CASE STUDY

Cold-Climate Demonstration of Natural Gas Engine-Driven Heat Pump and Electric Cold-Climate Heat Pump VRF Systems at Naval Station Great Lakes

ESTCP Project EW-201515

DECEMBER 2019

Patricia Rowley
Gas Technology Institute

Distribution Statement A
This document has been cleared for public release

Page Intentionally Left Blank

Page Intentionally Left Blank

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
15/12/2019

2. REPORT TYPE
ESTCP Case Study

3. DATES COVERED *(From - To)*
9/16/2015 - 3/16/2020

4. TITLE AND SUBTITLE
Gas Engine-driven Heat Pump (GHP) Cold Climate Field Demonstration

Case Study: Cold-Climate Demonstration of Natural Gas Engine-Driven Heat Pump and Electric Cold-Climate Heat Pump VRF Systems at Naval Station Great Lakes

5a. CONTRACT NUMBER
15-C-0075

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Patricia Rowley

5d. PROJECT NUMBER
EW-201515

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Gas Technology Institute
1700 South Mount Prospect Road
Des Plaines, IL 60018-1804

8. PERFORMING ORGANIZATION REPORT NUMBER
EW-201515

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Environmental Security Technology Certification Program
4800 Mark Center Drive, Suite 16F16
Alexandria, VA 22350-3605

10. SPONSOR/MONITOR'S ACRONYM(S)
ESTCP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
EW-201515

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A. Approved for public release: distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Variable refrigerant flow (VRF) heat pump systems are increasingly used in small commercial buildings in the U.S. as a high-efficiency heating and cooling option for multi-zone applications. However, the customized design and complexity of VRF configurations make it difficult to monitor and predict energy savings relative to baseline HVAC systems. Predicted energy savings are often based on energy modeling or data from controlled laboratory testing due to limited field data available for VRF systems, especially in colder climates. This ESTCP demonstration offered a unique opportunity to directly compare measured performance data for two VRF heat pump technologies to the baseline variable-air-volume (VAV) system and determine the potential energy and economic benefits for DoD facilities.

15. SUBJECT TERMS
Gas Engine-driven Heat Pump, GHP, Cold Climate, Natural Gas, Electric Cold-Climate Heat Pump, VRF Systems, Naval Station Great Lakes

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Patricia Rowley
UNCLASS	UNCLASS	UNCLASS	UNCLASS	10	19b. TELEPHONE NUMBER *(Include area code)* 847-768-0555

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Page Intentionally Left Blank

CASE STUDY

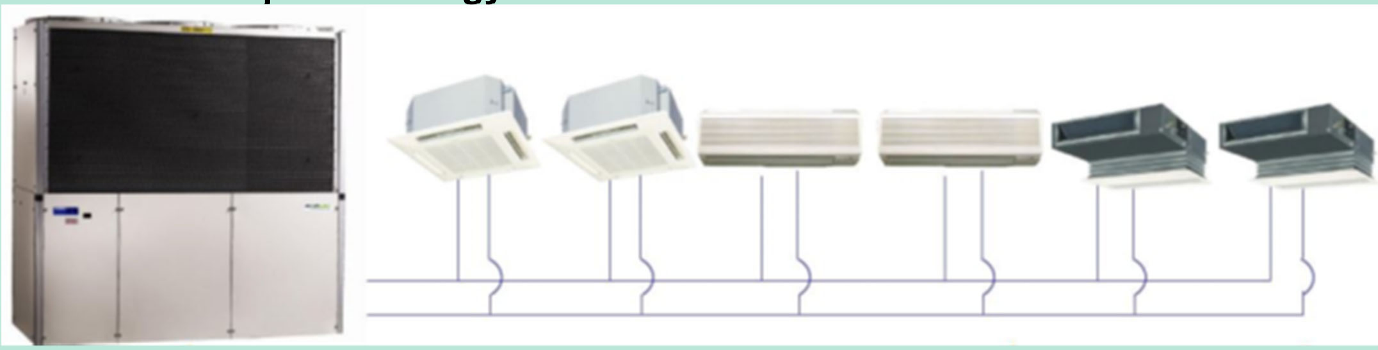
Cold-Climate Demonstration of Natural Gas Engine-Driven Heat Pump and Electric Cold-Climate Heat Pump VRF Systems at Naval Station Great Lakes

Variable refrigerant flow (VRF) heat pump systems are increasingly used in small commercial buildings in the U.S. as a high-efficiency heating and cooling option for multi-zone applications. However, the customized design and complexity of VRF configurations make it difficult to monitor and predict energy savings relative to baseline HVAC systems. Predicted energy savings are often based on energy modeling or data from controlled laboratory testing due to limited field data available for VRF systems, especially in colder climates. This ESTCP demonstration offered a unique opportunity to directly compare measured performance data for two VRF heat pump technologies to the baseline variable-air-volume (VAV) system and determine the potential energy and economic benefits for DoD facilities.

GTI conducted a side-by-side demonstration of two VRF heat pump technologies that offer significant potential for energy and cost savings, as well as improved comfort with zoned temperature control. One VRF system was a natural gas engine-driven heat pump (GHP)—an emerging technology designed to reduce peak electric demand and generate savings in both annual energy costs and life-cycle costs compared to conventional equipment. The second VRF system was an electric cold climate heat pump (CCHP)—a relatively mature technology, designed for colder ambient conditions without supplemental heating. Both VRF systems demonstrated improved comfort along with energy savings, reduced peak electric demand, and lower lifecycle costs compared to the baseline VAV system.

This study was conducted by GTI under the sponsorship of Environmental Security Technology Certification Program (ESTCP). For more information contact ESTCP at https://serdp-estcp.org

How Heat Pump Technology Works



A heat pump provides cooling by moving heat from the indoor space into the outdoor air, similar to an air conditioner. The heat pump also operates in reverse to provide heating by moving heat from the outside air into the indoor air.

A scroll compressor, which evaporates and condenses refrigerant, enables the transfer of heat from one space to another. Unlike an electric heat pump, which uses an electric motor to drive the compressor, a GHP uses clean-burning natural gas in a combustion engine to drive its compressor. The use of a variable refrigerant flow (VRF) loop eliminates the need for space-consuming duct soffits and allows for the placement of air handlers within each dedicated zone.

Heat recovery from the engine jacket and exhaust supplement the GHP output, increasing overall system efficiency in heating mode and providing additional heating capacity at low temperatures. In contrast, electric heat pumps often require inefficient resistance heating to supplement the heat pump output at low outdoor temperatures.

For heating-dominated climates, the GHP's high heating efficiency has the potential to reduce energy costs, offsetting the cost premium of the equipment. Heat recovered from the engine is used to supplement heat output and maintain supply temperatures without any backup heating.

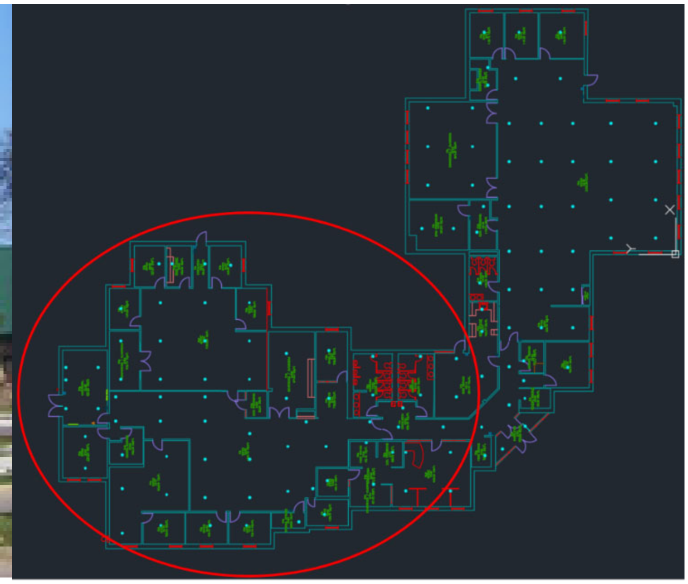
In cooling mode, GHP operating and maintenance costs are projected to be 30% less than electric-heat-pump equipment. In addition, GHPs significantly reduce peak electric demand and decrease electricity use by up to 80%. Since the air-cooled packaged unit does not require a cooling tower, annual savings in water consumption is estimated up to 17,000 gallons per 15-ton unit, compared to typical water-cooled electric chillers.

Additional benefits include:

- Multi-zone configurations provide heating and cooling for up to 33 zones
- GHPs can be configured with VRF fan coils for multiple zones or retrofit to existing hydronic systems
- Lower operating costs and lifecycle costs
- Reduced electricity use and peak electric demand
- Smaller footprint than conventional HVAC systems
- GHPs may qualify for demand-reduction incentives and credits

Specifications

- Heating COP: 1.2-1.4
- Cooling COP: 0.95-1.2
- Demonstration GHP (8-ton):
  - Cooling: 96,000 Btu/hr
  - Heating: 103,000 Btu/hr
- 8-ton or 15-ton units can be linked to provide up to 300 tons
- Installation Options:
  - Ducted or ductless VRF
  - Hydronic heat exchangers
  - Ground or roof-mounted outdoor unit
- R-410A refrigerant
- Designed to operate in extreme high and low temperatures
- Ultra-quiet operation



Demonstration

Site Configuration

The field site was a small multi-zone office building at Naval Station Great Lakes (NSGL) in North Chicago, Illinois (ASHRAE Climate Zone 5). The building was divided into two thermal zones, one served by the GHP and the other served by the electric CCHP. Since VRF systems typically do not provide ventilation, these were paired with a single dedicated outdoor air system (DOAS) sized to meet ventilation requirements and deliver supply air at space-neutral conditions.

An 8-ton GHP was specified to meet the cooling load for offices on the west side of the building. The GHP outdoor unit was installed with ten indoor VRF fan coil units with a total of 7.2 tons cooling capacity. The electric CCHP was specified for offices on the east side of the building. The 12-ton electric CCHP outdoor unit was paired with 10 indoor VRF fan coil units with a total of 6.8 tons cooling capacity. Both the gas and electric heat pumps featured in this demonstration used the same type of indoor VRF fan coil units and controllers provided by the same manufacturer.

Each VRF indoor fan coil was controlled by individual thermostat/controllers located in each conditioned zone. A central stand-alone touch screen controller (iTouch) installed in the building mechanical room was used to set zone temperatures and operating schedules for both VRF systems. The controller also has a BACnet/Lon interface option which can communicate with non-proprietary building automation systems.

Baseline Characterization

The existing baseline HVAC system was a 30-ton ground-mounted conventional variable-air-volume (VAV) system with reheat (9.5 EER, 80% TE). Prior to the VRF installation, GTI conducted a full year of baseline monitoring during the 2016 / 2017 to accurately characterize its performance across the range of operating conditions.

During heating operation, the baseline electric consumption was found to be higher than expected. Without a building automation system (BAS) for integrated controls, the central VAV gas heating and distributed VAV boxes operated independently, resulting in excessive electric resistance heating by the VAV boxes and a higher peak electric demand. Although the baseline system did not operate as designed, this may be typical VAV operation for smaller buildings or sites without a central BAS.

Demonstration Performance

Following the installation of the demonstration equipment, eighteen months of performance data was collected for both VRF systems and the DOAS. The demonstration equipment was extensively instrumented to measure gas consumption, electricity use, heating or cooling delivered, and interior room temperatures and humidity.

To determine energy savings, the measured energy use data was weather-normalized. Energy use for each VRF heat pump system was also normalized to the total building load to allow for a direct comparison to the baseline VAV system. This controlled for any changes in on-site routines or activities over the course of the baseline and VRF system monitoring.

GHP performance metrics were directly compared to CCHP to evaluate the performance objectives. Energy consumption for both VRF systems was also compared to the baseline. Site and primary energy, full-fuel-cycle GHG emissions and annual energy costs were calculated based on normalized energy use and regional energy prices. The NIST Building Life-cycle Cost program was used to determine life-cycle costs for each system.

Project Results

Peak Electric Demand Reduction:

Both VRF systems reduced peak electric demand by eliminating the electric resistance trim heating and the overcooling/reheat approach used in VAV systems.

- GHP/DOAS reduced peak electric demand 30 kW (82%) in cooling operation and 59 kW (90%) during heating compared to the VAV baseline.
- Compared to the CCHP, GHP reduced peak electric demand by 5 kW (36%) in cooling operation and 30 kW (82%) during heating.

Economic Benefits:

Both VRF systems reduced life-cycle costs.

- GHP/DOAS system reduced annual energy costs by 71% relative to the baseline and by 41% compared to the CCHP/DOAS
- Despite lower than expected part-load performance, GHP/DOAS life-cycle costs were 37% lower than the baseline and 4% lower than the CCHP/DOAS

Environmental Benefits:

Primary energy and full-fuel-cycle GHG emissions account for all upstream energy use (e.g. energy used to generate power, transmission losses, etc.) These parameters offer a more comprehensive approach to evaluate energy use than energy metered at the site.

- Both VRF systems reduced primary energy use by about 57% compared to the baseline.
- Both VRF systems reduced full-fuel-cycle GHG emissions by over 50% compared to baseline.

Comfort and Reliability:

- The site reported significant improvements in comfort with the VRF systems.
- Both VRF systems experienced operational limitations as well as some equipment installation and component issues which impacted reliability.

Conclusions

At this field site, CCHP and GHP VRF systems improved comfort while providing significant energy savings, lower peak electric demand, and lower life-cycle costs compared to the baseline VAV systems. These measured energy savings validate previous modeled estimates for VRF systems.

This field study compared an early-stage emerging technology (GHP) to a more mature technology (CCHP) with multiple manufacturers and decades of design optimization. These results suggest the need for additional GHP development to optimize part-load performance and reduce installed costs to support broader market adoption.

Several regulations apply to the use of VRF systems for DoD facilities (e.g. Unified Facilities Criteria UFC 3-410-01). These are addressed in detail in the full report.

Lessons Learned

This study demonstrated the potential energy and economic benefits of VRF technologies, and also identified some operational issues for cold climate applications.

- The CCHP was unable to meet the heating load for several days despite oversizing to meet the heating load. At low ambient temperatures, the CCHP operated at low efficiencies and did not meet zone setpoints. Supplemental electric resistance heat required for this site was estimated at 1591 kWh per year. This would increase peak electric demand to 60 kW with 34% higher energy costs largely due to demand charges. Supplemental heating would increase CCHP life-cycle costs by about 13%, reducing savings from 25% to 13% relative to the baseline VAV.
- This demonstration highlighted how VRF heat pumps regularly operate at very low part-loads even when sized appropriately. This is amplified when paired with a DOAS which may reduce facility heating or cooling loads.
    - Part-load operation adversely impacted the performance of both heat pumps; however, this specific GHP model had lower than expected performance at low part-load operation. GHPs use variable-speed engines to closely follow load and maintain efficiency. The extent of decreased part-load performance is not inherent in this class of technology and may be due to product-specific controls or engine sizing. This warrants further investigation.
    - GHP manufacturer specifications are based on full-load operation at select rating conditions and are not a good indicator of seasonal performance. GHP performance standards (ASHRAE, ANSI) are currently being revised to better reflect newer technologies such as VRF configurations. Updated performance metrics will also support the development of more optimized designs.
- The field site experienced a number of outages due to equipment installation issues and component failures of some conventional equipment (e.g. circuit breaker), highlighting the importance of well-trained installation and service providers, a common concern for emerging technologies.
- VAV systems are widely used for multi-zone applications such as office buildings. These systems may benefit from retro-commissioning and/or retrofitting integrated controls to improve efficiency and reduce energy costs for existing equipment.