propane

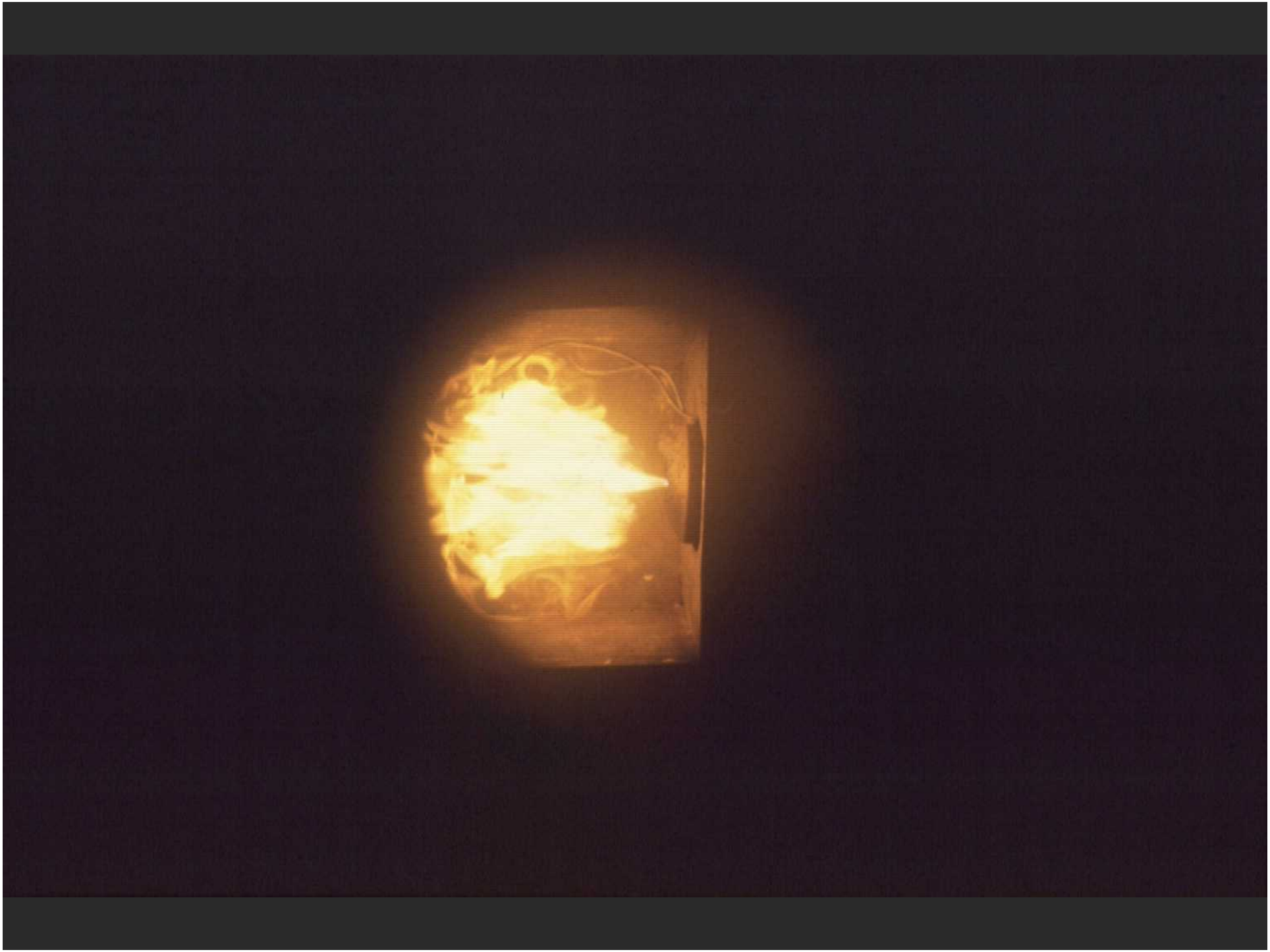
- Natural gas has a higher hydrogen content, so produces more water vapour
- Higher dewpoint with natural gas, so easier to condense than propane
- Propane condensing furnaces less efficient than NG
- Propane mid-efficiency furnaces or boilers more efficient than natural gas
- Propane boilers even more difficult to condense than natural gas

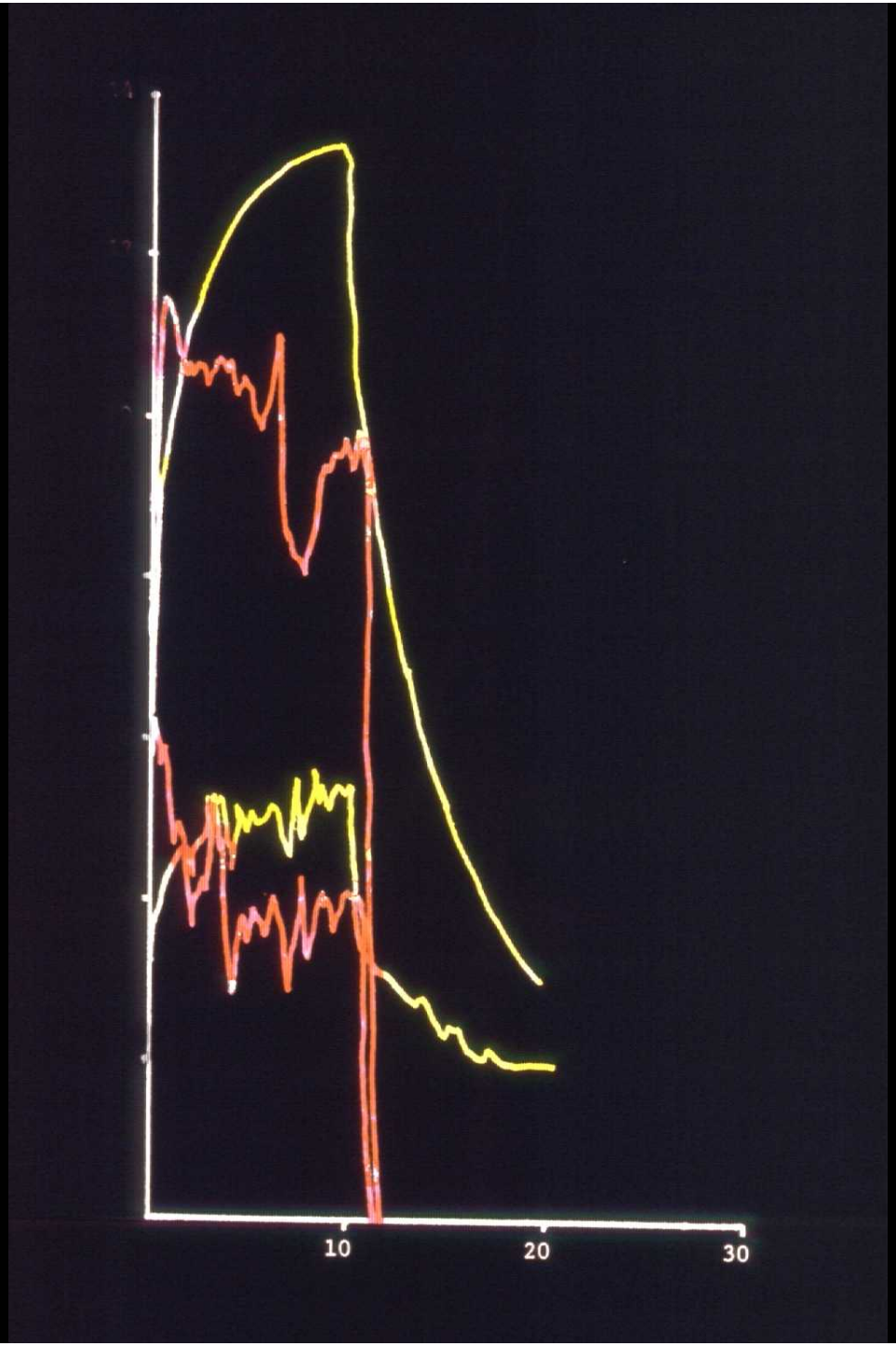
Oil-Fired Systems

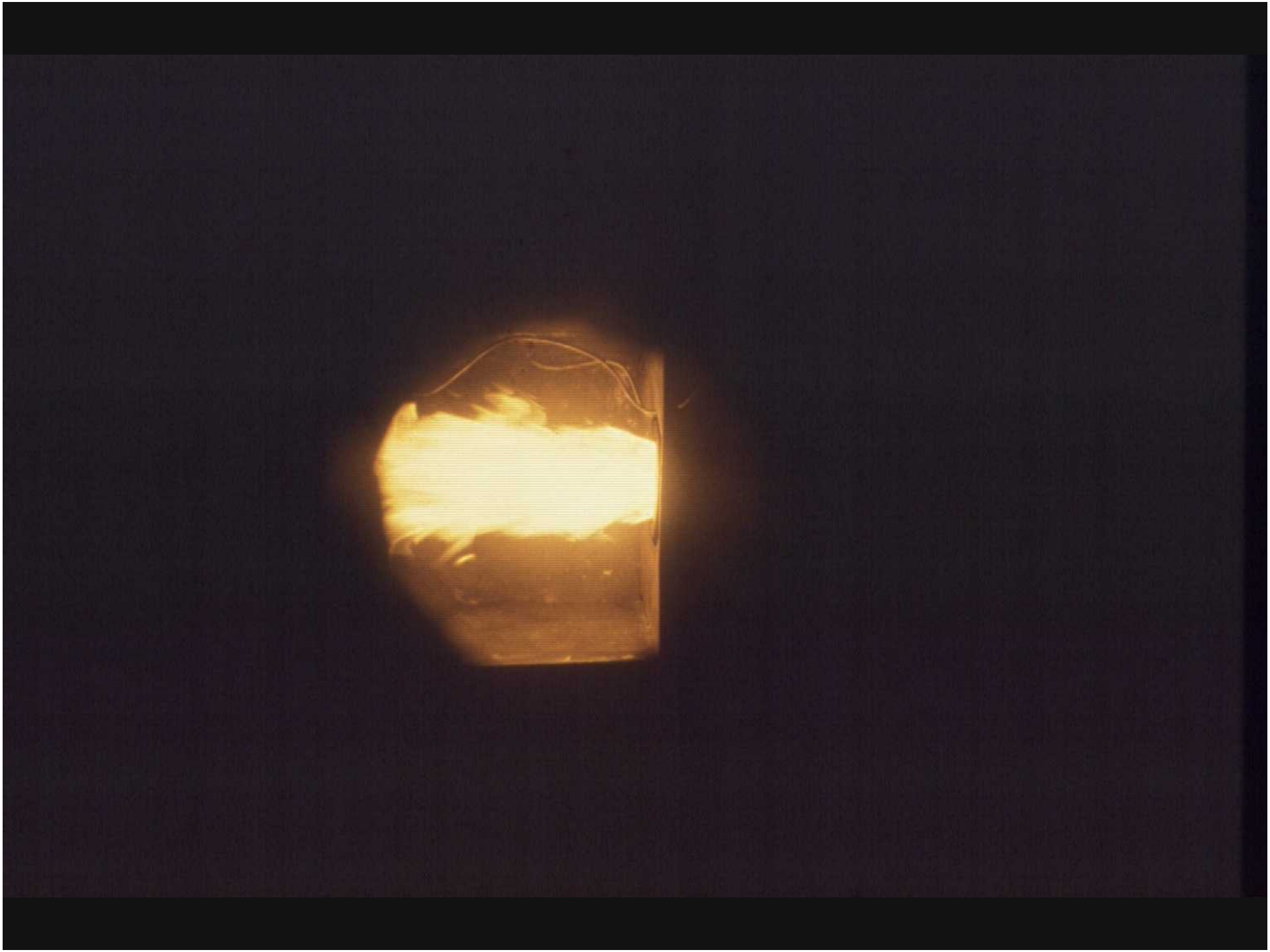

Flue Gas
CHIMNEY
BAROMETRIC DAMPER
RETURN FROM HOME
COOL AIR OR COOL WATER
OUTPUT TO HOME
WARM AIR OR HOT WATER
Combustion Air
HEAT EXCHANGER
POSITIVE CHIMNEY DAMPER
FLUE PIPE
Dilution Air
OIL BURNER
OIL RETURN
FUEL IN
VENTING OF WASTE PRODUCTS TO ATMOSPHERE
DRAFT CONTROL
COMBUSTION AND HEAT TRANSFER TO THE HOME

Most crucial element
to achieve
good performance
and high efficiency
is the
oil burner

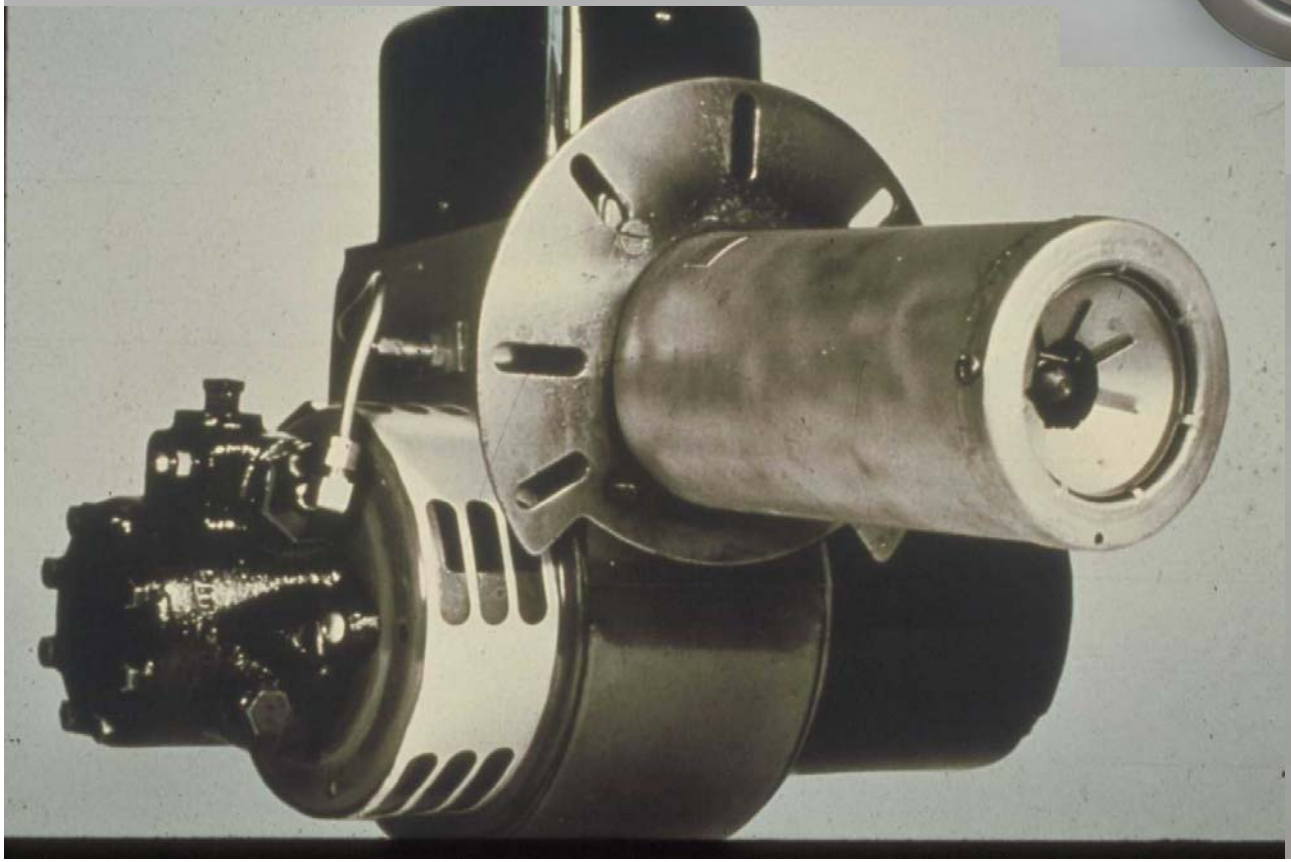





10
20
30



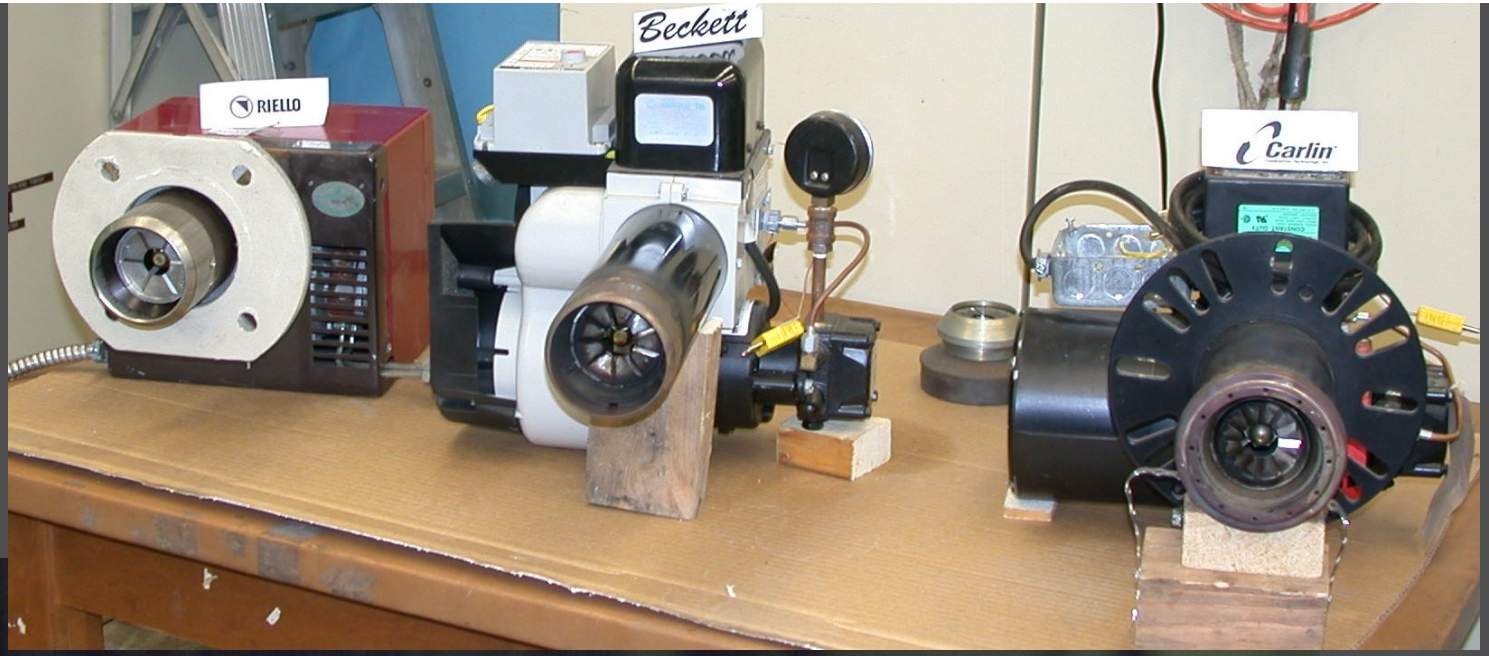

WESTCOTT® Flexible Stainless Steel Ruler




1
2
No. R590-12 WESTC

Retention Head Oil Burner

- Better fuel-air mixing (EA - 50%)
- Fair resistance to stack and house pressure fluctuations/depressurization
- Resists off-cycle flow loss
- Firing rate down to 70kBtu with good EA
- Efficiency should be 80-83%
- Should have delayed action solenoid valve to reduce soot/degradation

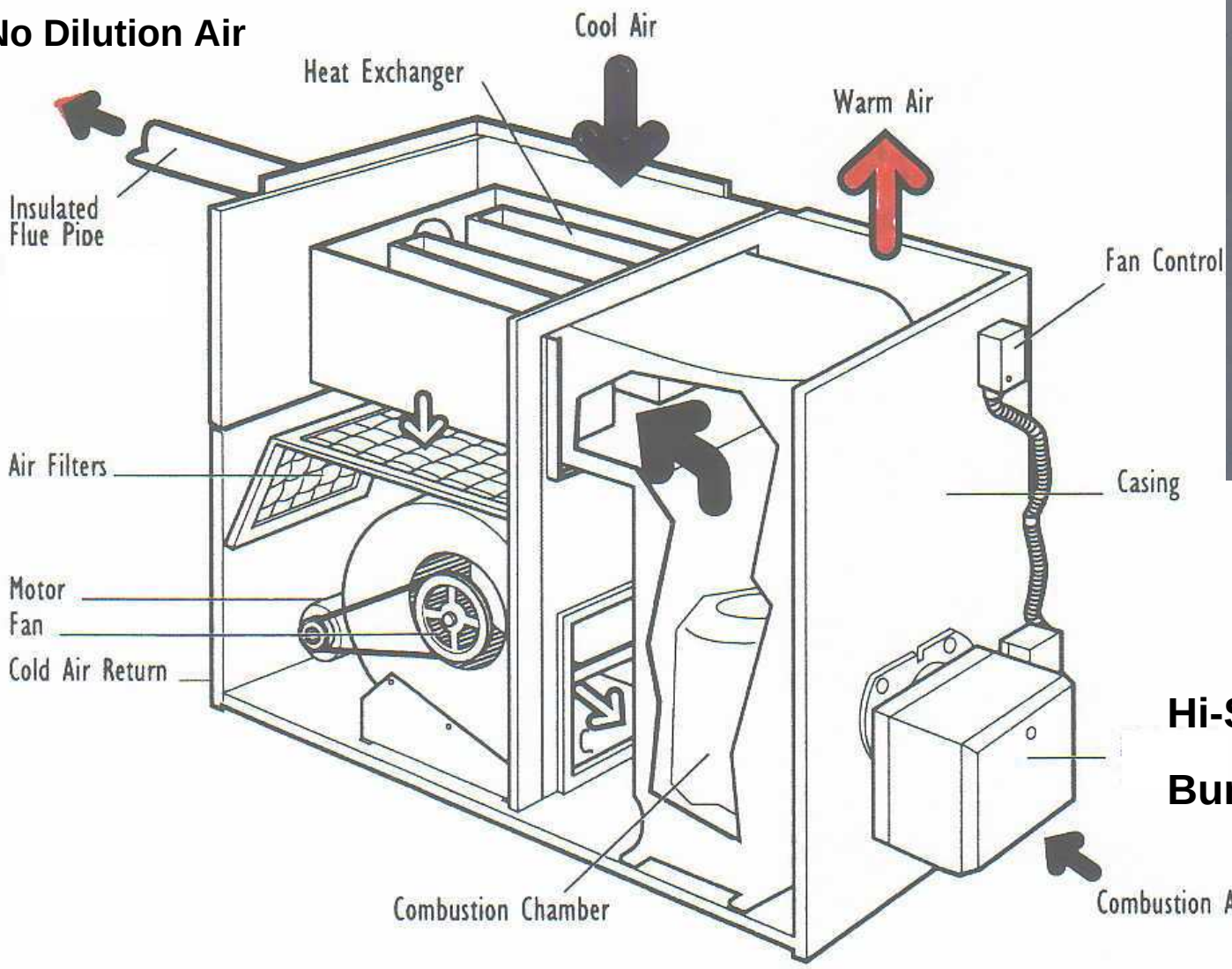


High Static Burners

High-Static Oil Burner

- Excellent fuel-air mixing (EA - 25%)
- Stable under stack pressure fluctuations
- High resistance to house depressurization
- Zero off-cycle flow loss (ex post-purge)
- Firing rate down to 70kBtu with good EA
- Efficiency should be 82-86%
- Minimal sooting/degradation
- Should be **burner of choice**
- Potential problem with low energy housing, with minimum firing rate ~ 70k Btu/h

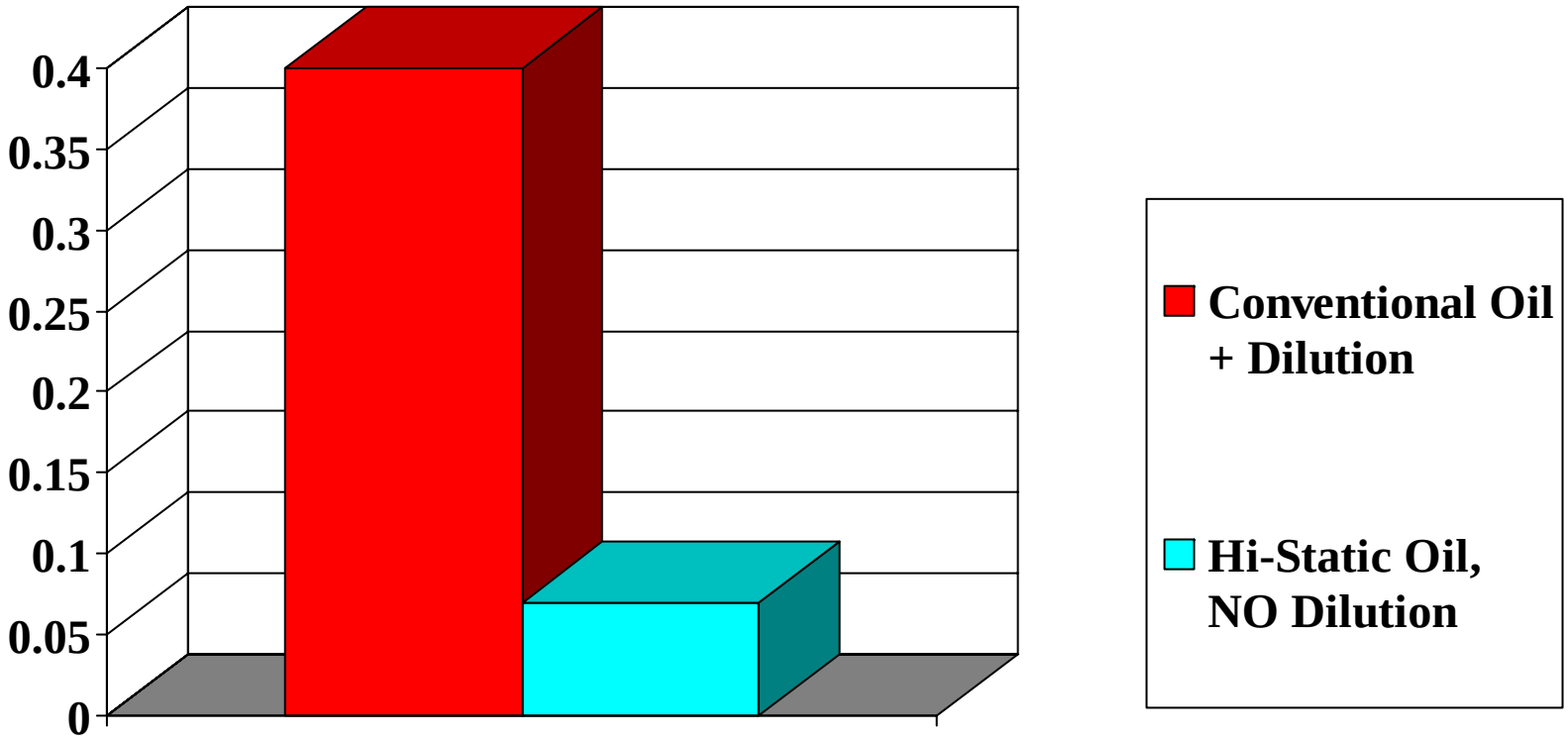
No Dilution Air



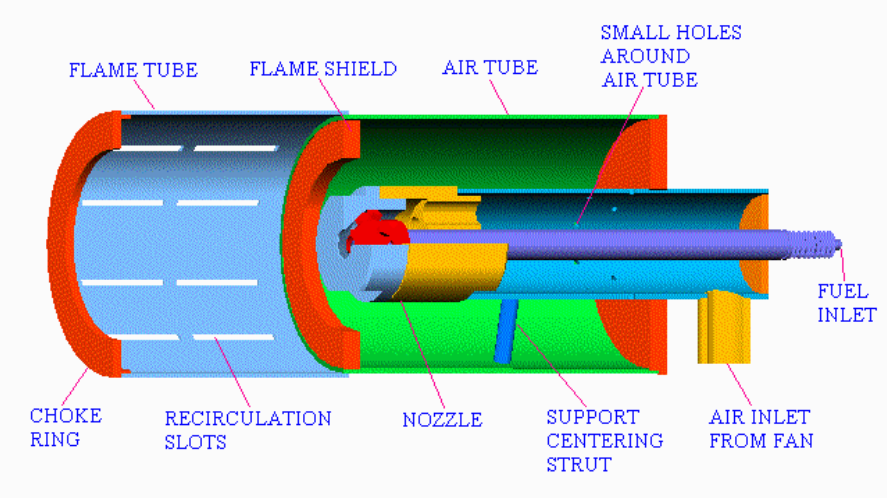
Hi-Static

Burner

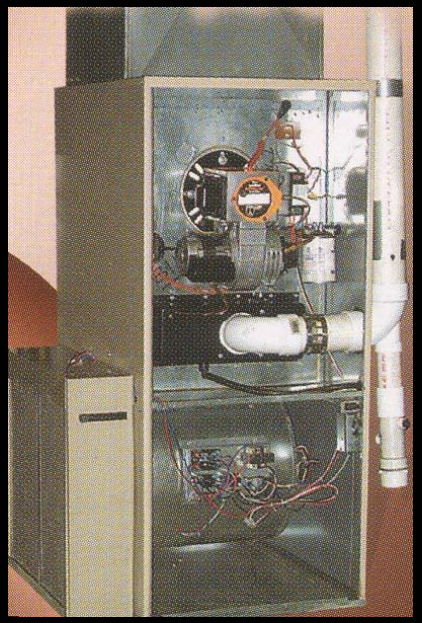
Air Requirements of Oil Furnaces



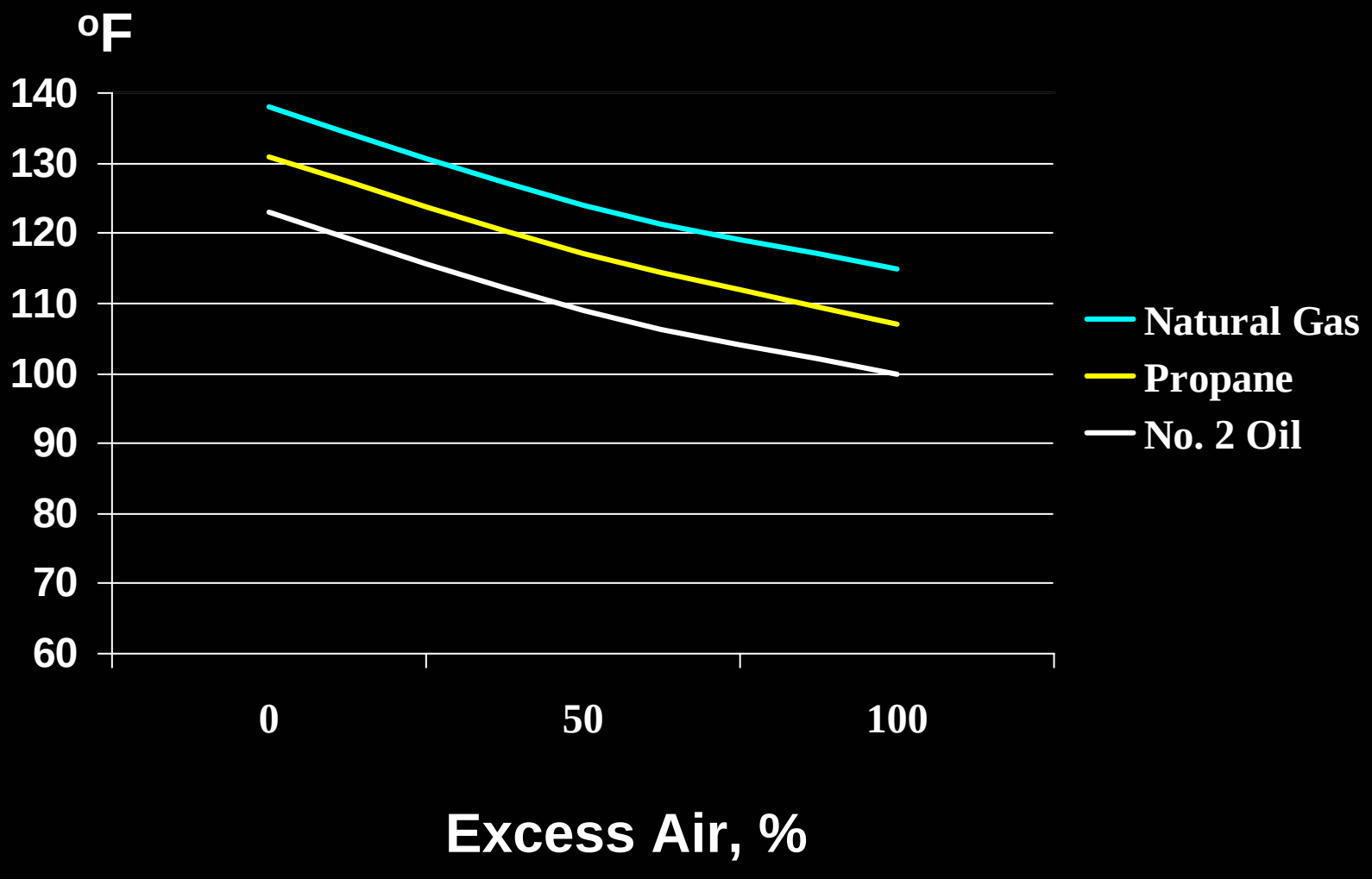
Advanced design low-firing rate clean oil burner



What about an Oil-Fired Condensing Furnace ?



Dewpoints for Different Fuels



Condensing Oil Furnace ?

- Much less energy tied up in latent heat than gas
- Dewpoint is low, so difficult to condense
- Need more condensing heat exchange surface (than gas) ($$$)
- Condensate is very acidic, due to S in oil
- Heat exchanger must be VERY hi grade ($$$)
- Sooting can result in “acid smut” which increases corrosive action

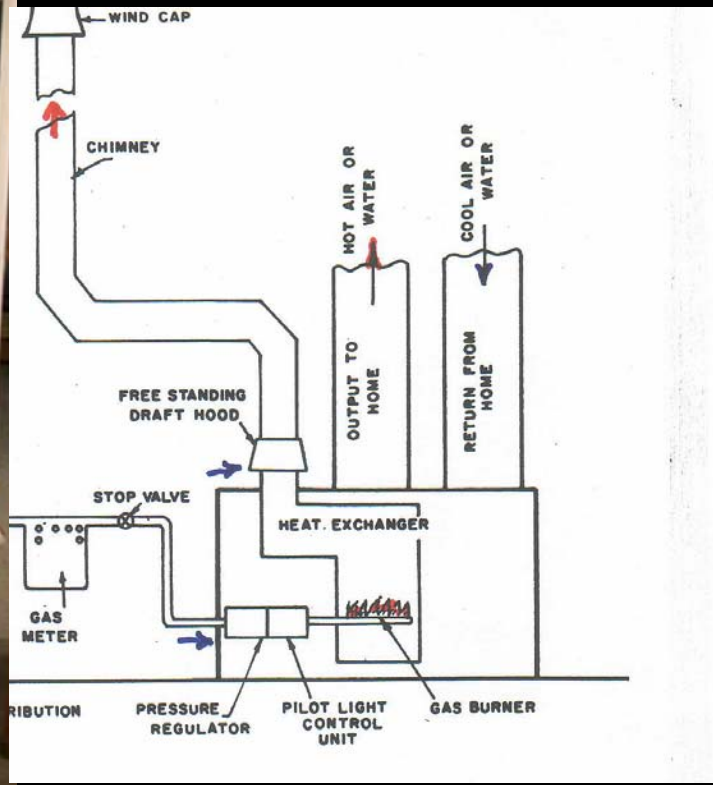
Do not

get a
condensing
oil furnace or boiler !

Mimimal efficiency gain,
at high cost &
probability of failure

Tap Water Heating:


RHEEM
RUUD
RENTAL APPLIANCE
DANGER


WIND CAP
CHIMNEY
HOT AIR OR WATER
COOL AIR OR WATER
OUTPUT TO HOME
RETURN FROM HOME
FREE STANDING DRAFT HOOD
STOP VALVE
HEAT. EXCHANGER
GAS METER
RIBUTION
PRESSURE REGULATOR
PILOT LIGHT CONTROL UNIT
GAS BURNER

Conventional Gas Water Heater

- Naturally aspirating
- Requires a chimney
- Continuous pilot (energy waste)
- Draft hood (extra heated air loss)
- Highly susceptible to spillage
- Large off-cycle loss
- Low seasonal efficiency (~ 55%)
- Should be an “antique” !

Most Gas-Fired Water Heaters are very inefficient !
(Most oil not much better!)

Power-Vented Water Heaters

- Pilot light or not
- Draft hood
- High on- and off-cycle losses
- High resistance to depressurization
- Minimal efficiency improvement

Sealed Combustion Water Heaters

- Pilot light or power vent
- May have min. off-cycle losses
- Potential for significant efficiency improvement

Alternative Gas-Fired Water heating Technologies

Instantaneous Water Heaters

Wide range of technologies and efficiencies


Next-Generation eKoComfort
High Efficiency Condensing
Space-Water-Ventilating System
with SDTC funding
IBC
PowerVent

Condensing Tank Water Heater

> 90% efficient, as mains water provides driving force for condensing

Using Efficiency Vermont's
"Fast Track Method"
a builder can get a break on
window glazing requirements with
an efficient heating system
(esp > 87% AFUE)
See Efficiency Vermont for more details

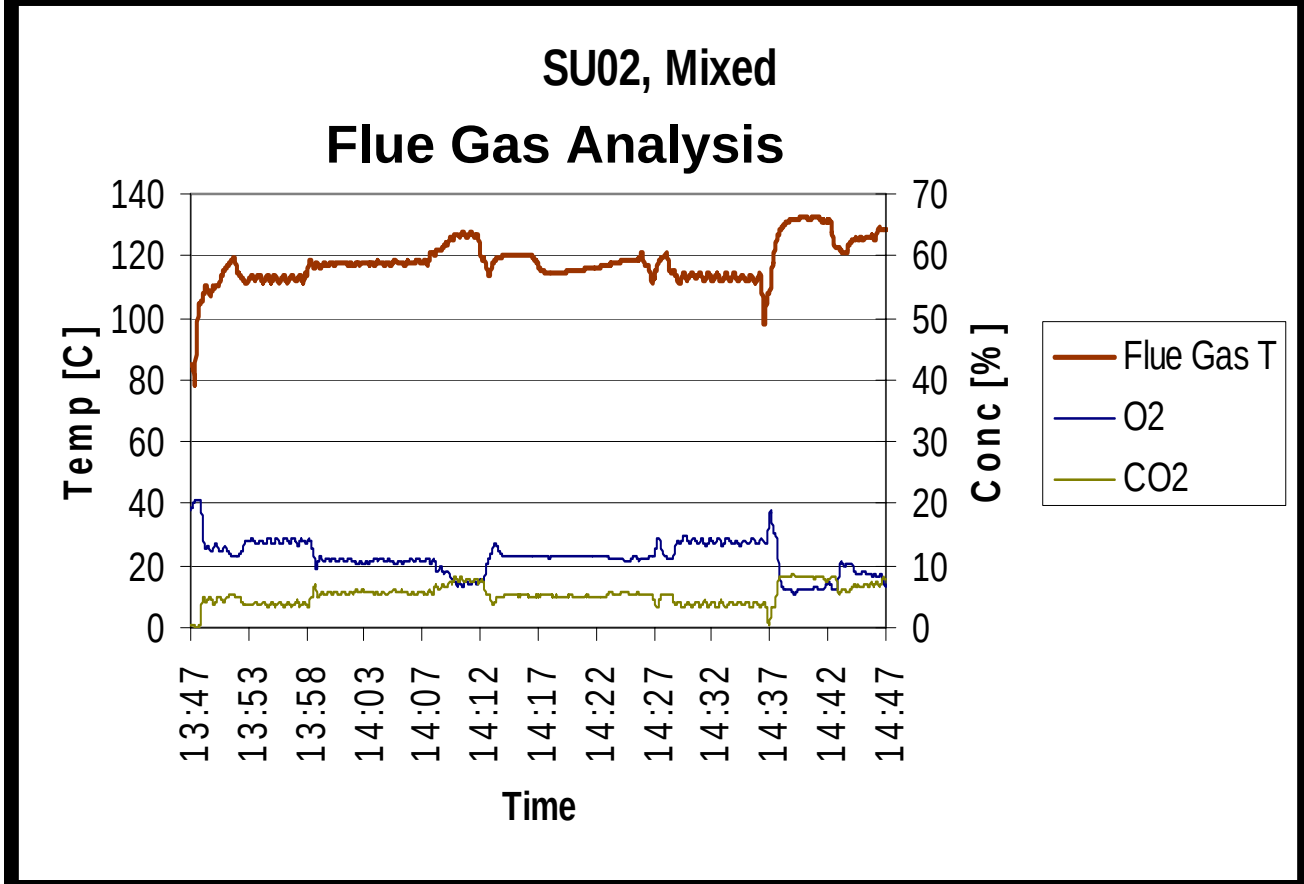
Combined Space-Water Heating Systems

In general, don't use a conventional water heater-based combo system

- Cheap, but very inefficient
- Spills combustion products
- Circumvents DOE Efficiency Std
- Without segregated water premature failure and contamination
- Difficulty in satisfying multiple demands

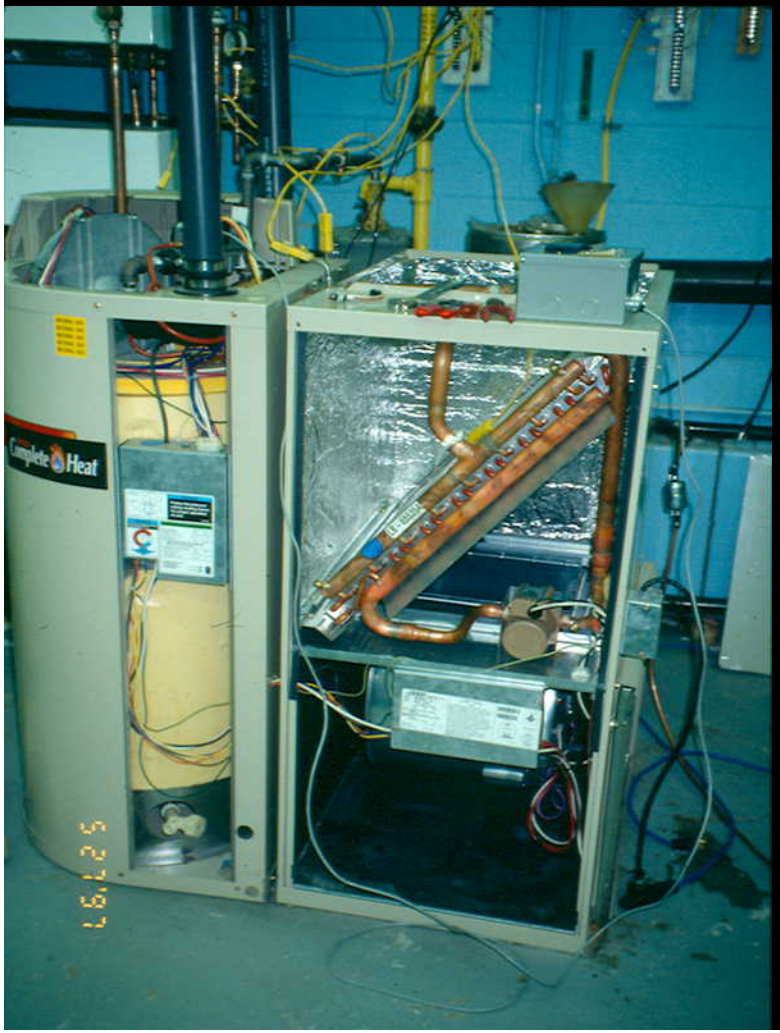

Tyvek
HomeWrap

Inefficient “Instantaneous” Segregated, Non-Condensing Boiler with Modulation

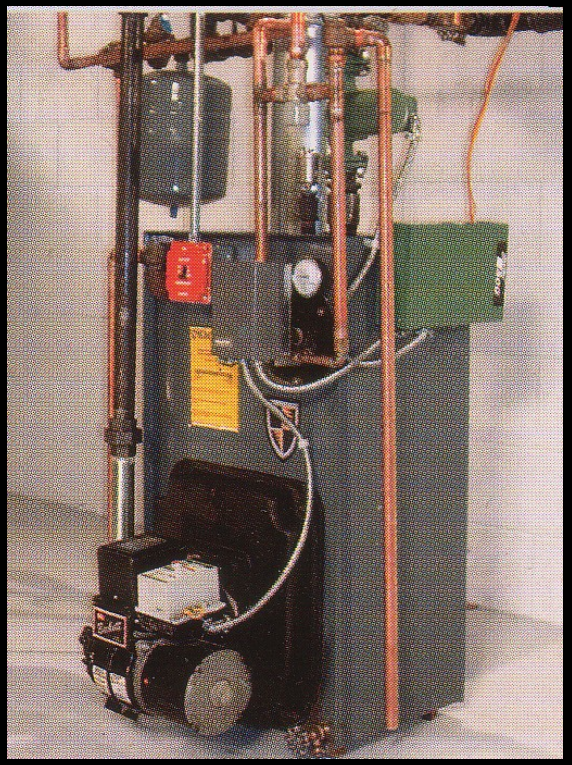


Efficient Low Mass Condensing Boilers with Segregated Tap water

Non-Segregated Condensing Tank-Based Space/Water "Boilers"



Tankless Coil Boiler



Oil-Fired Space/Water Heating Systems

In new and renovated housing:

- Space Heating falling
- Water Htg very inefficient
- Need for fresh air - Ventilation

eKOCOMFORT
(AIMS)
Advanced Integrated Mechanical Systems

A major Canadian initiative

to develop and market

high efficiency, integrated

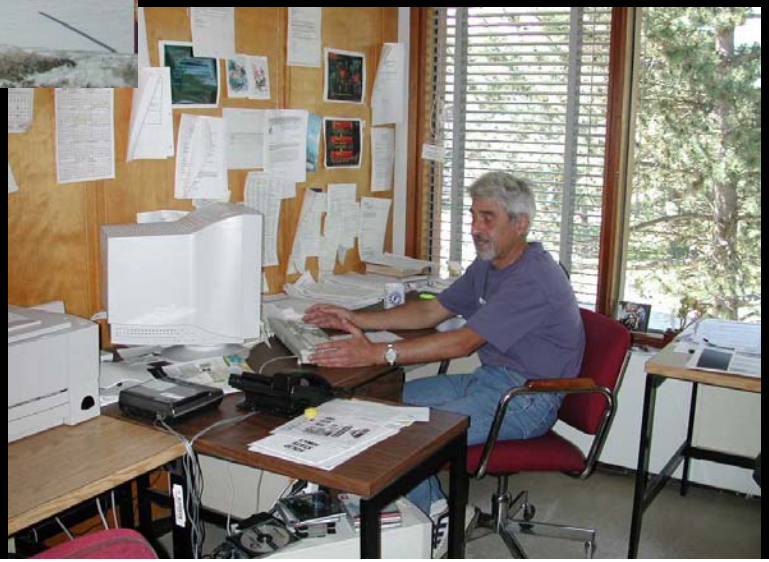
space-water-ventilating systems

“www.eKOCOMFORT.com”

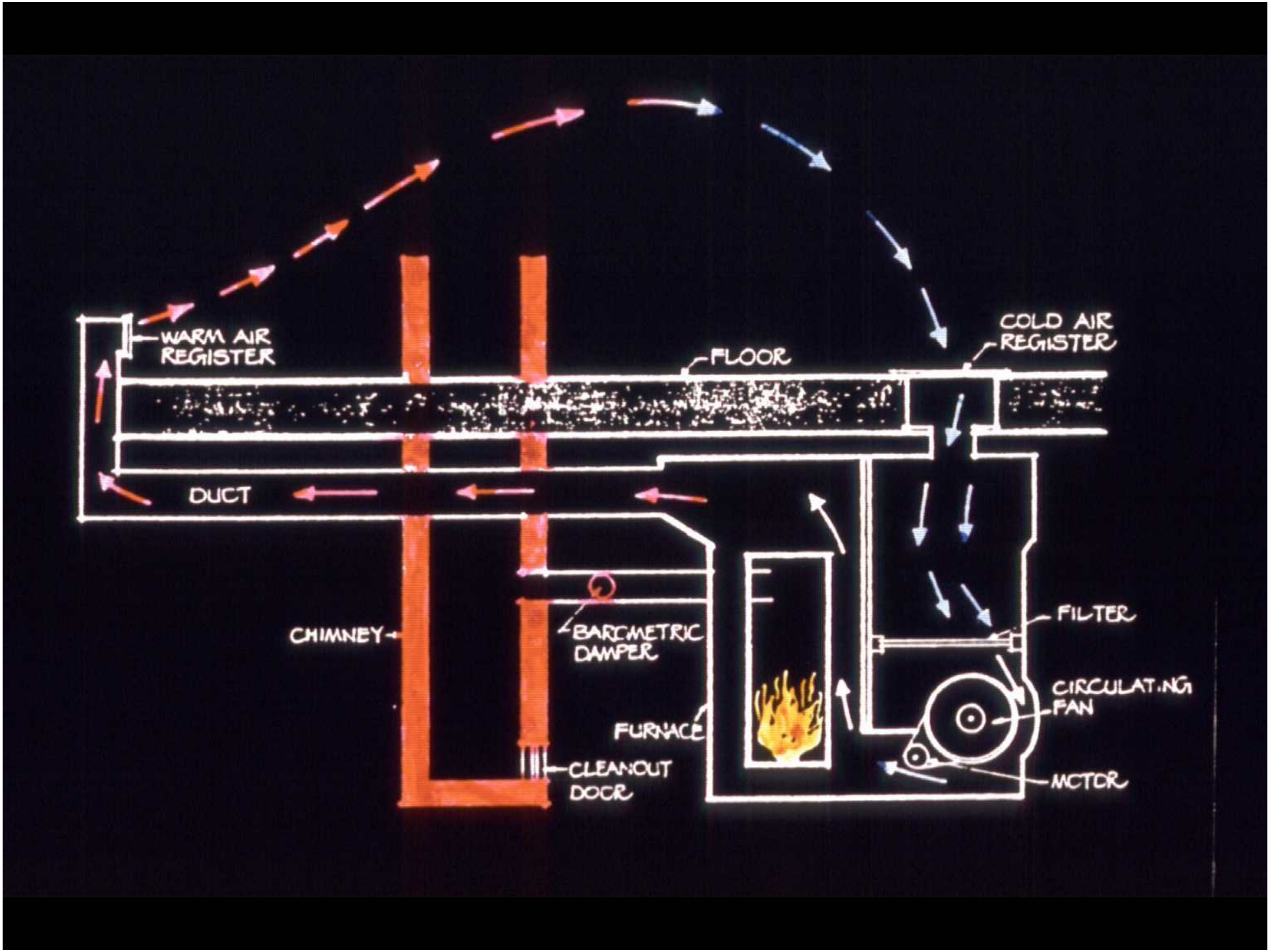
eKOCOMFORT

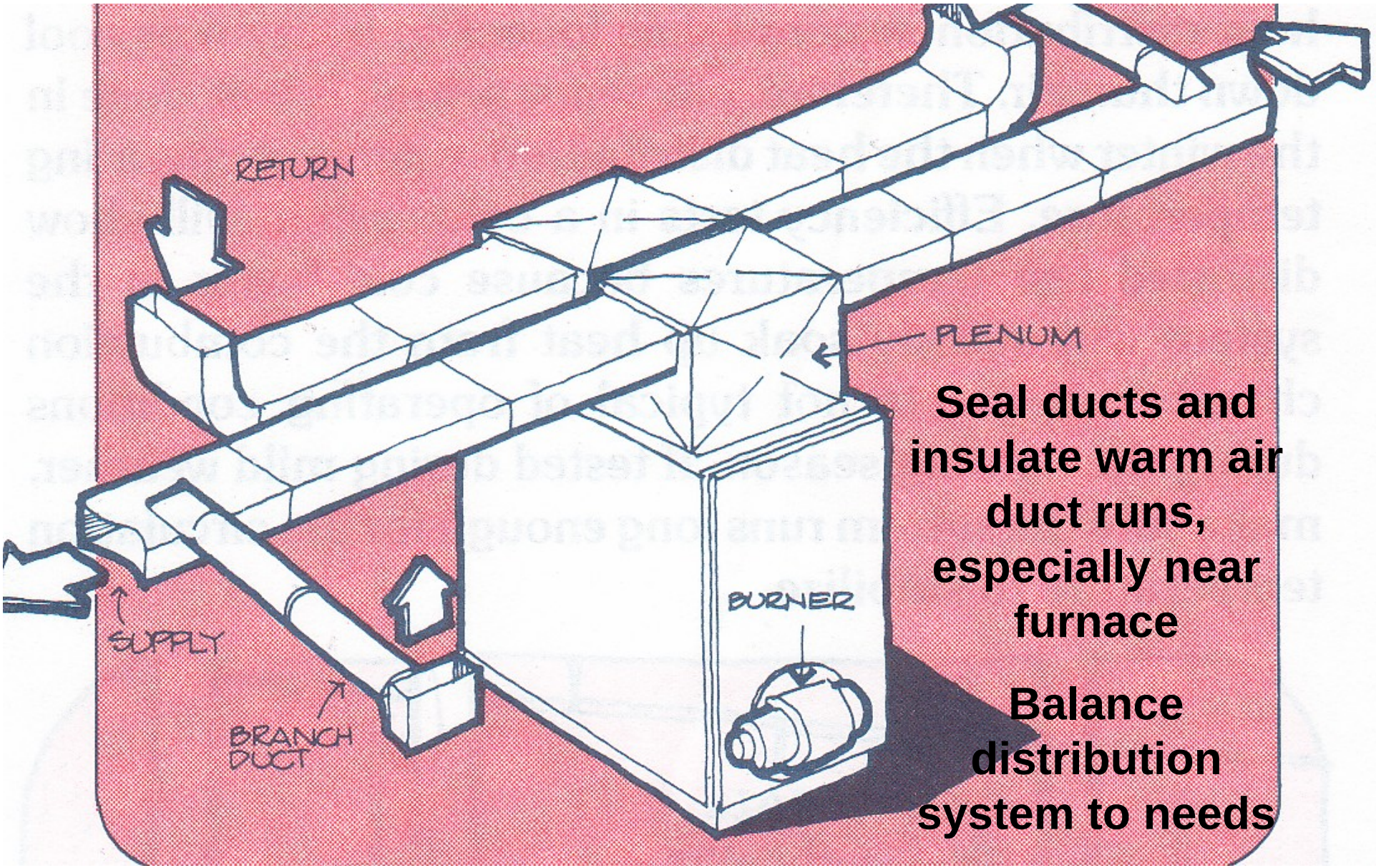
Low Mass Condensing Boiler at ACT

eKocomfot
High Mass Boiler
at CCHT



Other Prototypes at ACT


WARM AIR REGISTER
FLOOR
COLD AIR REGISTER
DUCT
CHIMNEY
BAROMETRIC DAMPER
FILTER
CIRCULATING FAN
FURNACE
CLEANOUT DOOR
MOTOR



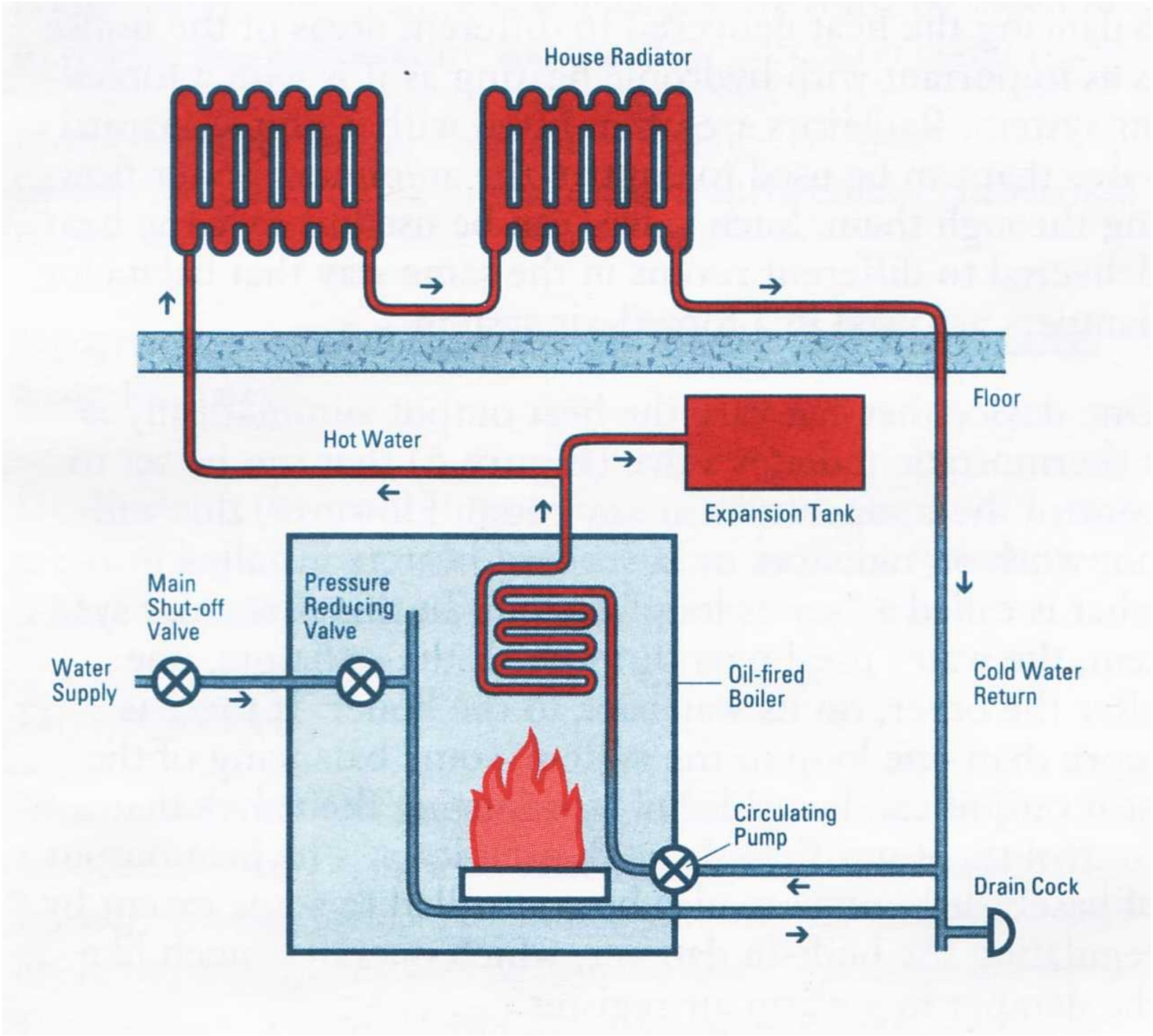
Seal ducts and insulate warm air duct runs, especially near furnace

Balance distribution system to needs


Small Diameter
High Velocity
Ducts
'93 7 28

Warm Air Systems

- Proper duct design
- Ducts inside house envelope
- Ducts well-sealed (mastic)
- Adequate returns (ALL bedrooms)
- Insulate basement duct runs
- Facilitates condensing op (gas only)
- Rapid thermal response (setback)
- Allows whole-house ventilation
- Consider small dia, hi-vel ducts


House Radiator
Floor
Hot Water
Expansion Tank
Main
Shut-off
Valve
Pressure
Reducing
Valve
Water
Supply
Oil-fired
Boiler
Cold Water
Return
Circulating
Pump
Drain Cock

Hydronic Systems

- High mass, less temperature fluctuations
- Many find greater comfort
- Not subject to “heat” leakage
- Pipes should be insulated
- Less suitable for setback savings
- Difficult to have condensing (gas)
- Can be adjusted for outside temperature (outdoor reset) for some boilers
- Require additional means for ventilation

Radiant Floors

- May yield comfort at lower room temp
- Well suited to tile floors (bath, kitchen, …
- Couples well with condensing generator (helps low temp on return) (hydronic or fan coil)
- Don’t use with insulating materials (thick rugs)
- Can be costly (installation and repair)

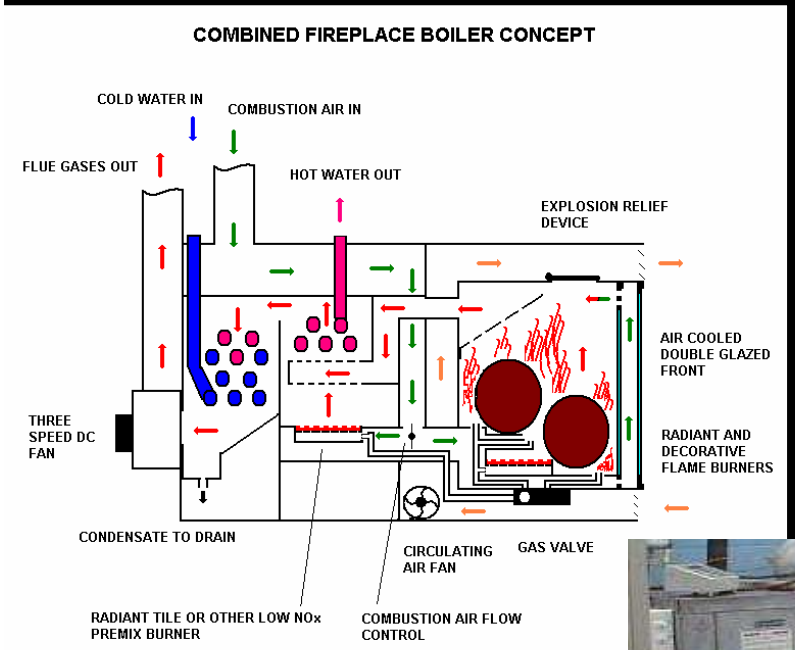
A hot-water based system that combines warm air from a fan coil with radiant floors and segregated tap water offers the best way to ensure high efficiency condensing operation

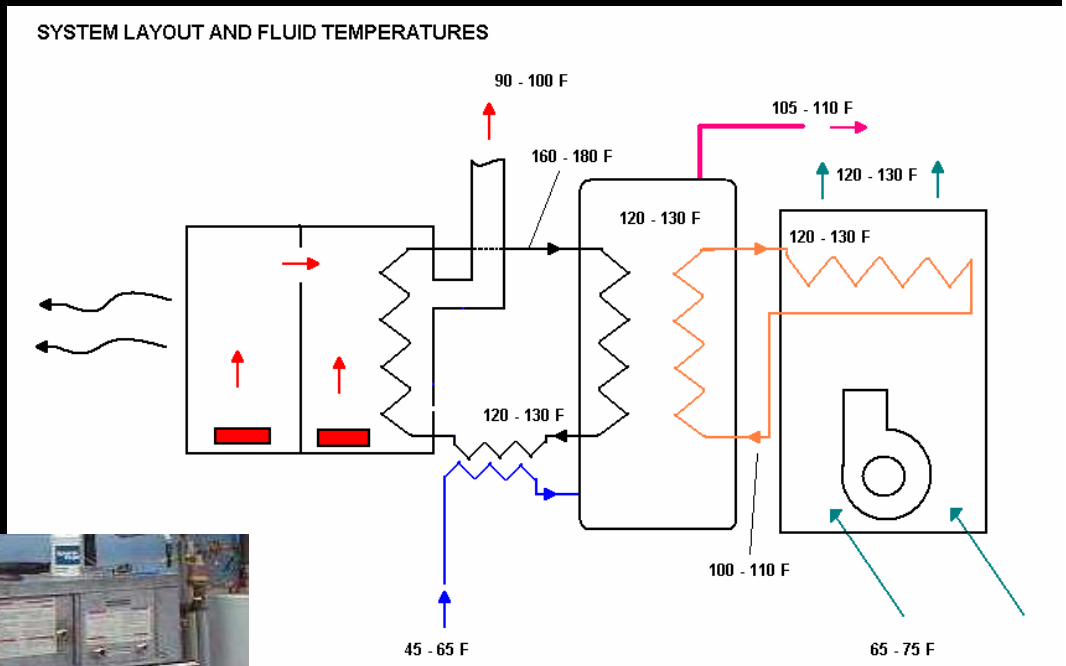
What’s coming in the future ?

Advanced Technologies
to supply
both Heat and Electricity

Next Generation Integ. System:

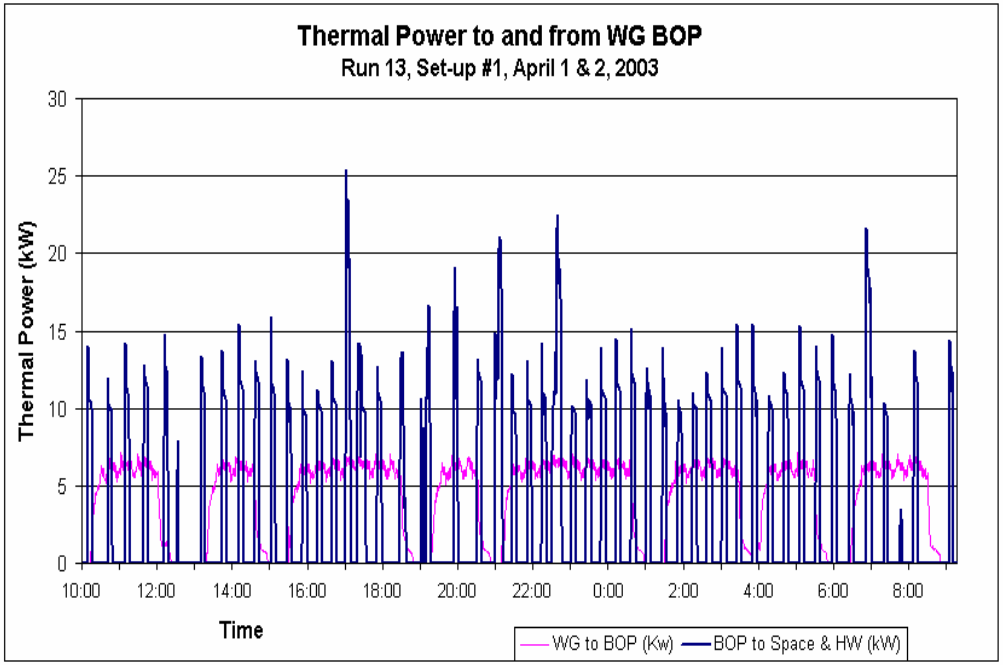
Condensing Fireplace-Based

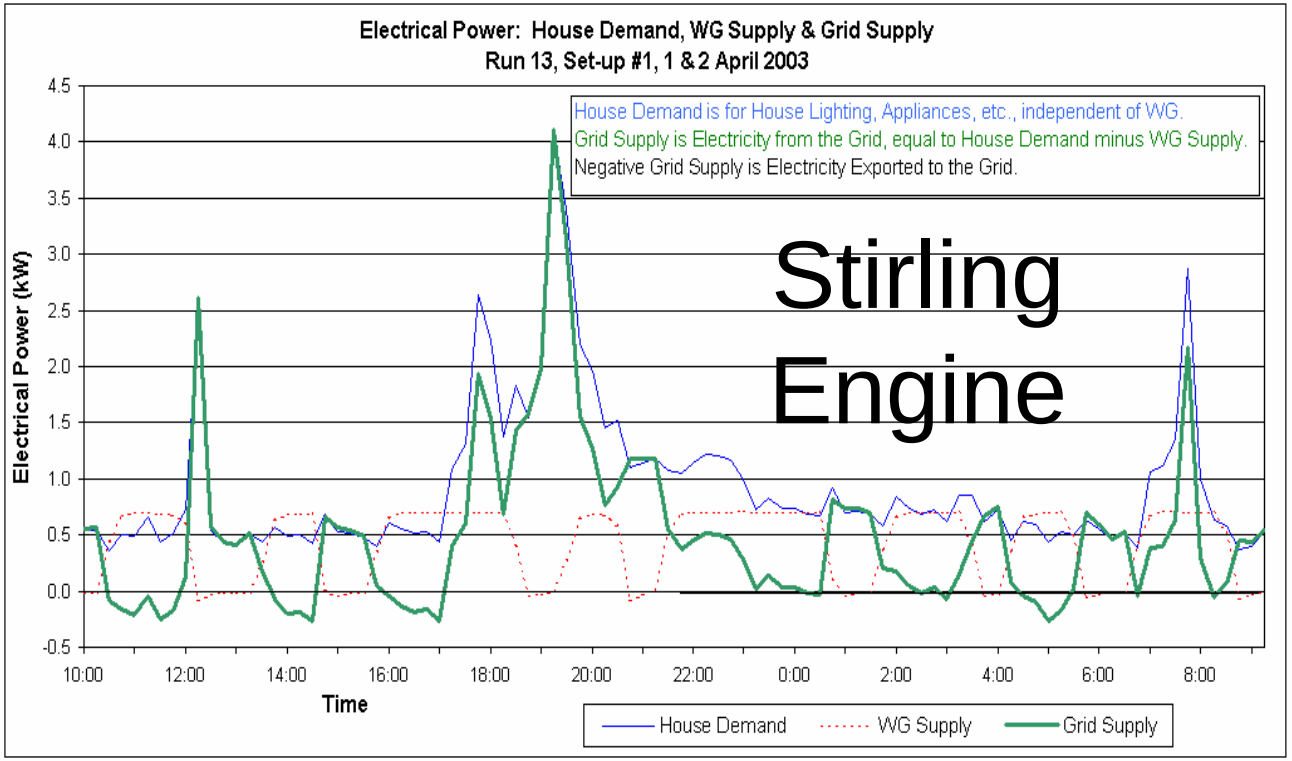




Conceptual 2nd Generation Design

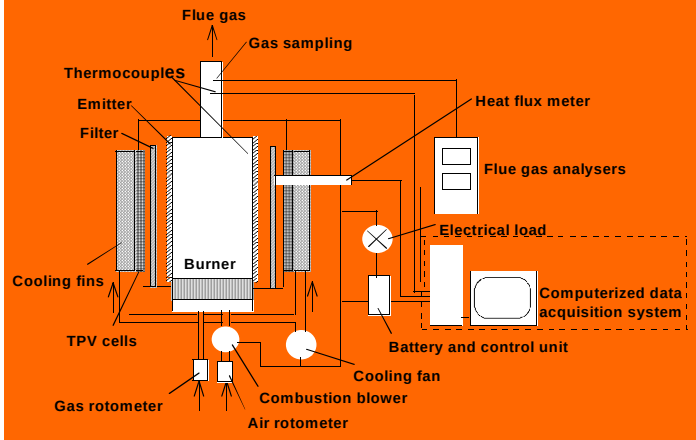
Paper being presented today at GasTech II





Stirling Engine

Thermophotovoltaics for heat and electricity



Fuel Cell Integrated System (MC or SO)

Integrated Gas Lighting System

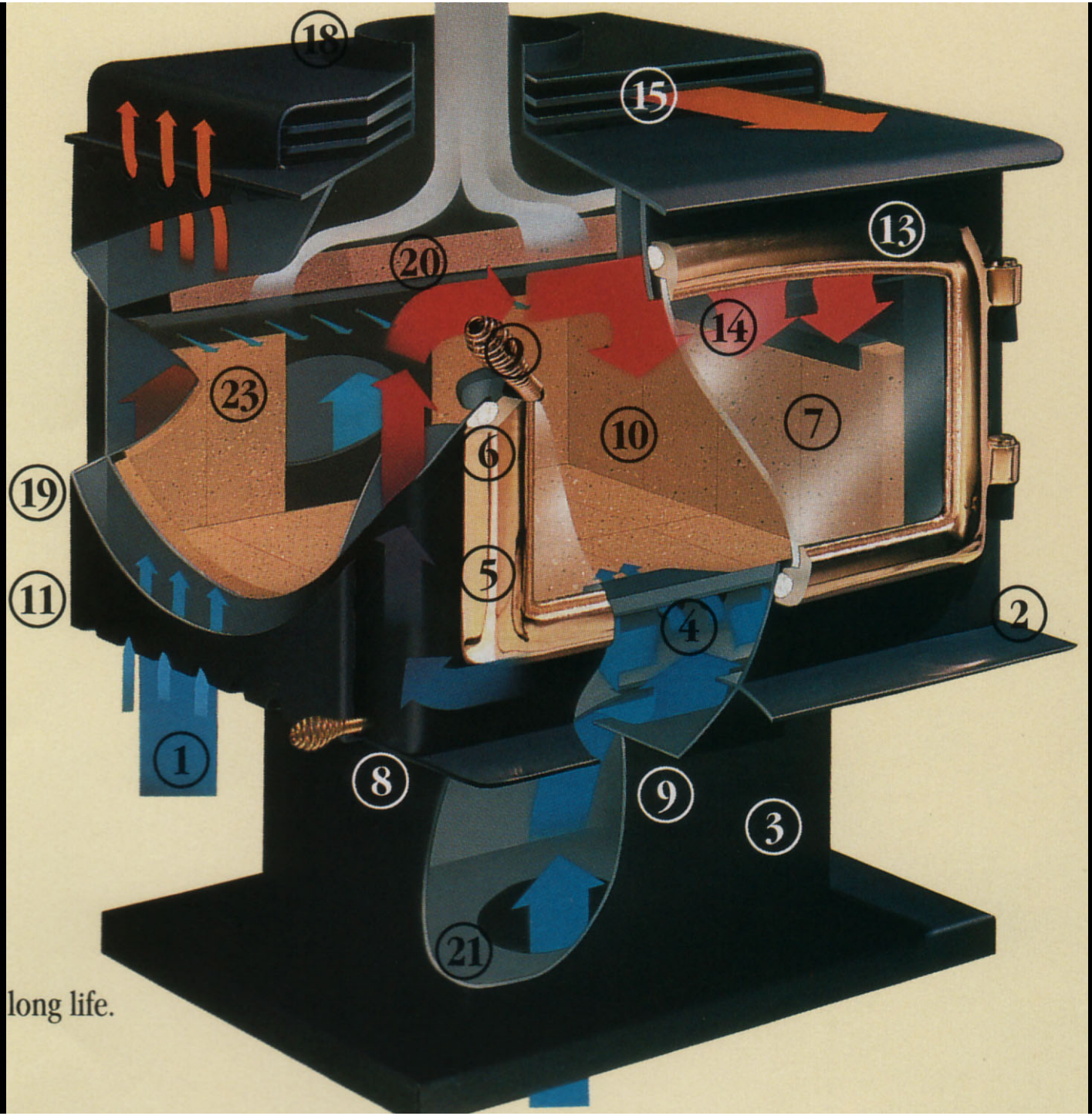
- Elim need for electricity by generating light directly by burning natural gas in optimized visually-radiant burner as central source in building
- Distribute the light throughout the building by means of light pipes
- Capture extra heat in integrated system, for space/water heating

Heating with Biomass

The airtight woodstoves of the 1970's and 80's were major sources of air pollution under most conditions !

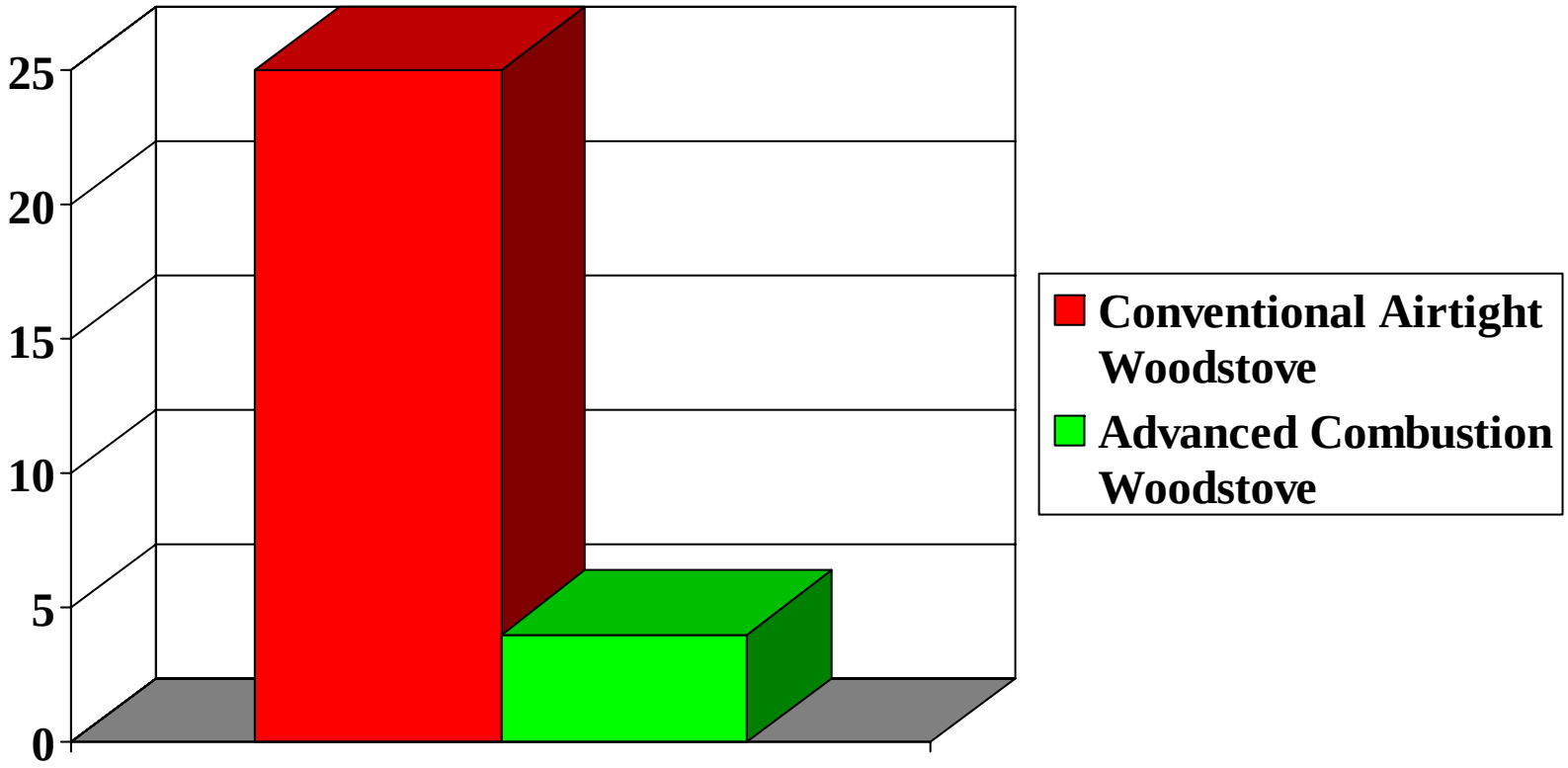
How Wood Burns

Emission regulations forced development of Advanced Combustion Designs

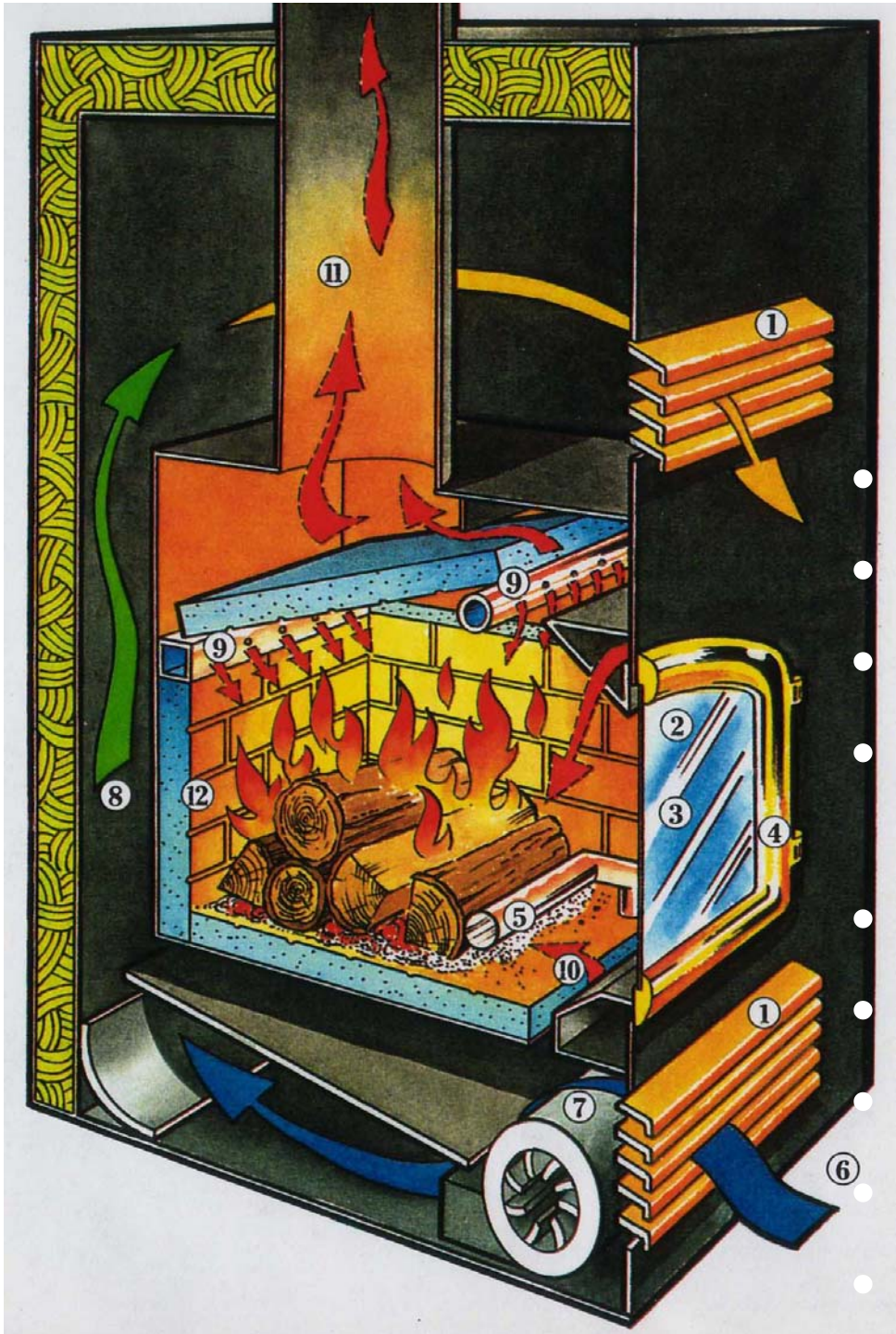


long life.

Woodstove Emissions



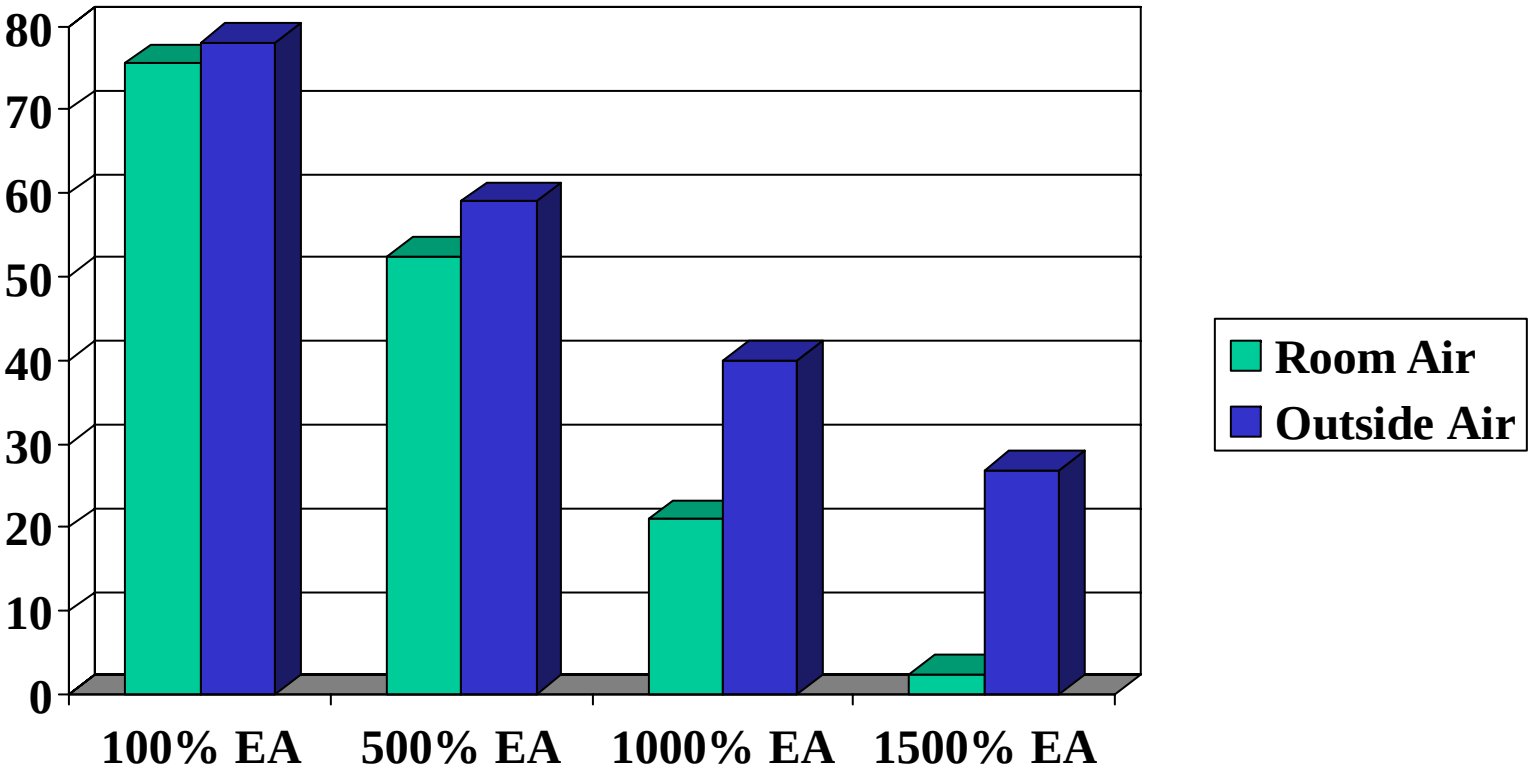
Advanced Combustion Efficient Clean-Burning Woodstoves



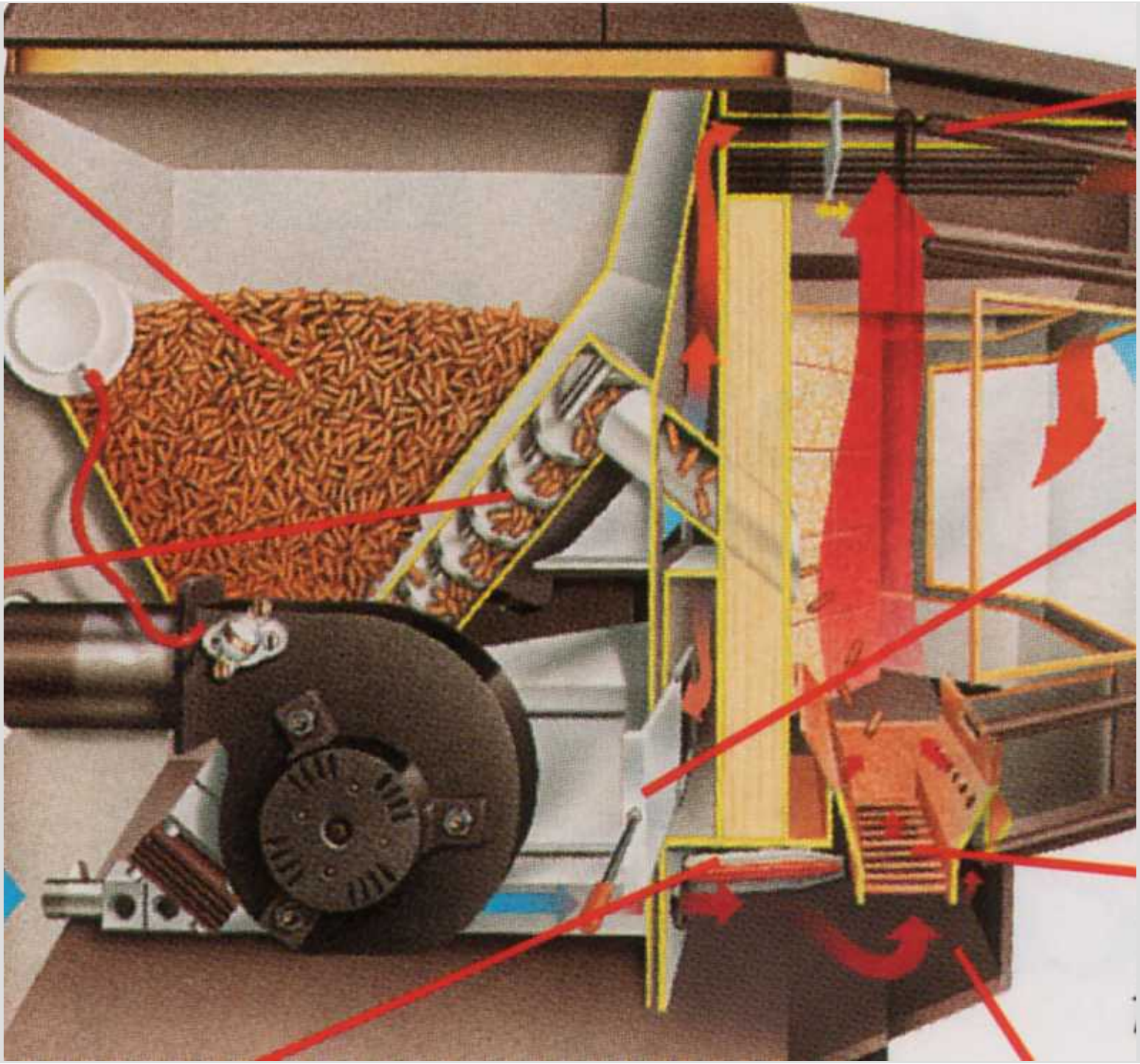
Characteristics of Efficient, Safe, Advanced Wood Fireplace

- Tested to EPA 1990
- Preheated prim & sec air
- Ceramic glass door
- Insulated comb. chamber & baffle
- Air wash for door
- Good circulating fan
- Insulated outer casing
- Sealed combustion
- Extremely attractive fire

Effect of Excess Air on Maximum Fireplace Efficiency

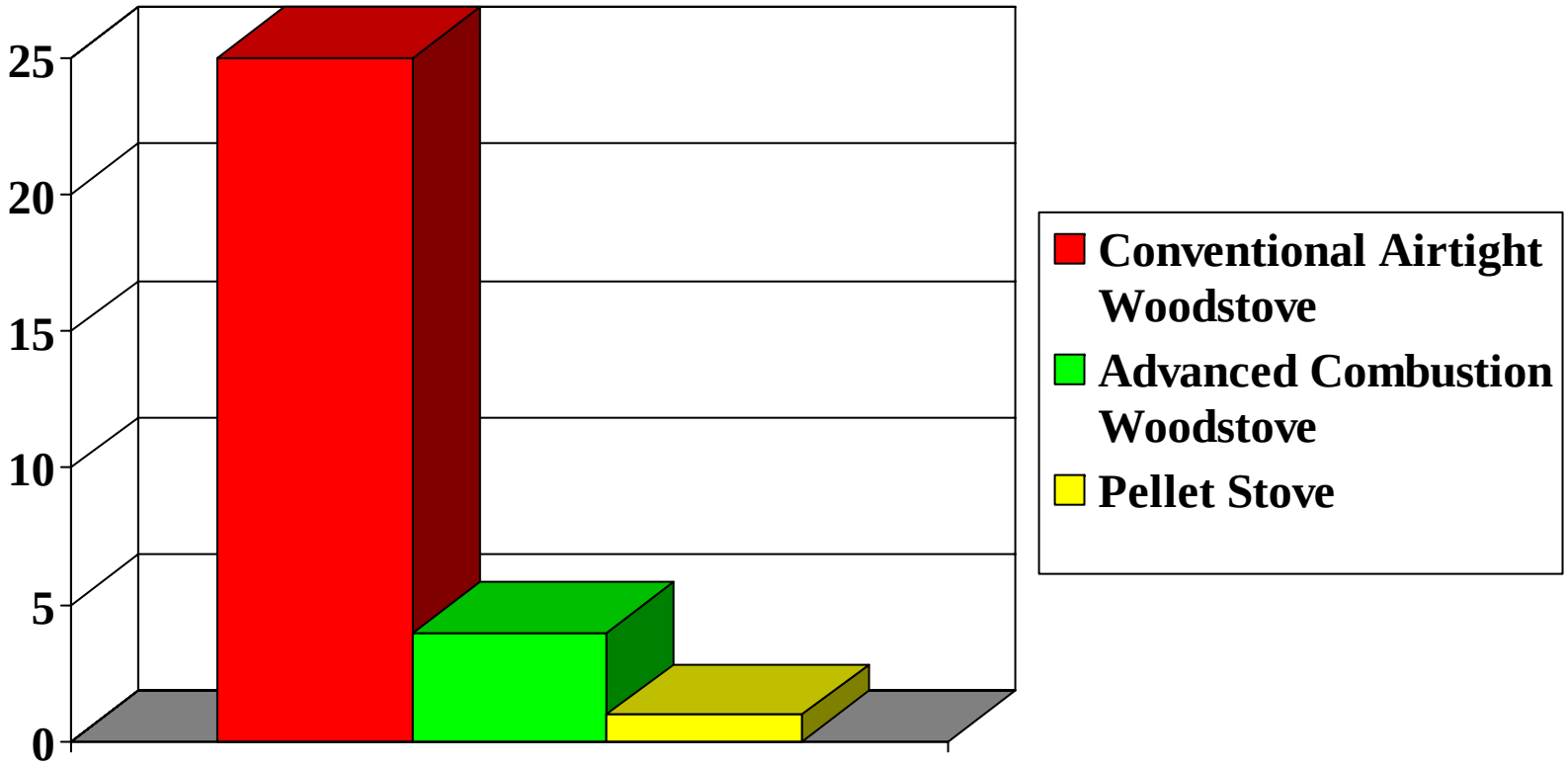


High Efficiency Biomass Pellet Stove




CE

Wood & Pellet Stove Emissions



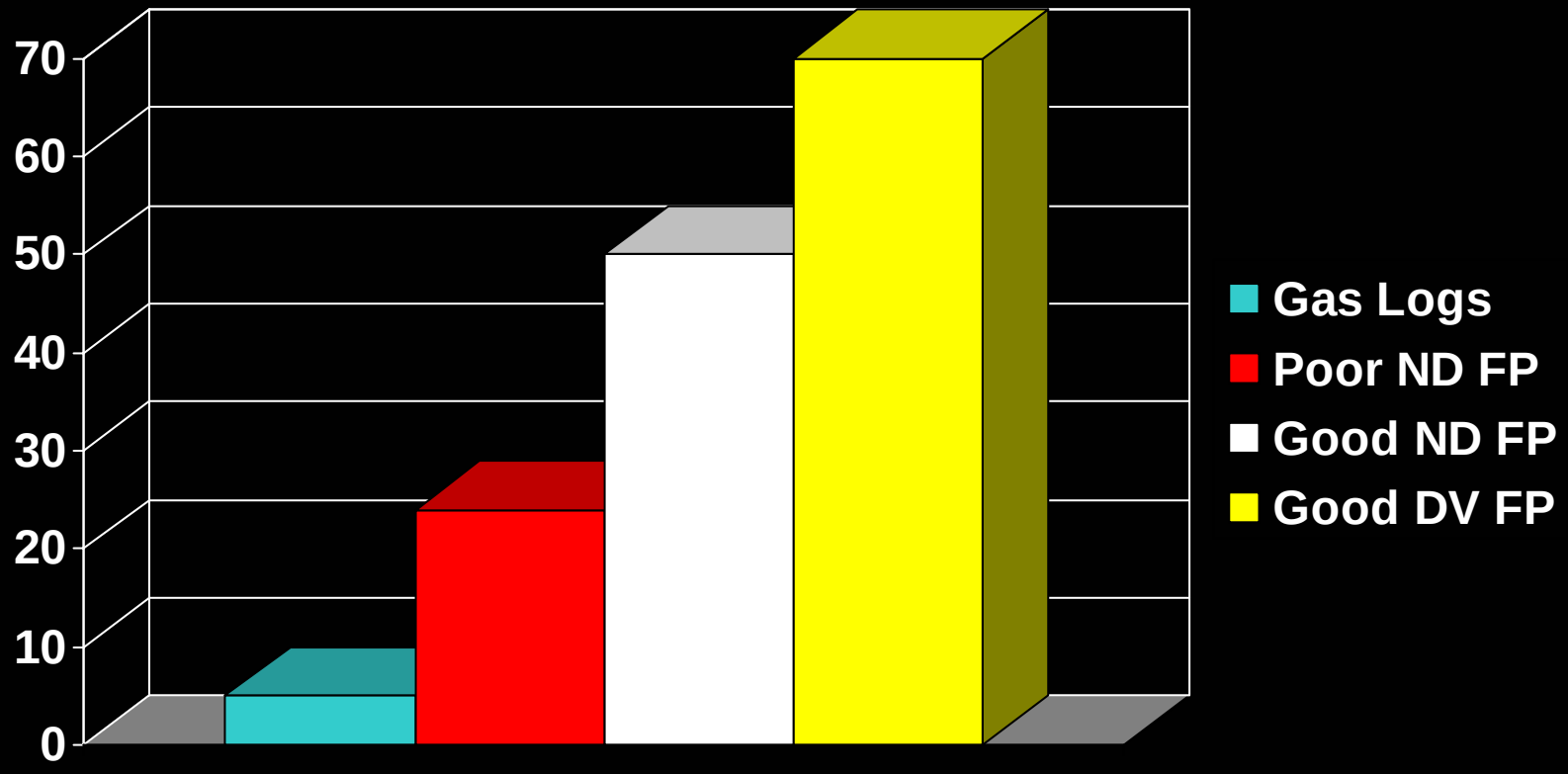
Characteristics of Good Pellet Stove

- Tested to EPA 1990
  - low emissions potential is realized
  - high efficiency due to low excess air (80%+)
- Wide firing range (modulation 6:1 or better) with good EA control over range
- Air wash for fire viewing
- Small diameter flue (3-4”)
- Can be side-walled (& DV’d) with care

Gas Fireplaces

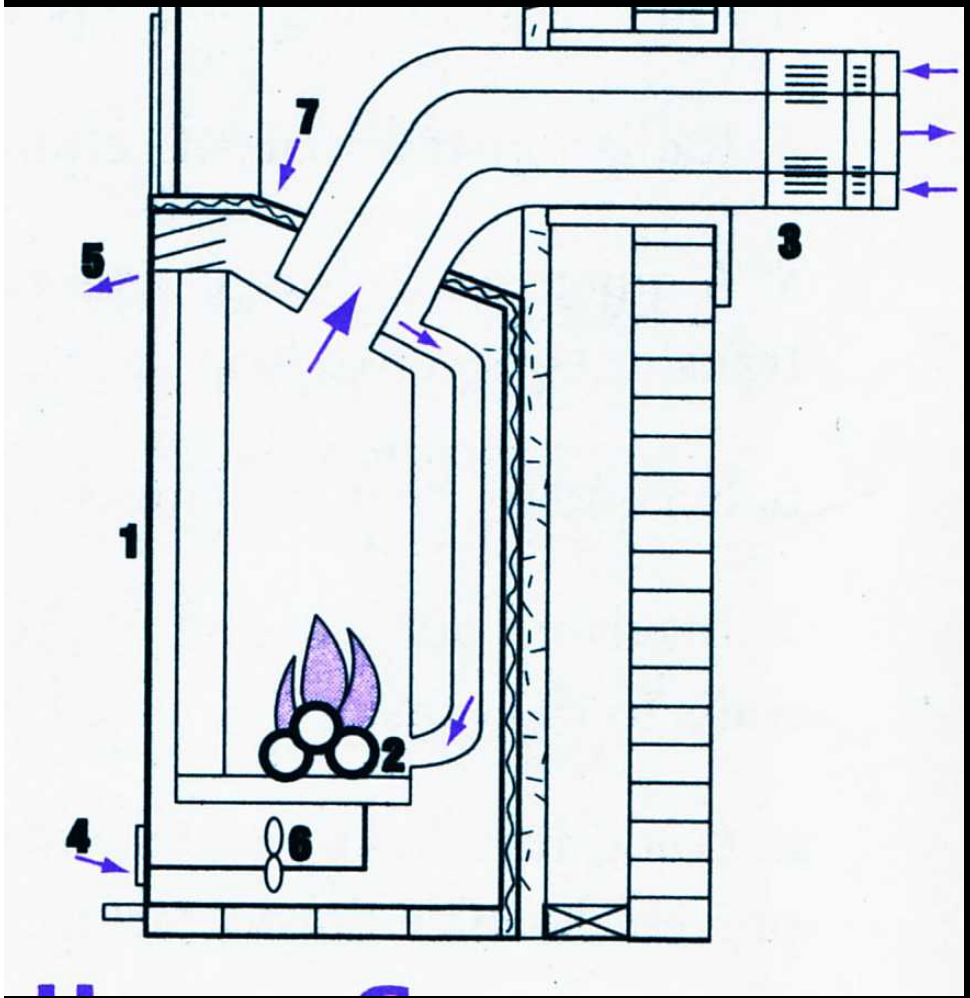
Efficiencies overestimated in US !

Gas Fireplace P.4 Efficiencies



Pilot lights can account for more than half the gas usage of a gas fireplace !!!

Characteristics of Efficient Gas Fireplace

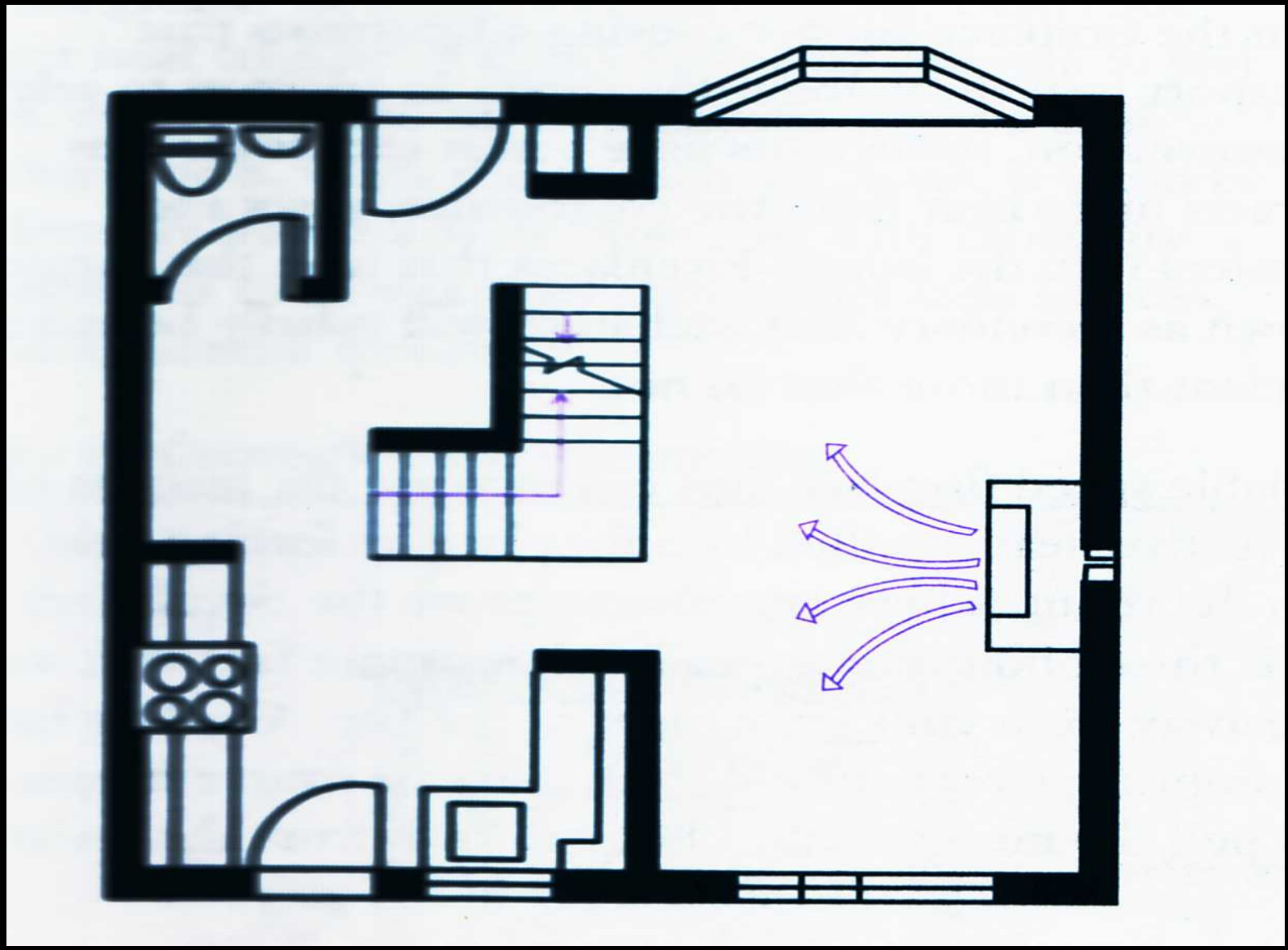


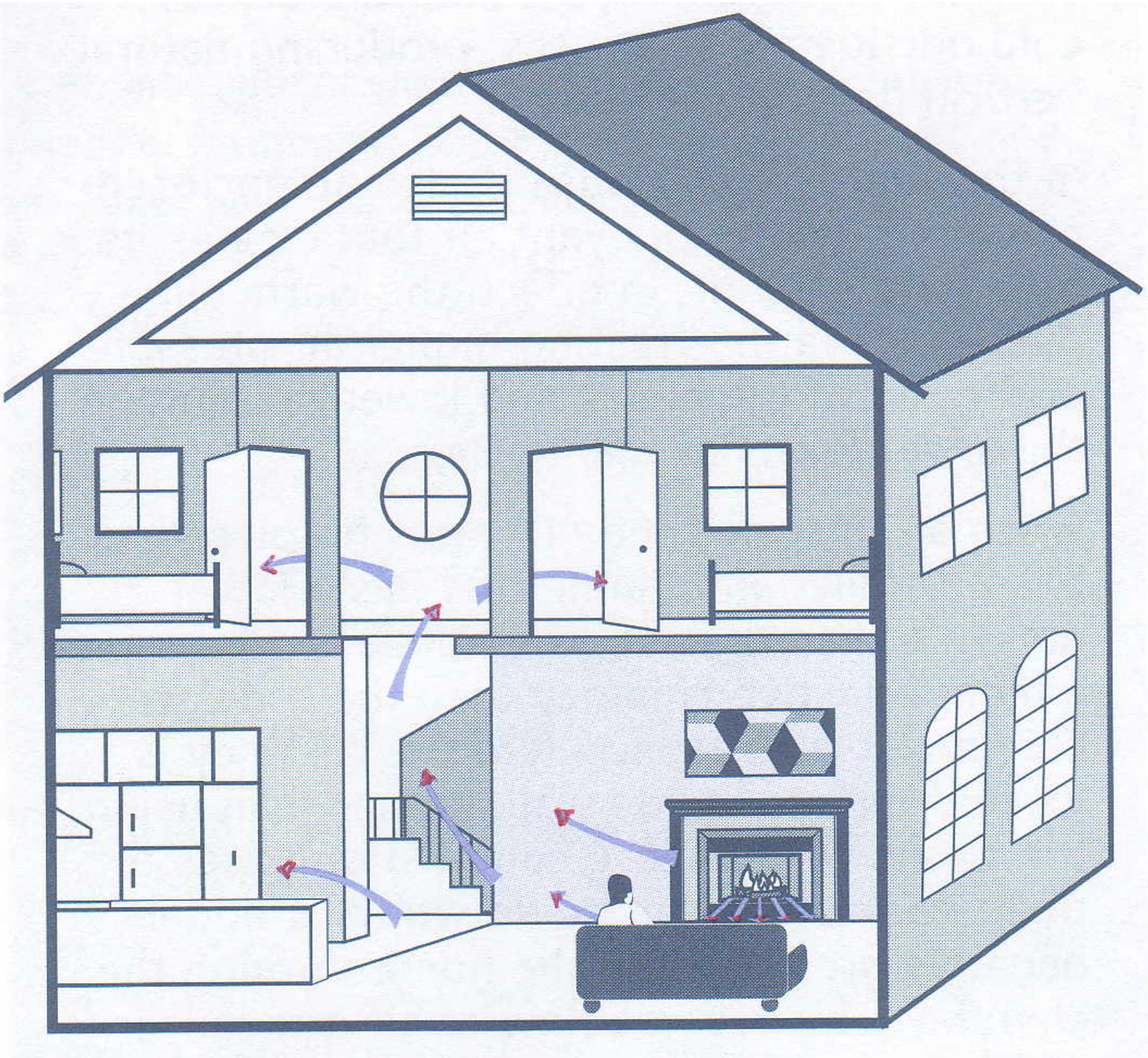
- Direct vent (sealed combustion)
- Ceramic viewing glass front
- Good input/output modulation
- Easily shut-off / relit pilot or IID
- Effective circulating fan
- Insulated outer casing
- High P.4 seasonal efficiency
- Stated resistance to 50 Pa
- Proper location

For a space heater
to be truly
efficient & effective,
it must be
properly sized & located

Most
“viewable” space heaters,
should be located
in a major living area
which “sees”
other parts of the house.
Try to lay out house
so this can occur

Good Space Heater Layout






LEONARDO

Summary

- High efficiency technologies offer superior performance and ancillary benefits, while eliminating probs such as IAQ, pollution, degradation, cold areas
  - Condensing gas furnaces
  - High static oil burners (FAN to come)
  - Advanced combustion wood stoves & fireplaces
  - Efficient DV gas fireplaces (high P.4)
  - Highly modulating pellet-fuelled appliances

Summary (cont.)

- Combining space/water energy needs can offers better or worse performance
- Integrated, well-designed space/water/ventilating appliances will offer major benefits re efficiency, comfort, ease of installation, ...

Summary (cont.)

Using Efficiency Vermont's "Fast Track Method" a builder can get a break on window glazing requirements with an **efficient heating system** (esp **> 87% AFUE**)

See Efficiency Vermont for more details

Summary (cont.)

Advanced integrated technologies such as

- Next generation condensing fireplaces
- Fuel cells
- Stirling engines
- Gas lighting
- Integration with renewables

will offer means to increase overall energy efficiency & comfort while reducing emissions, including GHG

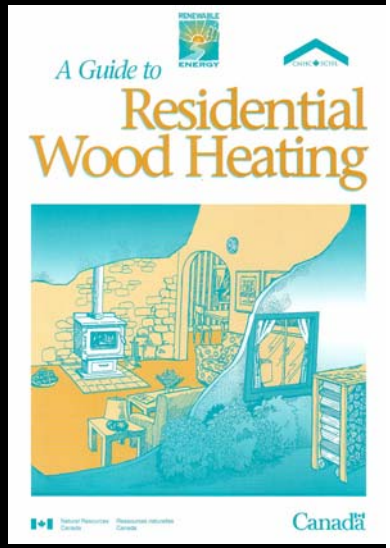
Review of Objectives

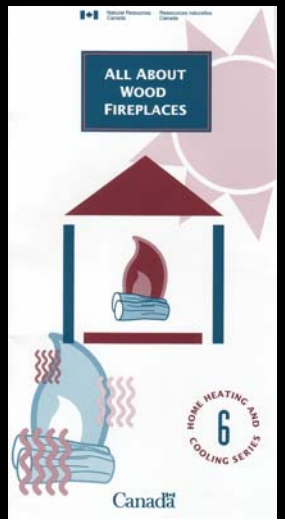
- Understand what makes heating systems efficient, learning the distinctions in appliance technologies and in energy sources
- Appreciate advantages & disadvantages of various “high efficiency” systems
- Be better able to choose or modify heating systems for high efficiency operation in new or existing housing

Heating Publications

http://energy-publications.nrcan.gc.ca/index_e.cfm

under Consumers:
Heating, Cooling & Ventilation



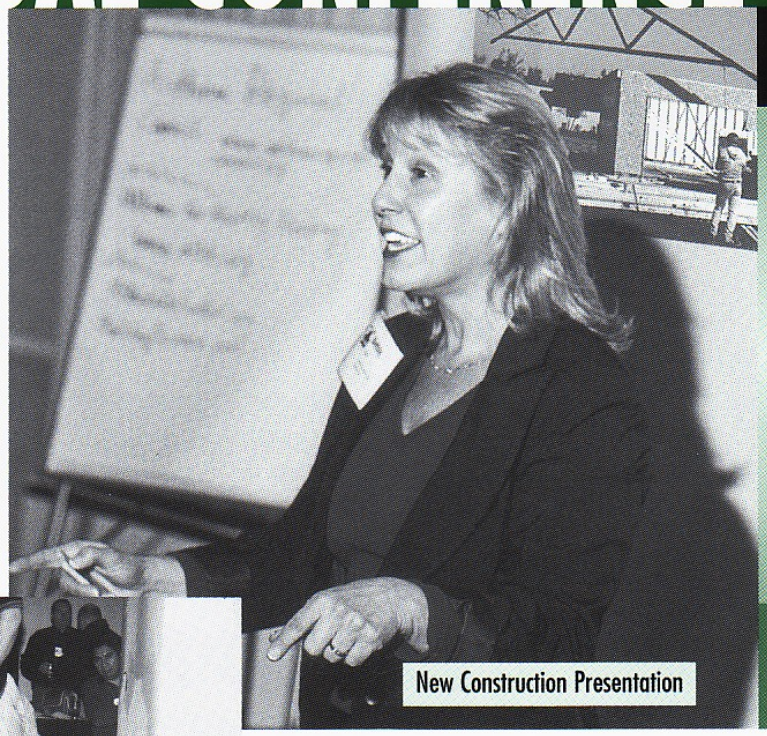


The Affordable Comfort

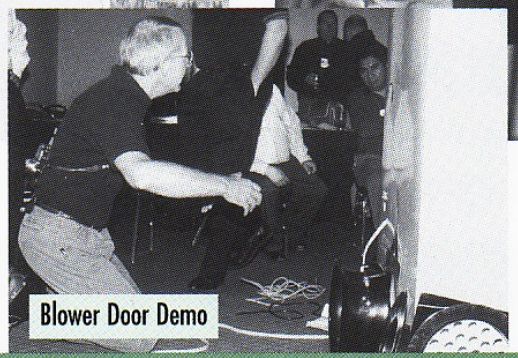
ANNUAL CONFERENCE AC '04

NOW IN OUR 18th YEAR!

nsulation Competition



New Construction Presentation



Blower Door Demo

This year in

Minneapolis, Minnesota

April 26 – May 1, 2004

The Hyatt Regency on Nicollet Mall

Make a Difference

TAKE THE LEAD IN 2004

F E A T U R I N G

If further questions,

contact me (Skip Hayden)
Advanced Combustion Technologies,

tel: (613) 996 3186
fax: (613) 992 9335
e-mail: skip.hayden@nrcan.gc.ca

AIMS: www.eKOCOMFORT.com

The potential is there.
The fun is there.
The comfort is there.

Take it !!!

Gas Boilers

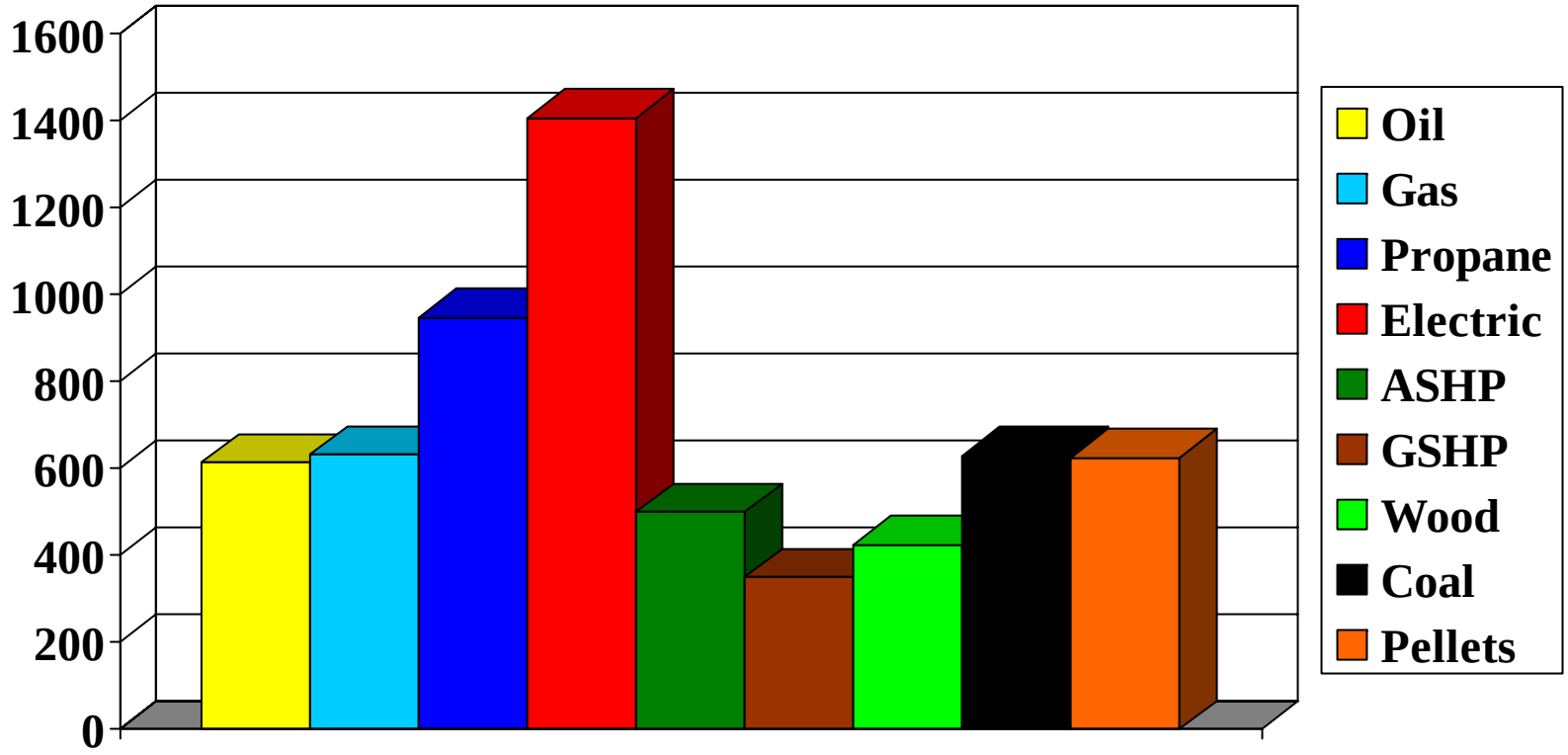
- **Sim range of technologies as furnaces**
- **Naturally aspirating with pilot light & draft hood still common**
- **Natural draft with flue damper common**
- **Condensing boiler performance depends on installation**

Relative Heating Costs in Vermont

Cost per Unit of Energy

Heating Oil		$ 1.17 /gal
Natural Gas		$ 9.28 /mcf
		$ 0.928 /therm
	+	$ 9.75 /month
Propane		$ 1.34 /gal
Electricity		$ 0.141 /kwh
Mixed Hardwood		$ 125 /fullcord
Wood Pellets		$ 3.62 /bag
		$181 / ton

Relative Vermont Heating Costs



Prototype high efficiency condensing gas fireplace for space and water heating + ventilation