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Which HVAC Configuration Offers the Highest Efficiency for Tall Buildings?

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Buildings account for 36% of global energy consumption and 40% of carbon dioxide emissions*. Therefore, energy efficiency is a lucrative investment for building owners, and an effective way to reduce environmental footprint. Since mechanical systems are typically the largest loads in tall buildings, they represent a significant opportunity for savings. We asked a CTBUH Expert, "Which HVAC Configuration Offers the Highest Efficiency for Tall Buildings?"

There are several potential HVAC configurations for tall buildings, each with advantages and limitations. Very high efficiency can be achieved if a ground-source heat pump is combined with hydronic piping, and smaller water-source heat pumps for each building zone. One kilogram of water can carry over four times more heat than one kilogram of air, while being pumpable and using over 800 times less space. This makes water an ideal heat-transfer medium for tall construction.

While an efficient HVAC design minimizes costs, the building envelope is also important. Poor insulation and air leakage reduce performance even when the most efficient HVAC technologies are used. While an efficient HVAC system reduces heating and cooling costs, a high-performance building envelope minimizes these loads in the first place. Energy-recovery ventilation (ERV) can further reduce loads under some weather conditions, by exchanging heat and humidity between the building's air supply and air exhaust. ERV can reduce four types of loads: space heating, air conditioning, humidification and dehumidification.

HVAC systems with forced airflow are common in low-rise constructions, but this configuration is unfeasible when long vertical distances are involved. In tall properties, the options are: separating the building into zones with independent HVAC systems, or using centralized equipment with hydronic piping.

The energy performance of a hydronic piping system can be enhanced by equipping pumps with high-efficiency motors. The National Electrical Manufacturers Association (NEMA) Premium Efficiency rating is used in North America, while the International Electrotechnical Commission (IEC)'s IE4 Super Premium Efficiency rating provides the highest efficiency according to international standards. High-efficiency motors with variable-frequency drives (VFDs) can also be used in air handlers, and brushless DC motors offer both efficiency and speed control for fractional horsepower units.

Chiller and boiler plants with hydronic piping are a cost-effective option for tall buildings, but they have a flexibility limitation. If both pieces of equipment share the same water loop, the HVAC system cannot deliver simultaneous heating and cooling. If a building requires both outputs at once for different building zones, chillers and boilers must have separate hydronic piping.

Since heat pumps allow reversible operation, they facilitate simultaneous heating and cooling of different building areas with a single hydronic piping system. Water-source heat pumps can use the same water loop, even when they are operating in different modes; units in heating mode extract heat from the flowing water, while units in cooling mode use it to reject heat.

The main advantage of this configuration is that heat removed from cooled zones can be provided to heated zones. The central heat pump connected to the hydronic piping system must simply deliver enough heating or cooling to balance loads. Also, if there is a moment when heating and cooling loads are equal, the main heat pump can be turned off, and there is only a pumping cost to keep water in circulation.

For maximum efficiency, a ground-source heat pump can be used as the central unit. Although air-source heat pumps are also efficient, but their performance drops rapidly with cold weather. Ground-source heat pumps are unaffected by this, since underground temperature does not experience drastic variations throughout the year.

If heat pumps with hydronic piping exceed the project budget, efficient operation is also possible with conventional chillers and boilers. However, a second hydronic piping loop is necessary if the building has simultaneous heating and cooling loads. Although boilers produce emissions, they can be minimized with a high Annual Fuel Utilization Efficiency (AFUE) - the most efficient boilers in the market have an AFUE above 98%.

With the HVAC technology currently available, the most efficient configuration for tall buildings can be achieved by combining heat pumps with a hydronic piping system, and adding high-efficiency motors and speed controls for pumps and air handlers. Under some operating conditions, energy recovery ventilation can boost efficiency and reduce HVAC loads. ■

About the Author

Michael Tobias is the founder and principal of New York Engineers. He leads a team of 30-plus MEP fire protection engineers, and has led over 1,000 projects in the US, Singapore and Malaysia.

* International Energy Agency