ENERGY SOLUTIONS CENTER

Track: Residential Natural Gas

Unit #3: Heating: Furnaces, Boilers & Other Less Common Systems

An overview of Heating Systems for Single Family Residences

Eric Burgis, Energy Solutions Center

Presentation Outline

- Residential Markets
- Sizing & Efficiency
- Available HVAC Technologies
- Associations & Resources

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Residential Building Types

- Single Family Homes
  - Detached
  - Attached
- Mobile Homes
- Multi-Family Units




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Single family Homes

- Detached – the house does not share or touch any inside or outside walls with another house or dwelling
- Attached - the house is attached to any number of other houses that are side by side with their own separate entrances

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Mobile Homes

- A large single family house trailer that is parked in one particular place and used as a permanent living accommodation
- Primarily heated with forced air or electric baseboard systems

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Multi-Family Units

- Housing where multiple separate housing units for residential inhabitants are contained within one building
  - A common form is an apartment building
- Discussion of Multi-Family Heating systems is not included in this training unit

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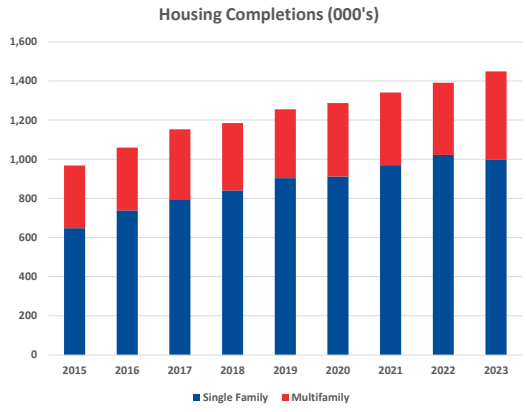
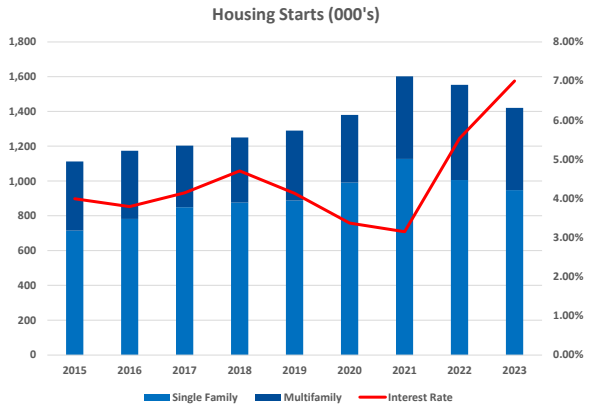
Residential Market Statistics

U.S. Housing Completions and Starts





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Source: Housing Completions and Starts from US Census, Interest Rates from Bankrate.com

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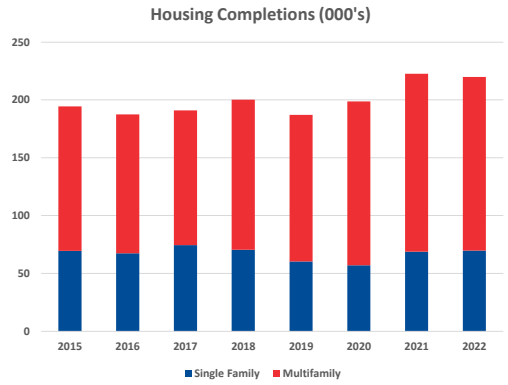
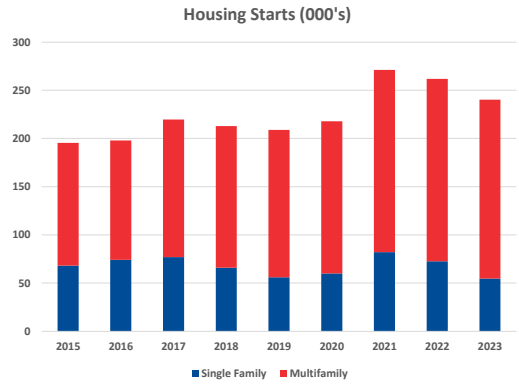
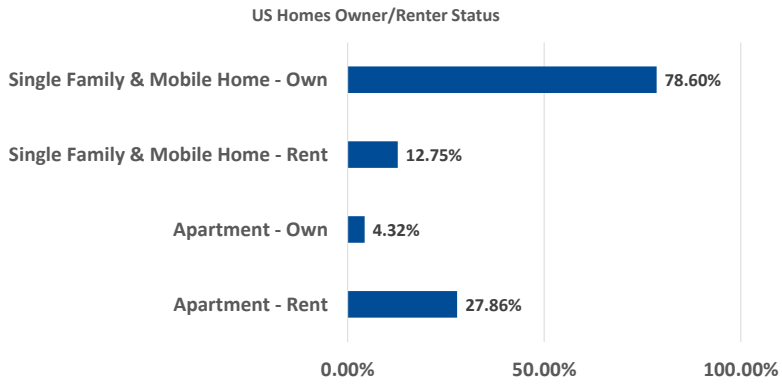
Canadian Housing Completions and Starts





Source: Canada Mortgage and Housing Corp

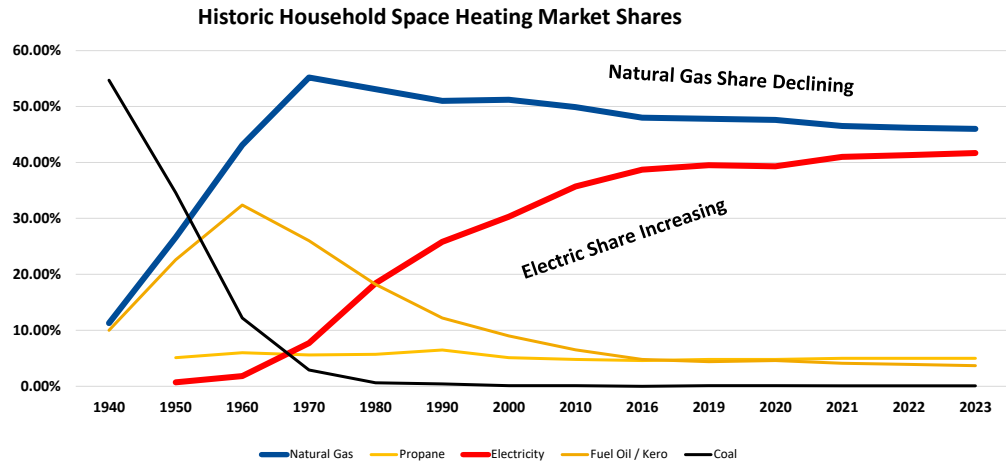
US - Dwelling Stock



Approximately 79% of people own the home they live in, about 13% rent their home

U.S. EIA 2020 Residential Energy Consumption Survey Table HC8.2, released 5/2023

Historical Trend in Heating Fuel Type



U.S. Bureau of Census & U.S. Census Bureau American Community Survey 1 yr estimates through 2023

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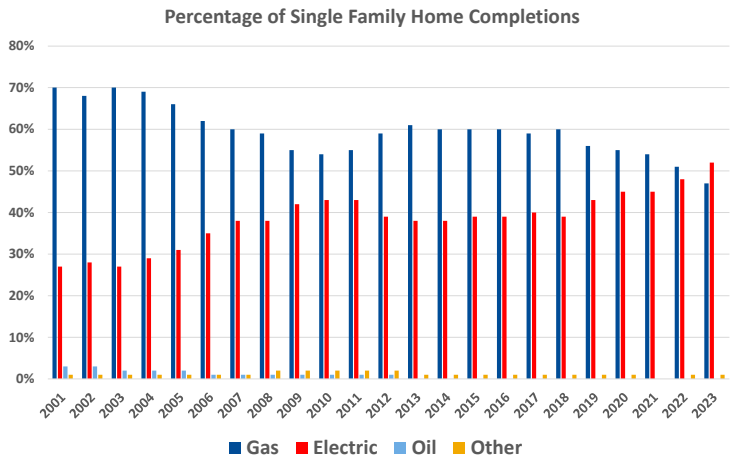
Natural & Propane Heat No Longer #1 Choice in New Construction

- The number of homes heating with natural gas has declined while electric heat increased.
- Gas* (Natural Gas & Propane combined) lost their edge over electric for heat in new construction homes as of 2023



US Bureau of Census Characteristics of New Housing

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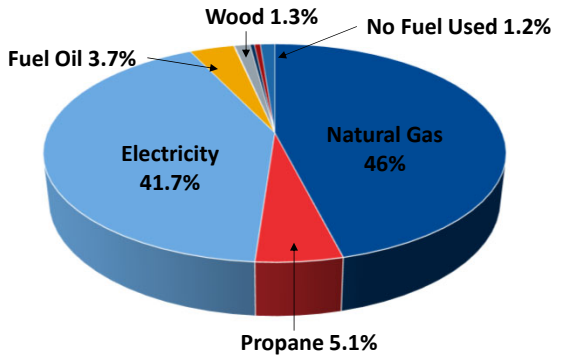
Main Heating Breakout



2023 US Census Bureau American Community Survey 1 yr estimates

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U. S. Primary Home Heating Sources
(Stated in 1000's)

Energy Source	2015	2017	2019	2021	2023	% Change
Natural Gas	56,983	57,687	58,703	59,246	60,380	+6.0%
Propane	5,576	5,529	5,930	6,327	6,623	+18.8
Electricity	45,103	46,773	48,469	52,279	54,808	+21.5%
Fuel Oil	5,992	5,649	5,416	5,219	4,875	-18.6%
Other	3,170	2,998	2,944	2,890	3,007	
No Fuel Used	1,384	1,326	1,341	1,583	1,640	
Total	118,208	120,062	122,803	127,544	131,333	

Source: U.S. Census Bureau American Community Survey 1 yr estimates

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Canada Primary Home Heating Sources
(Stated in 1000's)

Energy Source	2015	2017	2019	2021	% Change
Natural Gas	6,813	6,926	7,090	7,300	+7.1%
Electricity	5,663	5,950	6,239	6,540	+15.5%
Fuel Oil	859	770	665	553	-35.6%
Other	361	370	390	411	+13.9%
Total	13,696	14,016	14,384	14,804	

ESC Source: Natural Resources Canada National Energy Use Database

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Market Observations

- Potential causes for the changes in space heating energy sources:
  - Higher installation costs for replacing gas and oil systems compared to electric-based equipment
  - Heat pump technology improvements have allowed greater penetration into colder climates
  - Spread of bans on the use of natural gas
  - Focus on the environment
- Observed patterns of fuel switching include:
  - Most changes from gas to electric occurred in the South

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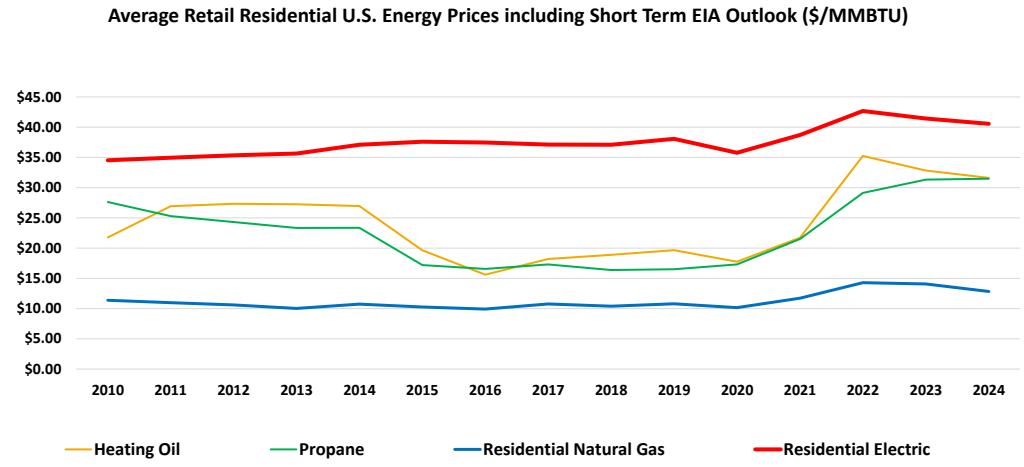
Pricing Trend of Energy Alternatives



Pricing per EIA data

High Performance Homes

- Energy Star – ENERGY STAR certified homes and apartments have been designed, built, inspected, tested and verified to standards set by the EPA to deliver energy efficiency savings of at least 10 percent when compared to homes and apartments built to minimum code levels

Available HVAC Technologies

Forced Air Furnaces

Boilers

Combo Heaters

Other Less Common Systems

Controls

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Forced Air Furnaces

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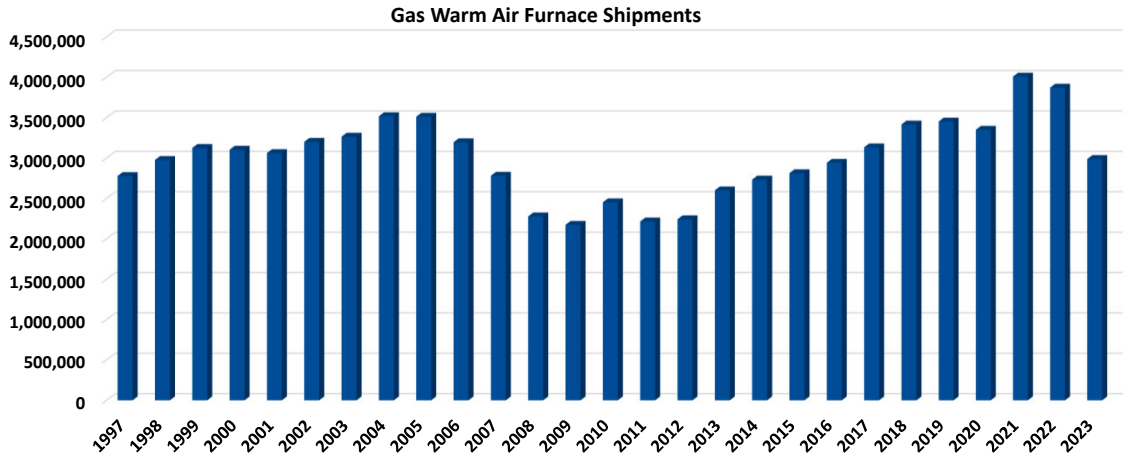
U.S. Furnace Shipments



Source: AHRI 2024

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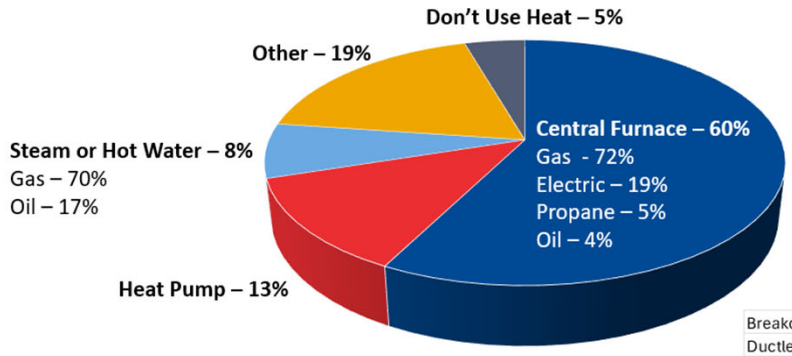
Main Heating Equipment in U.S. Homes



Breakout of Other - 19%	
Ductless heat pump (mini-split)	6%
Built-in electric units	43%
Built-in oil or gas room heater	19%
Portable electric heaters	17%
Heating stove burning wood	11%
Some other equipment	4%

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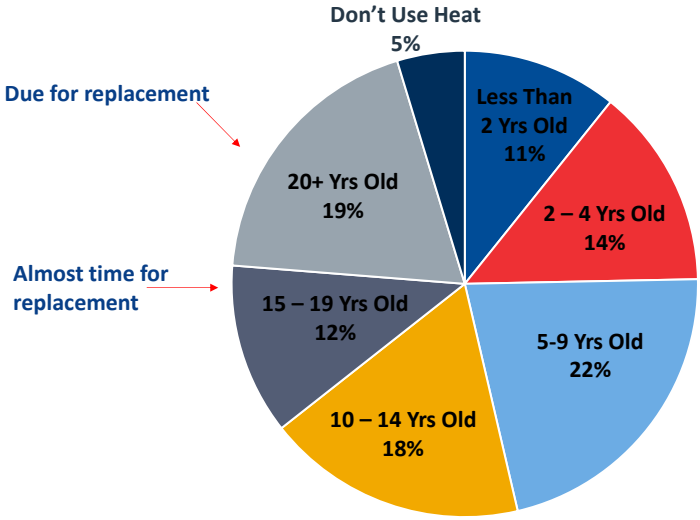
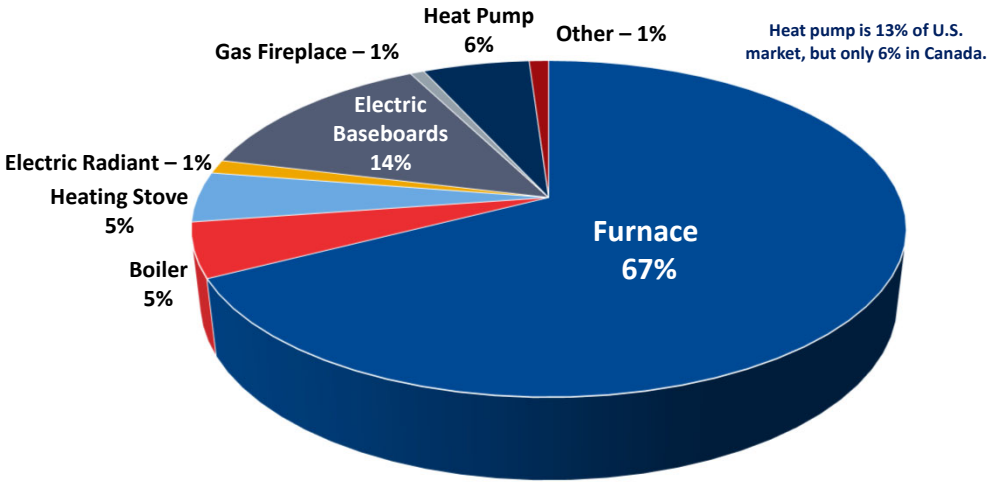
Age of Main Heating Equipment – U.S.



Source: EIA data released 3/23

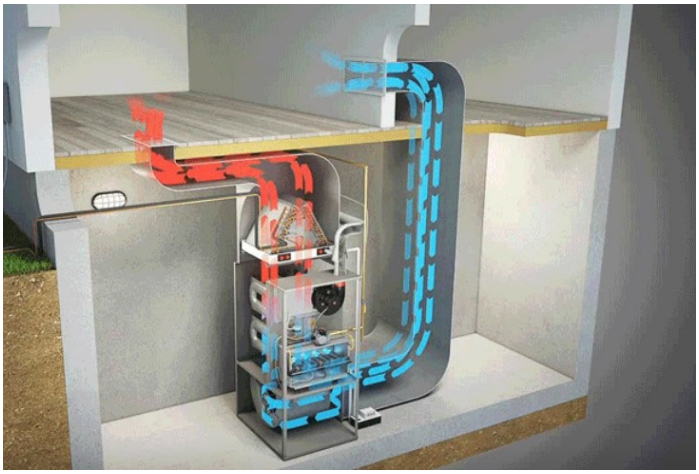
Space Heating in Homes in Canada



Source: NRCAN 2019 Survey of Household Energy Use

Forced Warm Air Furnaces

- Physics:
  - Warm air rises
  - Loses heat rapidly to the surroundings
  - Must be moved by mechanical means (fan)
  - Heats the air first… then people



https://entirewishes.com/wp-content/uploads/2023/03/What-to-Do-if-Your-Furnace-Wont-Turn-On.jpg

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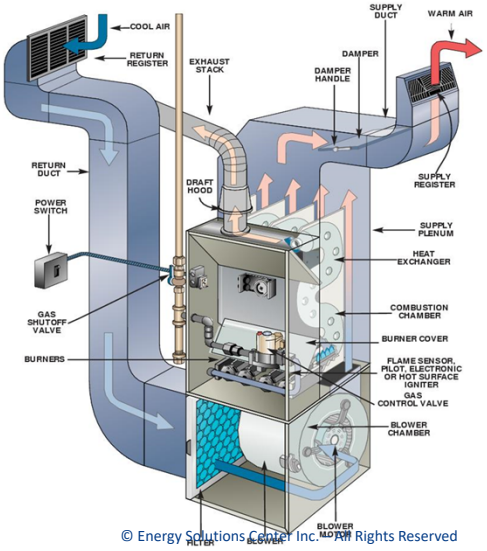
Components



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How Does a Forced Air System Work?

- Thermostat senses temperature – calls for heat at the furnace, causing the furnace burner to turn "on"
- Gas burner turns on in response to the thermostat
- Furnace will run until either the high temperature or "Fan Limit" temperature is reached inside the warm air plenum or the home thermostat senses that the desired temperature is reached
- The burner turns off, but the blower will continue to run a bit longer

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How Does a Forced Air System Work?

- Heat exchanger:
  - Hot combustion gases produced by the gas burner circulate inside of the furnace's metal heat exchanger causing it to get hot
  - Combustion gases leave the inside of the heat exchanger and flow through a flue vent connector to a chimney or vent directly outside

Tubular

Clamshell

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How Does a Forced Air System Work?

- Blower:
  - The furnace blower draws returning cool air from the living area and blows it across the outside of the heat exchanger (steel box), sending the now-warmed air into the furnace's output side or "supply air" plenum where it is sent into the home's warm air duct system for delivery to the occupied space

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How Does a Forced Air System Work?

- Air ducts:
  - Connect cool air from occupied space through furnace and deliver warm air back to occupied space
  - Home air duct system includes return or cool air ducts and warm air ducts
  - Warm air supply ducts connect to the supply air plenum and carry warm air into the occupied space where it flows out of floor, wall, or ceiling warm air registers or diffusers

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Types of Duct Work

- Rigid
  - Sheet metal (May be fiberglass lined inside or outside the duct)

  - Fiberboard

  - PVC (For small duct systems)

- Flexible Duct

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How Does a Forced Air System Work?

- Combination Fan & Limit Control:
  - This control turns the furnace blower on and off at the proper times
  - The controller ensures the blower fan does not turn on until the furnace has reached proper temperature (even though the building thermostat has asked for heat)
  - The controller allows the furnace blower to continue to run for an interval after the furnace burner has turned off, but will shut the blower off after the heat exchanger has been cooled down

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How Does a Forced Air System Work?

- Furnace Limit:
  - The Limit indicator setting is a safety control that will turn off the gas burner if temperatures inside the warm air plenum exceeds a safe level
  - When the thermostat is satisfied and turns off the gas burner at the furnace, the fan limit switch will cause the blower or fan unit to continue to operate until the temperature at the supply plenum has reached or dropped below the "cut-in" or "fan-on" lower limit

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How Does a Forced Air System Work?

- Furnace shut down – Normal operation:
  - The burner will continue to run the entire time that the building thermostat is requesting heat
  - The burner will stop running as soon as the thermostat is satisfied
  - If the furnace gas burner is a very high capacity (or if the furnace fan/limit controls have been set to cause this effect) the burner may, on some systems, cycle on and off periodically while the warm air blower continues to run

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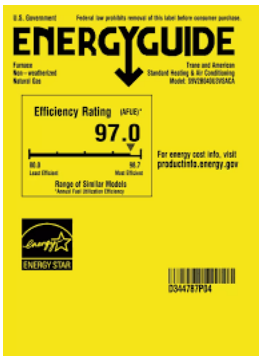
Forced Air Systems

- Efficiency
  - Standard
  - High
- Configurations
  - Horizontal Furnaces
  - Vertical



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Heating System Efficiency

- Each furnace model is assigned an Annual Fuel Utilization Efficiency (AFUE number)
- The AFUE measures how efficiently a furnace converts fuel into heat. The higher the AFUE the better.
- AFUE is not the whole story of heating cost efficiency
  - A high-efficiency heating system that has not been cleaned and serviced may be running poorly and wasting money
  - An 85% AFUE heating furnace that has not been cleaned might be running at an efficiency much lower – perhaps 65%

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Efficiency & Sizing

Efficiency and Savings

Annual Estimated Savings for Every $100 of Fuel Costs by Increasing Your Heating Equipment Efficiency

Existing System AFUE	New/Upgraded System AFUE								
	55%	60%	65%	70%	75%	80%	85%	90%	95%
50%	$9.09	$16.76	$23.07	$28.57	$33.33	$37.50	$41.24	$44.24	$47.36
55%	----	$8.33	$15.38	$21.42	$26.66	$31.20	$35.29	$38.88	$42.10
60%	----	----	$7.69	$14.28	$20.00	$25.00	$29.41	$33.33	$37.80
65%	----	----	----	$7.14	$13.33	$18.75	$23.52	$27.77	$31.57
70%	----	----	----	----	$6.66	$12.50	$17.64	$22.22	$26.32
75%	----	----	----	----	----	$6.50	$11.76	$16.66	$21.10
80%	----	----	----	----	----	----	$5.88	$11.11	$15.80
85%	----	----	----	----	----	----	----	$5.55	$10.50
90%	----	----	----	----	----	----	----	----	$5.30

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* Furnace Outlet

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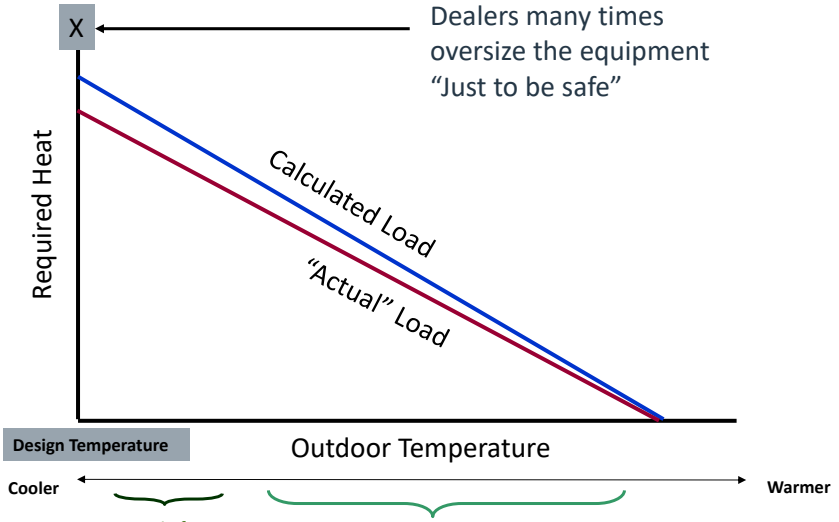
Heating Load



Cost of Over Sizing - Example

Smaller system estimated costs	Operating Cost* High Efficiency 90%	Operating Cost* "Low" Efficiency 80%
Oversized	$890	$1,000
Sized to Design Temperatures	$740	$830
Sized to Actual Temperatures	$680	$765

Customer would benefit by having a properly sized "LOW" efficiency furnace compared to an over-sized HE furnace. Of course, HE always saves money over conventional systems.

Size Matters

If your furnace is too large:

- Cycle on and off more frequently
- Wears down components faster
- Wastes energy
- Uncomfortable temperature swings
- Can be noisy

Bottom Line: wastes money and energy

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How Do Furnaces Become "Wrong-Sized"?

When you size for the worst-case scenarios!

- The most people that can be in a structure
- The absolute worst weather for
- Sizing to meet loads that only occur 1% - 2.5% of the time
- Using "rule of thumb" sizing

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How to Avoid "Wrong-Sizing"

- Incorporate a "whole building design concept"
- Design in accordance with accepted engineering standards
- Understand the specifics relating to the building and the owner needs

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Available HVAC Technologies

Standard Warm Air Furnace

- Offer a seasonal efficiency of at least 78% – 82%
- Most have naturally aspirated burners without a continuously lit pilot light
- Newer furnaces have electric ignition systems
  - Can consume from 3 to 5 percent less energy than a furnace with a conventional standing pilot light

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Furnace Features

- Electronic Ignition
- VFDs
- Condensing furnaces

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Electronic Ignition Systems

- The electronic ignition occurs typically in one of two ways:
- Intermittent Pilot – uses an electronically controlled high voltage electrical spark to ignite the gas pilot and the main burners
- Hot Surface Ignition – uses an electronically controlled resistance heating element

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Variable Frequency Drive (VFD) Motors

- An adjustable-speed drive used in high efficiency systems to control fan motor speeds by varying motor input frequency and voltage
- Will circulate a lower flow rate of air for a longer period of time
- Offer significant operating cost savings and whisper quiet operation

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High Efficiency Condensing Furnaces

- Uses a second heat exchanger
- Hot flue gasses are cooled to the point where the water vapor condenses
- Allows the furnace to extract more heat from the combustion process
- Flue gases are cool and can be vented outside horizontally with a plastic PVC pipe
- Condensed water is run to a floor drain
- Condensing furnaces are high efficiency with an AFUE of 90% and above and use hot surface ignition
  - Highest efficiency available >= 97%

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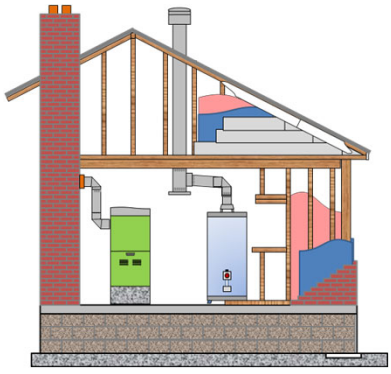
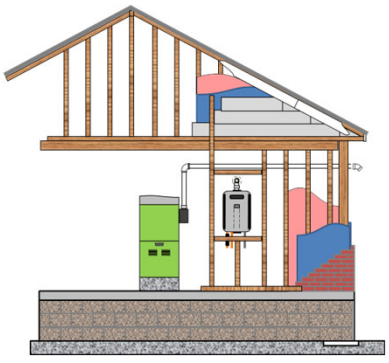
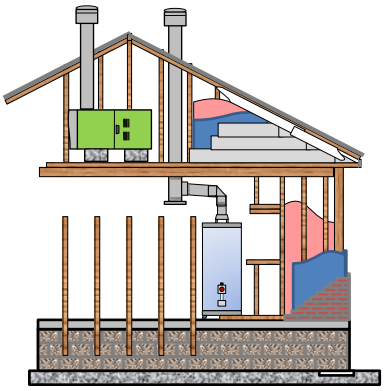
System Installation Options



Conventional Furnace vented into chimney stack



High Efficiency Furnace vented through the wall (PVC)



Horizontal Furnace vented through roof

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Gas Advantages

- Versus Electric Furnaces
  - Longer Life Expectancy
  - Higher Efficiency (site vs. source)
  - Lower Operating Costs
- Versus Electric Heat Pumps
  - Higher discharge air temps at the register (100°-125°F) (37.7°-51.6°C) vs. (90°-110°F) (32.2°-43.3°C) with a heat pump
  - No need for emergency/back-up heat in cold climate
  - Longer System Life Expectancy
  - Lower Life Cycle Costs

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Sample Gas Furnace Manufacturers

Amana Heating & Air Conditioning	Standard / Condensing	www.amana-hac.com
Armstrong Air Conditioning, Inc.	Standard / Condensing	www.armstrongair.com
Carrier Corp	Standard / Condensing	www.carrier.com
Dettson Industries	Condensing	http://dettson.com
Goodman Manufacturing (Daikin)	Standard / Condensing	www.goodmanmfg.com
International Comfort Prod. (Heil, Comfortmaker, Arcoaire, Tempstar, Keeprite, Day & Night)	Standard / Condensing	www.icpusa.com
Lennox	Standard / Condensing	www.lennox.com
Napoleon	Condensing	www.napoleon.com
Thermo Prod LLC	Condensing	www.thermopride.com
Trane Residential Systems	Standard / Condensing	www.trane.com
York International	Standard / Condensing	www.york.com

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Small Duct Systems

- Provide heating and cooling like a traditional HVAC system
- Ducts can be up to 50% smaller (2” – 2.5”)
- Works through aspiration – constantly moving air
- Ideal for new construction homes or older homes without an HVAC system

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Advantages of Small Duct System

- Minimally invasive
- Less leakage, energy efficient
- Remove up to 30% more humidity
- Creates more even temperatures
- Quiet operation
- Easy to install

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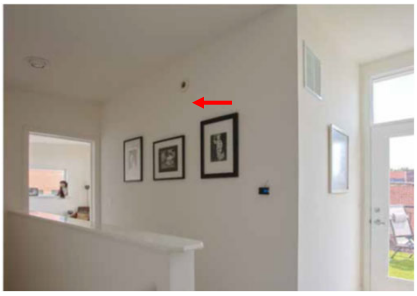
Small Duct Installation Examples



Photos courtesy of Dettson Industries

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Manufactures of Small Duct Systems

Unico, Inc.

1120 Intagliata Dr.
Arnold, MO
(800) 527-0896
www.unicosystem.com

SpacePak

125 N. Elm St.
Westfield, MA
(413) 564-5530
www.spacepak.com

Dettson Industries, Inc

3400 Boulevard Industrial
Sherbrooke, QC
(800) 567-2733
www.dettson.com

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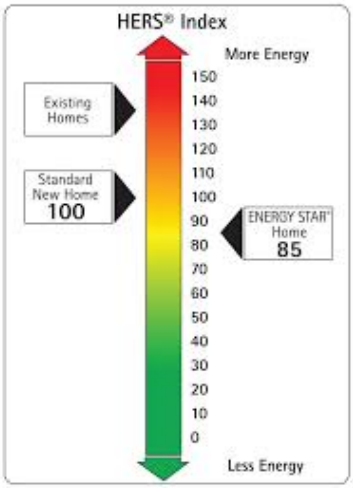
High Efficiency & the HERS Index

- RESNET (Residential Energy Service Network)
  - Founded in 1995
- Created HERS index to rate homes for Mortgage Industry
- Based off a home built to 2006 IECC standards
- Lower is better
- Every number = 1%



ESC RESNET® Residential Energy Services Network

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Variables Included in a HERS Rating

- All exterior walls (both above and below grade)
- Floors over unconditioned spaces (like garages or cellars)
- Ceilings and roofs
- Attics, foundations and crawlspaces
- Windows and doors, vents and ductwork
- HVAC systems, water heating system, and your thermostat

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CO^2 and Energy Cost Example

- Average U.S. 2,000 Sq Ft home
- All power generation and EIA average retail energy prices ($9.30/MMBTU and $.13/KWH)
- Using ESC's Residential Energy Calculator

	80% Furnace	92% Furnace	8.7 HSPF Heat Pump	10 HSPF heat Pump	Electric Strip heat
#'s of CO^2/Year	7,260	6,313	15,589	14,107	30,479
Energy Cost ($/Year)	$577	$502	$973	$881	$1,903

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Residential Boilers

- Sectional
- Condensing
- Wall Hung

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Sectional Boilers

- Sectional boilers
  - Consist of multiple sections that are connected together
  - Ideal for retrofit/replacement applications
  - Small footprint
  - Easily assembled or expanded
  - Sometimes multiple sectional boilers are ganged together as a modular boiler

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Condensing Boilers

- Condensing boiler
  - Higher efficiency than conventional boilers
  - Controls essential to running the system efficiently

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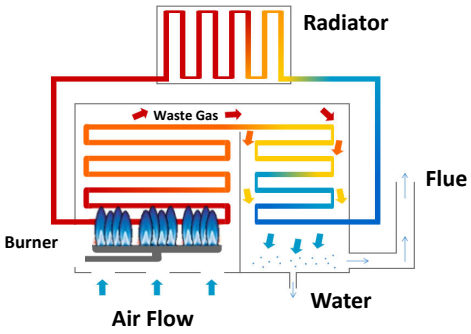
Condensing Boilers

- Condensing boilers reuse the heat from water vapors created by the boiler's combustion
- Return water temperature is critical with this type of boiler system
- The boiler extracts additional heat from the waste gases by condensing this water vapor to liquid water, thus recovering its latent heat



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Condensing Boilers

- One CF natural gas yields two CF water vapor
- Two CF water vapor condenses to one ounce water
- About 9% of the BTU content in each CF natural gas burned leaves the stack as latent heat of vaporization in this water vapor
- By condensing this water and lowering the stack temperature 98% efficiency can be reached
- This water will only condense at gas temp <135 °F (57 °C)

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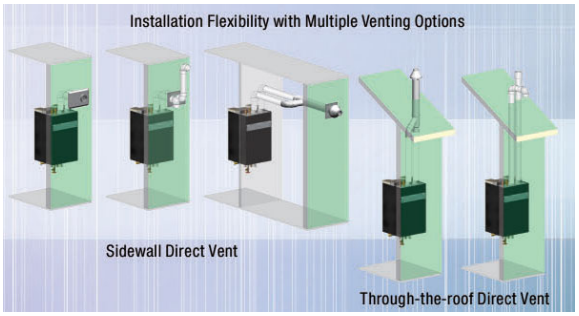
Wall Hung Boilers

- Take up less room, Compact design
- Multiple venting options



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Boiler Standards

Energy Independence and Security Act
Prescribed Standards for Residential Boilers

Boiler Type	AFUE(%)	Design Requirements
Gas Hot Water	84	No constant burning pilot, automatic means for adjusting water temperature
Gas Steam	82	No constant burning pilot
Oil Hot Water	86	Automatic means for adjusting temperature
Oil Steam	85	None
Electric Hot Water	None	Automatic means for adjusting temperature

Source:https://www.federalregister.gov/documents/2023/08/14/2023-16476/energy-conservation-program-energy-conservation-standards-for-consumer-boilers#h-17

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Sample Boiler Manufacturers

Allied Technologies	Standard/ Condensing/ Wall Hung	www.alliedboilers.com
Buderus Heating Systems	Standard/ Condensing/ Wall Hung	www.buderus.com
Carrier Corp	Standard / Condensing	www.carrier.com
Dunkirk Boilers	Condensing/ Condensing Combi	www.dunkirk.com
Heat Transfer Products, Inc.	Condensing/ Wall Hung	www.htproducts.com
Laars Heating Systems	Standard/ Condensing/ Wall Hung	www.laars.com
Lochinvar	Standard/ Condensing/ Wall Hung	www.lochinvar.com
Peerless Boilers	Standard/ Condensing/ Wall Hung	www.peerlessboilers.com
Raypak, Inc.	Standard/ Wall Hung	www.raypak.com
Triangle Tube	Condensing/ Wall Hung	www.triangletube.com
U.S. Boiler Co. (Burnham/Crown)	Sectional/ Condensing	www.usboiler.net
Weil Mclain	Standard/ Condensing/ Wall Hung	www.weil-mclain.com

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Steam & Hot Water Heating Systems

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Steam & Hot Water Heating Systems

- Use heat exchangers to transfer heat to space
  - Radiator – Radiates heat to space
  - Fan Coil System – Forced air system through steam or water coil

Baseboard Style

In Ceiling Fan Coil System

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Modern Radiators

- Flexibility of Design
- Aesthetics
- Durability
- Comfort
- Energy Efficiency
- Range of BTUH Outputs
- Ease of Installation

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How a Fan Coil Unit Works

- Unit consists of a heating coil and fan
- The coil receives steam or hot water from a boiler and transfers heat to the air through heat transfer to the space
- Fan coil units can also use chilled water to provide space cooling for total HVAC applications

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https://surna.com/content/elementor/thumbs/Cassette-fan-coil-e1626453050463-q1gbh7h52mpzgagyo4ork97wmvu4a9rqypdw7bbwz4.jpg

Hydronic Floor Heating

- Radiant Floor Heating
  - PEX piping incorporated into flooring system
  - Hot water from boiler circulates through system
  - Heat radiates to space
  - No air movement
  - Quiet

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Why Choose a Boiler Over a Furnace?

- Ideal for colder climates
- Offers more consistent heat – radiant heat
- No drafts
- No or very little noise produced
- Multiple uses from single unit
  - Space heating
  - Water heating
  - Snow melting

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Residential Snow Melt Systems

- PEX Tubing installed under walk and driveways
- Hot water distributed through tubing to melt snow and dry surfaces
  - Improves safety
  - No snow removal service
  - Increases home value

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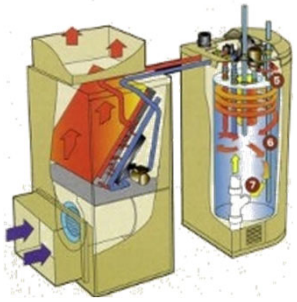
Combo Systems
Two Types

- Water heater that also provides space heat
- Boiler for space heating that also makes hot water

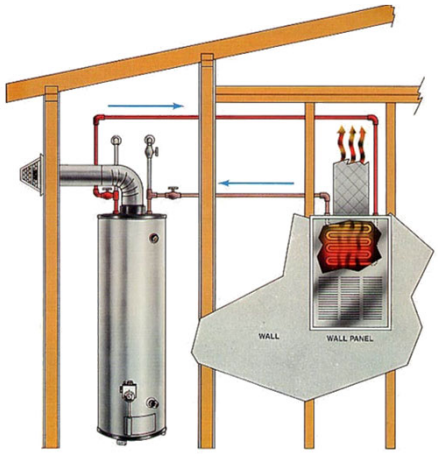
"A highly efficient combination system can reduce water heating and space heating energy use by 15 percent or more compared to a standard water heater and space heating installation"



ESC http://www.builditgreen.org/attachments/wysiwyg/22/Combo-Systems.pdf 75

Water Heater Combo Systems

- System design and component selection is critical
- High efficiency models are available that allow venting of the water heaters through a wall instead of a chimney
- Competitive with other conventional options such as heat pumps and electric water heaters
- Can use tank or tankless water heater units



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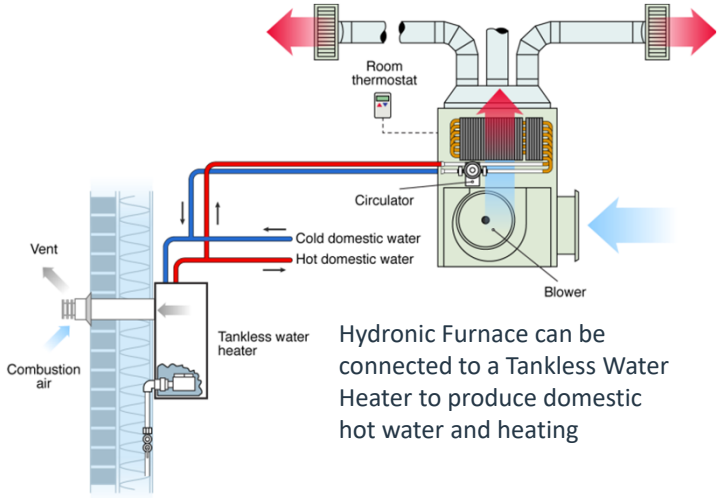
Tankless Heater + Hydronic Furnace



Hydronic Furnace can be connected to a Tankless Water Heater to produce domestic hot water and heating

Boiler Combo Systems

- Boiler has a small water coil typically above the combustion chamber. As the boiler runs hot water is produced
- Hot water from the boiler is used to provide space heat through hydronic / radiator system
- Hot water is also sent to an indirect storage tank, with internal coils to transfer heat from the boiler water to make domestic hot water

Source: GAMA

Other Less Common Heating Systems

- PTAC – Packaged Terminal Air Conditioner
- Through the Wall Systems
- Wall Furnace
- Garage Heater
- Floor Furnace
- Direct Vent Gas Baseboard

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PTACs

- A single package that contains all the components of an air-cooled air conditioner, furnace and air-handling system
- Used where individual zones have an outside wall and are conditioned separately with individual occupant control

Manufacturers:
Amana
Friedrich
Suburban

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Thru-The-Wall Units

- Thru-The-Wall Units combine heating and cooling in one compact easy-to-install unit

Thru-The-Wall Manufacturers	
Magic-Pak	Williams Furnace

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Wall Furnace

- 8,000 – 60,000 Btuh
- Sealed combustion direct vent
- Can heat one or more rooms
- Thermostatically controlled

Wall Furnace Manufacturers	
Rinnai	**Williams**

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Garage Heater

- 25,000 btu of heat
- Thermostatically controlled
- Inexpensive to operate
- Maintenance free

Multiple Manufacturers

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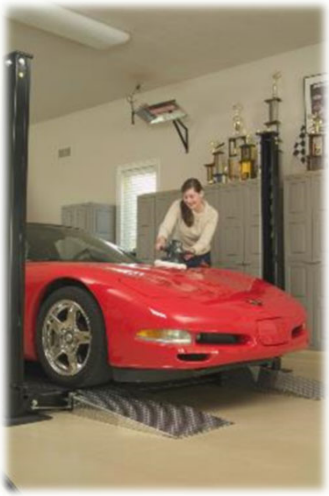
Who needs one?

- Finished space above garage
- Pet Lovers
- Active Garage Users



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Floor Furnace

- 30,000 Btuh fits between 16” joists
- Four models up to 75,000 Btuh
- Vented
- Spark Ignition
- Thermostatically controlled after start-up

Floor Furnace Manufacturers	
Cozy	Williams

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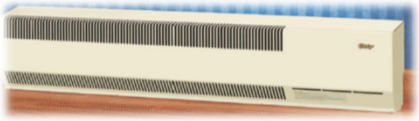
Direct Vent Gas Baseboard

- 5,000 Btuh (4’) (1.2 m)
- 9,000 Btuh (6’) (1.8m)
- Sealed combustion - Direct vent
- Mounts on outside wall
- Thermostatically controlled



Outside Finish

Gas Baseboard Manufacturer
Cozy

Side Valve Concealer

Bottom Valve Concealer

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Controls & Energy Savings

Controls & Energy Savings

- Programmable Thermostats
  - Help reduce energy consumption and costs when home is unoccupied and at night

- Forced Air Zone Controls
  - Allow for control of air volume to individual rooms or areas

- Mini Duct systems (High velocity)
  - Cool faster
  - Remove more humidity

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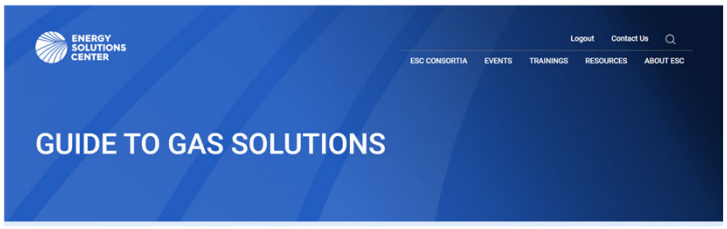
Associations & Resources

Energy Solutions Center

- ESC
  - Located in Washington, DC
  - www.escenter.org



https://www.energysolutionscenter.org/guide-to-gas-solutions/

Associations & Resources

- Energy Star – www.energystar.gov
  - EPA program helping businesses and individuals save money and protect the climate through superior energy efficiency.
- AHRI – www.ahrinet.com
  - The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) is a trade association representing manufacturers of HVACR equipment.
- NAHB – www.nahb.org
  - The National Association of Home Builders helps promote the policies that make housing a national priority.
- ACCA – www.acca.org
  - Air Conditioning Contractors of America promotes professional contracting, energy efficiency, and healthy, comfortable indoor environments.

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Thank You

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