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Photo 1 : Rooftop units under installation in the USA.

The US Market for Packaged Air Conditioners

By Wei Sun, PE

HVAC&R Advisor, USA

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The US market for packaged air conditioners is the largest in the world and quite different from other large markets. In 2004 based on ARI statistical data, the total factory shipments of unitary air conditioners and heat pumps reached a record 7,401,067 units, a nine percent increase over the previous year.

Since all homes are airconditioned, the continuous residential construction boom has had a strong impact on small AC equipment sales.

Product Classification and Standard usage in US

In the US, small capacity air conditioning and heat pump units are classified and defined in a different way than in Asian and European countries. This is due to a long time tradition in the US that central air systems dominate not only large institutional, industrial, heath care and commercial applications but also residential buildings. Based on major HVAC manufacturers product catalogues, small airconditioners are commonly classified in two main categories: “Unitary” and “Air Terminal”.

Each of these categories consist of the following types of units:

“Unitary” AC units are defined as:

- Air Conditioner (window, through-wall, packaged terminal AC)
- Split System (Ducted, Ductless)
- Packaged Rooftop
- Vertical Self-Contained (water-cooled, remote aircooled)
- Water Source Heat Pump “Air Terminal” AC units are defined as:
- Terminal Box (CAV, VAV, fan-powered)
- Fan Coil (two-pipe, four-pipe)
- Unit Ventilator

Unitary AC Products

1. Air Conditioner

Due to the similar design configuration, window AC, through-wall AC and packaged terminal AC units are often listed in the same category. Most of these units last around 10 years, while heat pump type units last less simply because the compressors work much longer each year.

Room Air Conditioner (RAC). Window units in various capacities are often equipped with expandable sides to fit into existing casement window openings (two halves which can slide up and down). Similarly throughwall units are often installed inside metal sleeves and secured with flanges on the walls. Such units are commonly used in apartment buildings and help to maintain a neat external building facade compared to the protruding window units.

Both these type of units are part of the appliance market, can be purchased from major retail stores in capacities between 5000 Btu/h to 15,000 Btu/h and offer the lowest cost among AC systems for the same cooling capacity.

Product improvement is focused on adding more products with “Energy Star” labels and also on SEER energy efficiency improvements. LGE, Fedders, Frigidaire, Whirlpool, GE, Amana and Samsung are the major players, although many US brands are made by Chinese manufacturers for OEMs.

Packaged Terminal Air Conditioner (PTAC). The PTAC unit market is unique to the North American market. These units are sold particularly for hotels, nursing homes and some individual offices with larger sizes and have greater cooling capacities than room air conditioners. The units are constructed with a standard 42”×16” rectangular opening in the wall. Electric resistance heat and/or the heat from the reversed cycle of heat pump are the main heating sources. Their capacities range from 7,000 to 24,000 Btu/h.

GE is the market leader; its products are currently made with a joint venture in a Shanghai facility. Amana and Friedrich PTAC products are made in the US. Carrier products are now manufactured in Mexico. Many new models have improved aesthetics, flexibility, features and higher efficiencies.

Hydronic type PTAC units are available where a steam or hot water coil is used inside a PTAC unit. Their capacities range from 7,000 to 15,000 Btu/h. Major suppliers for hydronic-type units are McQuay, Amana and Ice Cap.

Most of these products are considered commercial products and are not available in retail stores; therefore the manufacturers enjoy less competition from overseas competitors. However, due to being similar in size and configuration to room air conditioners, more competition from overseas is expected. Some US manufacturers are also switching their source of supplies to overseas.

A typical PTAC unit.

2. Split System (Ducted, Ductless)

Several types of split systems are commonly used in the US market:

- **Residential Ducted Split.** Used in typical singlefamily homes in North America, residential ducted split systems are often incorporated with home furnace (either gas-fired or electric) systems. Most of the time, indoor DX coils / furnaces are located in basements or inside large closets. For larger sized homes (3,500 square feet or above), two separate ducted split systems are commonly used, one system for the first floor and another for the upper level.

A typical ducted split installed in a home.

Most of these systems are installed by local contractors; cost effectiveness is their main concern to compete. Variable Frequency Drive (VFD) and Variable Refrigerant Flow (VRF) have not been commonly used yet in this huge residential market. The major renovation focuses are to enhance the SEER rating of the cooling system and improve heating efficiency of the furnace. More than 30% of the current residential furnaces sold have an efficiency of 88% or above. These units are often called “highefficiency” furnaces with a sealed combustion chamber, compared to the “standard-efficiency” furnace at 80% efficiency with direct-fired and open chamber configuration. The common cooling capacity for these systems ranges from 1.5 to 3.5 tons. In the southern states, an outdoor heat pump unit in combination with an indoor electric furnace is sometimes utilized.

- **Residential Ductless Split (Mini-Split).** For most North American contractors and end users, Asian style ductless split with multiple indoor units (also called minisplit systems) are not considered as a cost effective alternative. People in North America consider an AC/heating system as a necessity and commodity item, rather than a decorative feature in the living space. Also, most contractors are unaware of the products or are reluctant to use them. The market is growing but is still small.

- **Commercial Ducted Split.** Commercial ducted split systems' configurations are similar to the residential ducted split systems, but with many more variations and options. A typical indoor evaporator unit is a standalone unit: either the horizontal type which can be concealed in the ceiling space, or the vertical type which can be installed in a mechanical room or closet. The indoor unit is often called an "indoor air handler" utilizing hot water, steam, electric and/or a heat pump for heating. The outdoor unit can be either the condensing or heat pump type. The applications are mainly for light commercial buildings, such as small office buildings, medical clinics and some computer rooms.

  Since the introduction of the Asian style split system with multiple indoor units for small office buildings, even though some large indoor units have the option to be ducted to serve multiple rooms, the acceptance from building design engineers still remains skeptical. This is due to much longer refrigerant pipes that run with a higher potential of leaks, and difficulty to bring outside air to each indoor unit. More detailed discussions will be provided in a later section regarding "VRF" applications.

3. Packaged Rooftop Unit (RTU)

America is a large country with hundreds of developed cities and towns spread out over the huge land area. Single storey buildings are extremely common as plenty of land is available.

The packaged rooftop unit (RTU) is a popularly used system for light commercial, small office, retail, school and small factory buildings in the US. Rooftop units are factory-assembled and self-contained, and usually are selected and specified by building design engineers instead of contractors. See ***Photo 1.***

Sixty per cent of commercial building energy consumption in the country can be attributed to rooftop units.

Gas heating is much more popular than electric heating due to the cheaper operating costs. Cooling is commonly provided by a DX coil with a condenser section for heat rejection to ambient. These packaged units are usually equipped with supply and return ducts to deliver the heated or cooled air directly to spaces, and pull the return air back to the unit through ductwork systems. Since the unit is outdoor, it becomes much easier to

use gas-fired heating for the required combustion air and flue venting. These units can also be placed on a concrete pad on the ground with side (horizontal) supply and return ducts.

Manufacturers continue to offer units with increasing efficiency and decreasing price, more high efficiency equipment is becoming available as a result of the Unitary Air Conditioner Technology Procurement Program sponsored jointly by the DOE and the Federal Energy Management Program.

These light commercial duty packaged units range from 1.5 to 20 tons cooling capacity. Most units have options to add economizers. Since VFD drives are more reliable and cheaper, VAV air distribution systems are more commonly used in the States where a single HVAC unit can offer multiple controlled zones. However, one of the major restrictions for small rooftop units is that they are only provided with on/off operations, and are often not provided with the VFD option. Manufacturers have noticed the market needs, but the response is slow. Trane, Carrier, Lennox, Goodman, Bryant, Rheem and York are the major suppliers.

Larger 25 to 135 ton heavy duty rooftop units are available with many more enhanced options including a VFD drive, flexibilities and control capacities.

4. Vertical Self-Contained (Water-Cooled, Remote Air-Cooled)

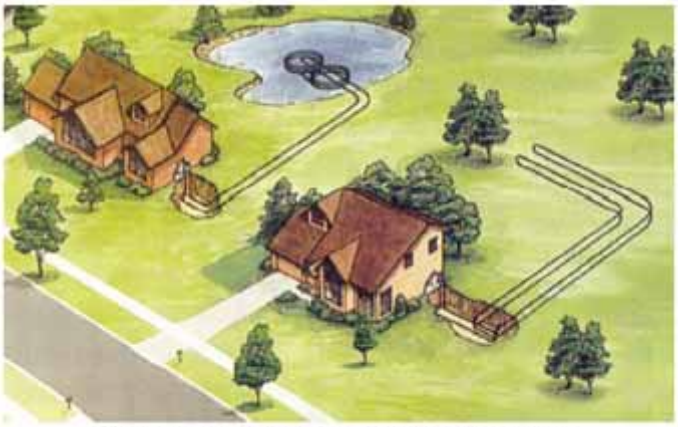
These systems are popular in multi-story commercial buildings with similar floor-plan configurations. Two models are available: The air-cooled model is an outdoor condenser (without a compressor) that rejects the heat from the refrigeration circuit, while the indoor unit contains the compressor inside its enclosure; the outdoor unit is therefore called “condenser unit” rather than “condensing unit” in the US. Another model is the water-cooled type that often uses a water-glycol condenser or cooling tower water system to accomplish heat rejection.

These units are often installed in mechanical rooms which are often centrally located in a multistory commercial building; these rooms are vertically stacked to provide easy access for heat rejections either through cooling tower water risers or grouped refrigeration risers.

Most of these commercial duty units have a capacity from 3 to 15 tons. New models allow VFD drives and variable air flow terminal devices (VAV boxes). Large heavy duty vertical selfcontained units can go from 20 tons up to 110 tons with many enhanced options and controls. Major players are Trane, McQuay, Carrier and Mammoth.

5. Water Source Heat Pump (WSHP)

A building's water loop is typically cooled by cooling tower water and heated with boiler water as required based on the net load. This type of HVAC system allows heat to be transferred from one part of the building to another depending on the need. WSHP has significant energy saving advantages in recovering "waste heat". For example, during the winter, the waste heat generated in the interior zones of a large building can be transferred through the water loop to the perimeter zones for heating.



Two types of geothermal WSHP installations.

The WSHP system has been increasingly utilized with geothermal application : Using the ground or a water pond as a natural source or sink to obtain the required cooling and heating energies. In this application, the cooling tower and boiler are no longer required, instead, a large water piping loop needs to be buried into the earth as a heat exchanger or submerged in a pond. Whether it is the conventional or geothermal WSHP application, manufacturers have put in a lot of effort to promote more acceptance through offering better documented design and application guidelines.

The US remains the world leader for water source heat pumps. Although the marker for boiler/cooling tower applications is relatively stable, the geothermal market is growing steadily each year, especially from the market of new school buildings.

Climatemaster, Trane, McQuay, Water Furnace, Florida Heat Pump and Addison are among the major players. Most units are in the range of 0.5 to 5 tons capacity. The current market size is about 50,000 to 60,000 units per year.

Air Terminal Products

1. Terminal Box (Single-Duct, Dual-Duct, Fan-Powered)

The US is the largest market in the world for terminal box units. Variable volume AHU units coupled with terminal boxes are becoming the most commonly specified system for

US office buildings. Terminal boxes have several types: Single duct, dual duct and fan-powered.

- **Single Duct Terminal Box.** A single duct terminal box contains a blade damper or piston valve to modulate and regulate air flow. The supply air is around 550F and is delivered from an air handling unit (AHU) to these terminal boxes and then to the controlled zones; each zone regulates the flow volume to provide the required cooling for interior rooms. This type of unit can also be added with a reheat coil (either electric, hot water or steam) to provide controlled heating capacity to exterior zones where cooling or heating is required.

- **Dual Duct Terminal Box.** The dual duct terminal box is also called "mixing box" which has cold air and hot air dual inlets, both air streams are mixed in a controlled ratio to deliver the required temperature at constant air flow to the space. This type of box was popular during the 60's and 70's in the US, but is now considered outdated due to significant energy waste. The latest US building codes and ASHRAE standard discourage simultaneous heating and cooling.

- **Fan-Powered Terminal Box.** The fan-powered terminal box utilizes a small centrifugal fan to mix ducted air (primary) with plenum air (secondary) to allow a high-capacity heating coil and longer distribution ducts. Based on the fan location, the fan-powered box can be either a parallel box (on/off flow) or a series box (constant flow).

Major suppliers of these boxes are Titus, Krueger, Trane, Price, Nailor, Metal Aire and Tuttle & Bailey. Each completed box has an enclosure with a modulating damper, actuator and controller.

The current trend of terminal units is that they are increasingly moving towards direct digital (DDC) controllers, and each box's flow rate, room temperature and damper position can be monitored and reset at a remote location. Light-weight air terminal boxes are sold in huge quantities each year and are easy to make and it will not be a surprise to see more competition in the coming years.

2. Fan Coil (Two-Pipe, Four-Pipe)

Two typical types of fan coil units are available in the market.

• **Four-Pipe Fan Coil.** A four-pipe fan coil unit has a built-in fan and two (heating and cooling) coils. The heating coil could run either hot water or steam and the cooling coil is usually for chilled water. The fan draws air from a room either heated or cooled by one of the coils and discharges it back to the room for heating or cooling. The four-pipe system allows simultaneous heating and cooling at different fan-coil units and is more flexible and commonly used.

• **Two-Pipe Fan Coil.** A two-pipe fan coil unit has a built-in fan and only one coil. In heating mode, the coil runs heating water (it normally does not use steam). In the cooling mode, the coil runs chilled water. The supply and return pipes are usually sized for chilled water, since chilled water piping usually requires a larger size than heating piping. Two-pipe systems require all units to run either heating or cooling, but not simultaneously for heating and cooling. Two-pipe systems are still found in older buildings, but not very popular in the new building market.

Due to simple configuration and control, fan-coil units are regarded as commodity items. Unit capacity normally ranges from 250 to 1200 CFM or 0.5 to 2.5 tons. Units among different manufacturers are often inter-changeable. Trane, Carrier and McQuay are the major suppliers.

Fan-coil technology is very mature; most improvements are made to allow more control options and more installation choices such as exposed, concealed or recessed type for both horizontal and vertical units.

3. Unit Ventilator

Unit ventilators have very similar configurations as four-pipe fan coil units, but they are uniquely designed and constructed to meet the special market for schools, so they are often called “School Unit Ventilators”.

Each unit is often mounted on the exterior wall of a typical school classroom and has mounting legs on floor. The unit provides the required heating, cooling and ventilation to the room. These units are often equipped with economizers to save energy. Units are built with strong steel casings to allow children sitting on them or other abuses. These units are more expensive, they have a capacity in a range of 750 to 2000 CFM, or 2 to 6 tons. Unit ventilators can also be installed horizontally above the ceiling with ductwork connections. Technology trends are to have more options and better controls. For example, one manufacturer allows the use of a DX coil, or another has outside and return dampers that are controlled by so-called “ASHRAE Cycles” for unit ventilators.

Evolving Technology Trends

1. Enforcement of Air Conditioner 13 SEER Standard

The US Department of Energy (DOE) recently announced that it will enforce a 13 Seasonal Energy Efficiency Rating (SEER) Standard for residential central air conditioners and heat pumps, starting in January 2006. The current 10 SEER standard which went into effect in 1992, will continue to be the national minimum efficiency standard until January 23, 2006. DOE once estimated that SEER 13 split air conditioner will cost the average consumer $122 more than a SEER 12 unit. This new standard has a significant impact on the US

AC manufacturers. Fortunately, a good portion of the manufacturers already have their new products developed and are selling them in the market.

The air conditioner manufacturing industry had challenged the 13 SEER for years and the DOE had promulgated a 12 SEER standard in 2002. But earlier this year, the industry withdrew its challenge and a US court ruled to reinforce the 13 SEER Standard.

However, the DOE excluded the products smaller than 30,000 Btu/h (2.5 ton) from the 13 SEER requirement. These so-called “space constrained products” include through-the-wall packaged and split, ductless split and single package and non-weatherized equipment. The current 10 SEER standard will continue until a subsequent rule is to be made by DOE later this year to set forth the compliance date for these products.

2. HCFC Phase-out

R-22 has been used as a refrigerant by HVAC manufacturers for over 40 years, but it is an ozonedepleting agent. The US Clean Air Act has a target date for January 1, 2010, on which HVAC manufacturers must cease the production of products that use R-22. A large number of existing split systems with original R-22 are due for replacement.

3. Variable Refrigerant Flow (VRF)

Variable Refrigerant Flow (VRF) systems were initially introduced in Japan in the 80’s and have since been utilized throughout the world. VRF split systems have been in the US for years, but the market penetration is negligible.

VRF technology is utilized for split commercial AC systems so that one single condensing unit can serve multiple indoor evaporator units of varying capacities. The condensing unit often uses multiple compressors or inverter-driven variable speed motors to provide excellent part-load performance and zoned temperature control. A VRF system

circulates refrigerant directly to multiple evaporator units to achieve heat transfer to the space.

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Since the VAV system is currently a commonly used system in new buildings, naturally, building design engineers are eager to compare the VRF versus the VAV systems. The obstacles of a full acceptance in the US market are analyzed here:

- **Potential refrigerant leakage.** VRF system's long refrigerant piping in ceiling spaces and indoor units in occupied rooms contributes a potential refrigerant leakage. ASHRAE Standard 15-2001 (Safety Standard for Refrigeration Systems) requires utilizing refrigerant leak detection and room exhaust (once the leak is detected) unless the space is large enough that the leaking refrigerant can be fully diluted. In the US there is a perception of increased liability exposure due to the large volume of refrigerant present in the system and long runs through occupied spaces. Although major Asian manufacturers have identified the danger of leaks and provided appropriate warnings in their technical manuals, this US standard imposes a major obstacle for building design engineers to fully adopt the VRF technology and its applications.

- **Outside air intake for indoor units.** ASHRAE Standard 62 and other US building codes require providing a certain quantity of fresh outside air for each occupied room. Compared with traditional VAV ducted air system, VRF has a disadvantage in this respect since each indoor unit needs to be individually ducted or ducted in manifold to the outside for fresh air.

- **Lack of detailed energy/cost saving information.** Unbiased case-study publications with detailed energy/ cost analysis for various building types and climates need to be provided to increase public awareness. Comparisons between traditional central VAV systems and VRF systems also need to be provided. These efforts are ideally to be conducted by US building design engineers and supported

by VRF system manufacturers.

- **Lack of building design strategies to minimize negative impact.** Some US design engineers have designed certain building HVAC system as effective treatments to minimize the negative impact of potential refrigerant leakage, however more research and publications of practical treatments needs to be pursued to convince the design community.

4. Response to IAQ Concerns and Approaches

Low building ventilation rates in the 70s and 80s caused deteriorated indoor air quality (IAQ) in US buildings and many variations of the so called “Sick Building Syndrome” (SBS) have been identified and IAQ-related litigations were filed. Since the revision of ASHRAE Standard 62-1989 “Ventilation for Acceptable Indoor Air Quality”, there has been a strong impact on HVAC systems and product designs. New products such as the Energy Recovery Ventilator, Dedicated Makeup Air Unit, Precision Flow Control, AgION antimicrobialcoated steel for unit housing and CO2 sensor have been introduced.

5. Advanced Control Technologies

The majority of existing buildings in the US are in need of significant HVAC renovation and upgrading. Direct digital control (DDC), with highly accurate data sensing and process capabilities, provides superior control of HVAC system as compared to older technologies such as mechanical, pneumatic or electrical control systems.

The application of Building Automation Systems (BAS) is increasing. The general downward trend in electronics costs has resulted in common use of microprocessor controls. More sophisticated programming tools have provided control technicians to complete work easier and faster.

Most small AC manufacturers provide their own control system included in the packaged AC units. The trends are utilizing more LCD panels, more digital functionalities and more diagnostic and safety measures.

6. Faster Product Fabrication and Delivery to Market

Construction duration of US buildings has been shortened during the last ten years, mainly to reduce the idle work time. Work sequence and scheduling between different trades is

getting tighter than before to control or reduce the wasted labor cost. This trend creates a market need to reduce the waiting period after the product purchase order is issued. Implementation of the Demand Flow Manufacturing (DFM) process allows the manufacturer to deliver the ordered products to the market faster than before.