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"Dynamic controls for hybrid and efficient RTUs"

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Abstract

This paper examines the use of dynamic control systems to optimize operating costs and reduce emissions in commercial hybrid (dual-fuel) rooftop units (hRTUs), while also highlighting the energy savings delivered by efficient rooftop units (eRTUs). Hybrid RTUs can switch between electric heat pump and gas furnace modes, providing operational flexibility that supports either economic or environmental goals. eRTUs further enhance efficient energy delivery through advanced design features.

To evaluate the performance of dynamic controls using real-time utility tariff data and regional emission factors via cloud integration, four hRTUs were installed in Virginia, USA for baseline and demonstration monitoring from August 2024 to August 2025. The study compares dynamic control strategies and energy delivery with conventional static switchover methods and gas-only furnace baselines, focusing on cost savings and emissions reduction.

The paper will present the outcomes of implementing dynamic control systems and efficient design elements, emphasizing improvements in cost-effectiveness and environmental impact through real-time, data-driven decision-making. It also addresses limitations encountered during the study and offers recommendations for enhancing the feasibility and performance of such systems in future commercial HVAC applications. This research supports the advancement of smarter, more adaptive HVAC technologies aligned with variable energy pricing and evolving emissions standards.

Keywords: RTU; efficient; hybrid; dual-fuel; smart controls

1. Introduction

Commercial hybrid (dual-fuel) rooftop units (hRTUs) are a growing market segment with the unique capability to switch between electric heat pump and gas furnace operating modes, offering flexibility for reducing energy costs and/or environmental impact. Switchover between operating modes can be based on a selected outdoor air temperature (OAT), an economic or emissions balance point, or capacity balance point. While often set during initial startup and commissioning, the actual optimal switchover point is highly variable, subject to local real time electric and gas utility rates, operating conditions, and building load characteristics. Presented in this paper, the field demonstration implemented an advanced dynamic fuel-switching controller to optimize in real time the heating fuel source for lowest cost or emissions.

Additionally, the demonstration equipment qualified for "better than standard" efficiency tiers based on research by Northwest Energy Efficiency Alliance (NEEA) [1]. Added cabinet insulation thickness and low leakage dampers cost effectively reduce delivered energy losses to ambient and meet the building load demand with less overall.

Project objectives were to compare dynamic control strategies and delivered energy against traditional static switchover and gas-only furnace baselines, analyzing their impact on cost savings and emission reductions. This paper will detail the successes of the dynamic control system and design features in terms of cost efficiency and emission performance, highlighting the key benefits of real-time, cloud-integrated decision-

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making. Additionally, the limitations and challenges faced during the study will be discussed, providing valuable insights into the feasibility and recommendations for future improvement of such systems in commercial applications. This research aims to contribute to the development of more intelligent, flexible HVAC systems capable of adapting to fluctuating energy prices and emission regulations.

2. Methods

In this demonstration, hybrid and efficient RTUs were installed in Virginia, USA in IECC climate zone 4A. The installed equipment is a premium commercial RTU, featuring characteristics qualifying for the NEEA advanced efficiency tiers including low leakage dampers and R12 cabinet insulation. The RTU has a rated efficiency of 3.4 Coefficient of Performance (COP) at 47°F (8.3°C) ambient temperature which decreases to 2.2 COP at colder ambient temperatures (17°F (-8.3°C)). The design includes a supplemental non-condensing gas-fired furnace with a 12:1 turndown ratio and rated at 80% thermal efficiency. Additionally, the RTU is capable of utilizing both the electric heat pump and gas furnace simultaneously as needed to meet the space heating demands. Each installed RTU was instrumented with sensors to record air flow rate, temperature, and relative humidity for the supply and return ducts, outdoor air temperature, relative humidity and site barometric pressure, gas flow volume and pressure, and unit power consumption. Data was averaged over 30 second intervals for logging and analysis completed in hourly, daily, and seasonal time periods.

Prior to installation of the demonstration equipment, the existing RTUs with gas heating only were monitored for baseline comparisons. When the demonstration equipment was installed, performance was established at the minimum switchover temperature (0°F / -18°C) for operation prioritizing electric heat pump heating mode and at the maximum switchover temperature (50°F / 10°C) for operation predominantly in gas furnace heating mode when the ambient temperature was below the switchover temperature. With performance characterizations at each extreme, modeling could extend the measured data to evaluate intermediate switchover setpoints and advanced control strategies.

Upon establishing the characterizations for each RTU operating mode, dynamic fuel switching controls were implemented. These controls, supplied by a third-party, automated adjustment of the switchover temperature to induce the lowest cost or lowest emission operating mode with cloud-based integration of real-time utility rates and North American eGrid emissions. Electric utility rate tariffs had a seasonal peak/off-peak time of use rate with moderate demand charges. Posted online one day in advance, the local utility classifies each upcoming day as "A", "B", or "C", each with a set rate schedule and varying peak periods. The dynamic controller successfully captured the daily change in rates and relayed the desired switchover temperature to the RTU.

3. Results and Discussion

Key insights from the demonstration included impact of the eRTU tier 1 design features, application of the dynamic controller, and additional considerations of the system and controller. Details of each insight follow.

3.1. eRTU Design Features

As previously described, the demonstration RTU includes low leakage dampers and R-12 cabinet insulation. These design features reduce parasitic losses between the outdoor RTU and ambient; in other words, a greater percentage of the exchanged heat by the heat pump or gas furnace is delivered to the conditioned space instead of being lost to the environment, thereby reducing the overall load required from the RTU.

In comparison of the demonstration RTU with the baseline equipment, there was a difference in the discharge air temperature (DAT) setpoint. With gas furnace heating only, discharge air from the baseline equipment was near 100°F (37.8°C) while the demonstration RTUs with heat pumps and supplemental gas furnace heating were set to deliver 90°F (32.2°C). Measured return air temperatures (RAT) also varied, with the average return air while operating in heating mode was 2°F (1.1°C) lower with the demonstration RTUs, summarized in Table 1. Air flow rates were similar for both baseline and demonstration periods. A temperature correction was applied to normalize the two data sets to a common temperature difference, 90°F (32.2°C) DAT and 70°F (21.1°C) RAT.

Table 1: Air Temperature Comparison

Metric	Baseline Conventional RTU	Demonstration Dual-fuel RTU
Average Delivered Air Temperature (DAT)	95°F / 35°C	90°F / 32.2°C
Average Return Air Temperature (RAT)	71.5°F / 21.9°C	69.5°F / 20.8°C

Figure 1 presents the results from the field demonstration after normalizing the temperature difference. On a daily basis, the heat energy delivered by the demonstration RTU ranged from 2% to 10% less than the baseline RTU. These results are in agreement with expectations from NEEA eRTU research.

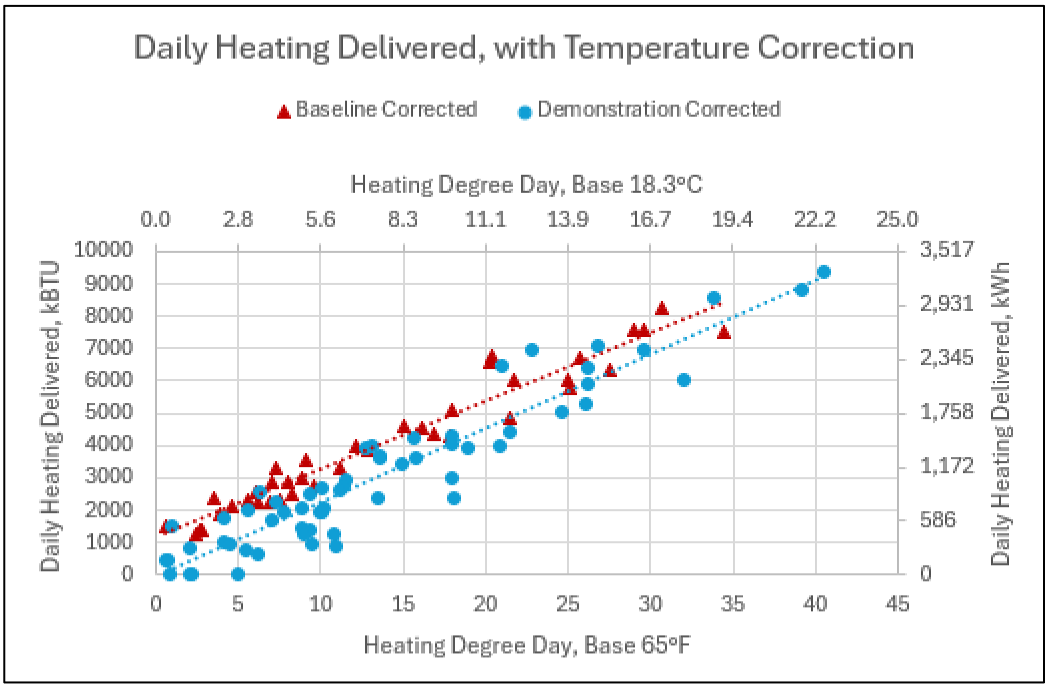

Figure 1: Daily Energy Delivered by Baseline and Demonstration RTUs

3.2. Application of dynamic smart fuel switching controller

The most cost-effective operating mode in heating, electric heat pump or gas furnace, is dependent on the local utility prices, ambient temperatures and the equipment efficiency. Utility prices can vary at different time scales by provider. Rate structures include fixed rates that may be set for each month, time-of-use (TOU) rates that follow a set daily schedule with hourly known rates for peak or off-peak designated hours, or dynamic real time pricing that can fluctuate throughout the day in intervals as short as 5 minutes. The benefit of the smart fuel switching controller is to automatically respond to any changes in utility price when optimizing for operating cost by selecting either electric or gas heating operating mode. Similar optimization is available for GHG emissions. The energy consumption, whether electric or gas, is dependent on the energy demand of the building load, and the part-load efficiency of the RTU at the actual ambient conditions.

For the purposes of the smart controller, the rated efficiency curves are input to the control algorithm for the installed equipment. A future enhancement could be machine learning algorithms that can map unit energy use to outdoor air temperatures to develop a site-specific characterization curve, if appropriate power consumption or gas meter data is available. As shown by the graph in Figure 2, based on measured data from the field site, the actual efficiency of the heat pump (blue) fell short of the rated conditions (green) extrapolated from 47°F (21.1°C) and 17°F (-8.3°C) rating points.

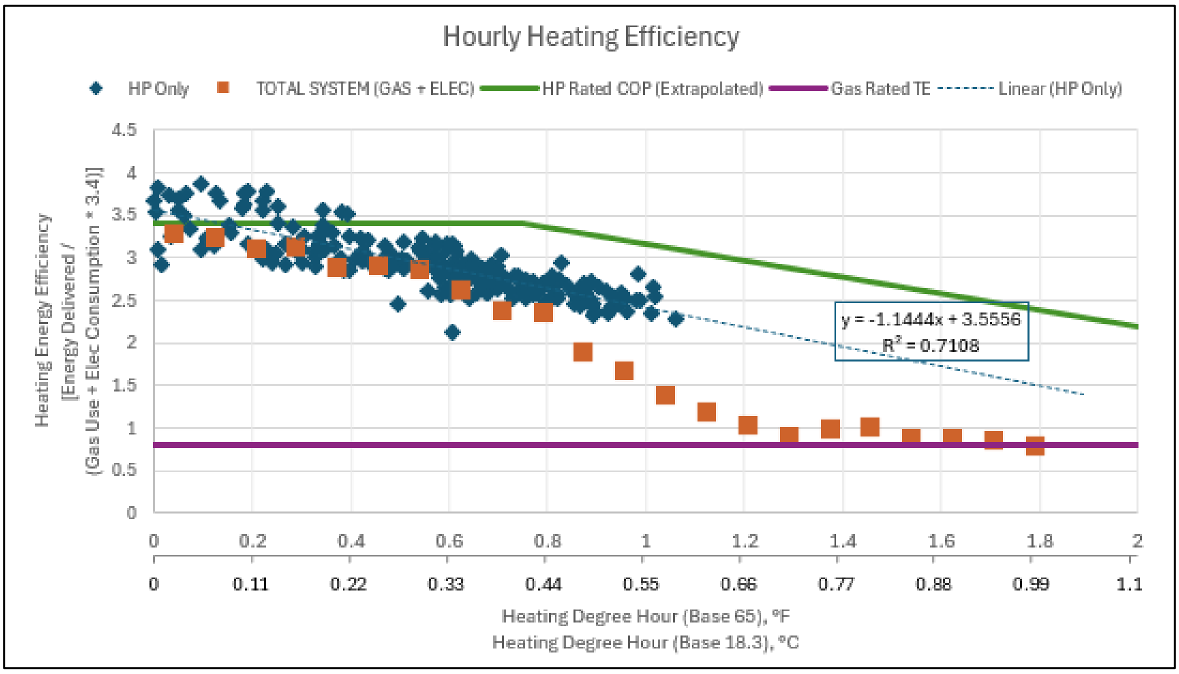

Figure 2: Actual vs rated heat pump and system efficiency

Selection of the heating fuel source to optimize operating cost is a function of the electric to gas price ratio (E/G) in common units, and the ratio of heat pump efficiency to gas furnace thermal efficiency (ER). If E/G exceeds the ER, the gas furnace is the lower cost fuel source, and vice-versa. One of the limitations of available third-party smart fuel switching controllers are utilization of fixed efficiency curves, which do not take into account the impact of field conditions on performance rather than published test conditions. Commercial RTUs in particular, in the North American market, are rated to specifications in AHRI Standard 340 [2] with 70°F (21.1°C) indoor dry bulb and 47°F (8.3°C) outdoor dry bulb. Actual conditions at the indoor coil are usually cooler due to mixing outdoor air with return air to meet minimum ventilation requirements specified in ASHRAE Standard 62.1 [3]. In the field demonstration, mixed air temperatures were as low as 50°F (10°C), impacting the actual heat pump efficiency for a given outdoor air temperature compared to the published ratings utilized by the controller.

Figure 3 presents the E/G ratio, the rated efficiency ratio (ER), and the actual measured ER by hour during the project monitoring period. Of note, with the utility rate structure, there were only 2 designated "A" classification days occurring during winter heating season. On those days, the E/G ratio during the peak rate period was near 8, well above the ER and would favor gas heating, while at the off-peak period the E/G was

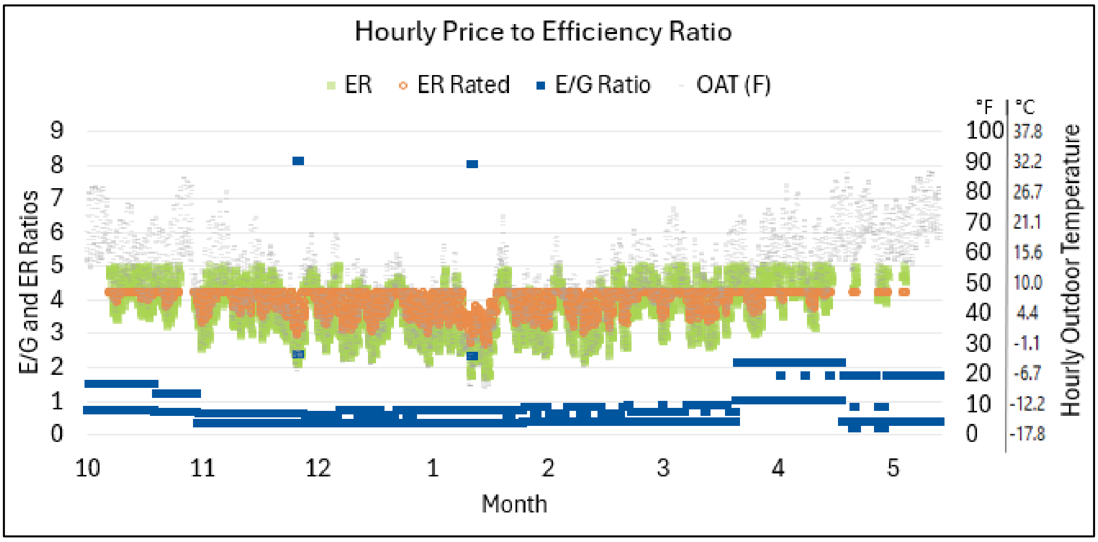

Figure 3: Hourly Electric to Gas (E/G) Price Ratio and Efficiency Ratio

near 1 and favors electric heat pump operation. An intermediary rate period is of interest as the E/G ratio above 2 falls between the ER based on the rated efficiency of the heat pump (orange) and the actual efficiency at the operating conditions (green). Controls as implemented would operate in heat pump mode even though the actual fuel source for optimized cost would have been gas heating.

Smart fuel switching controls are most applicable where the E/G and ER ratio is the same, i.e., the ratio of E/G to ER is near 1 during the heating season. At the field demonstration, except for a handful of "A" classified days, the optimal operating mode based on current utility rates, load, and equipment performance favored the electric heat pump. Ambient temperatures were relatively mild during the monitoring period. Cost savings to implement the smart fuel switching controller were minimal; similar annual operating costs and performance could be obtained with a conventional fixed switchover temperature.

Other locations with varying utility rates and colder ambient temperatures could benefit from the dynamic controls. Figure 4 highlights locations in the USA where the E/G to ER ratio is near 1 in red and would be good candidates for the advanced controls. Locations colored blue have low average commercial electric rates relative to gas utility rates and would favor primarily electric heat pump operation. Conversely, states colored grey have high electric utility rates compared to gas and would favor gas heating. As the figure is based on average commercial EIA rates [4,5], each application should consider actual site specific utility rates.

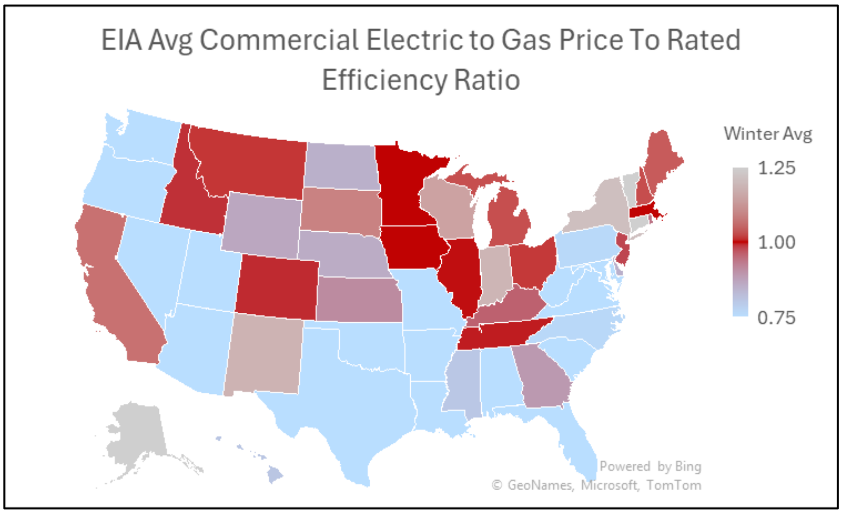

Figure 4: Winter Average 2024 EIA Commercial E/G to ER Ratio by USA State

3.3. Additional Considerations

As discussed, equipment part-load efficiency and site specific utility rates play a major role in optimizing the fuel source for heating in dual-fuel hRTUs. Commercially available third-party controllers continue to develop and address deficiencies such as lack of consideration for electric demand charges and improvements to characterizing the equipment performance beyond the published rating points. For this demonstration, it was also evident that the electric utility pricing was manually populated in a lookup table in the controller algorithm, with dynamic updating for the day classification only. The local utility pricing changed from winter to summer months, yet the controller continued operating unchanged, and required manually updating the monthly gas price. While daily classifications were automated over the cloud integration, more work is necessary to obtain real time electric and gas utility pricing, and ensure it contains the total utility costs, including transmission, delivery, supply and demand charges for commercial applications.

Evaluation of return on investment for dynamic controls also needs to consider when ideal fuel source switching would occur. In the example of this study, the "A" classified days occurred on the 2 coldest days of winter, at temperatures near or below the capacity balance point of the hybrid RTU. If the heat pump capacity cannot meet the building load, the gas heating would engage regardless of the switchover temperature set by the smart controller. In a similar vein, the heat pump in the demonstration was capable of lifting the mixed air temperature by up to 25°F (13.9°C). Depending on the DAT setpoint, the system supplements the heat pump with gas heating (both electric heat pump and gas furnace simultaneous operation) if the mixed air temperature at the evaporator coil is more than 25°F (13.9°C) below the DAT. Combined supplemental gas and electric heat pump heating further muddles the value proposition of the dynamic controller. The system prioritizes meeting the space conditioning load and comfort over the optimal cost or emissions operating mode. Lower DAT would shift more operating time to the electric heat pump if the switchover temperature is below the OAT, but needs to consider the tradeoff of lower air temperatures delivered to the space and the impact on occupant thermal comfort and increased equipment run time to meet the load.

4. Conclusion

Advanced controls to switch fuel source based on optimizing operating costs favored heat pump heating at the demonstration site due to the utility rate schedule and mild ambient temperatures. A smart fuel switching controller would be beneficial in locations where the electric to gas price ratio (E/G) is similar to the ratio of electric heat pump efficiency to the gas furnace thermal efficiency (ER). When the ratio of E/G to ER is well below 1, electric heat pump heating would be favorable, and well above 1, gas heating would be favorable. Multiple factors need to be considered to determine the optimal switchover temperatures for the lowest operating cost. A key parameter is the local E/G ratio (on a cost per common unit of energy basis). Those E/G ratios vary from over 5 to less than 2 across the USA, and in this particular location, the E/G ratio was relatively low below 2 for "B" or "C" day classifications, favoring more electric heat pump operation. Similar results play out for emissions, depending on the fuel mixture of local power generation.

Controller cost, local emission factors, or efficiency optimization would be well received by facility energy managers, but the infrastructure to fully implement these algorithms is lacking. Discussions with utility service providers, aggregators, or policy makers to publish real time utility pricing rates via Application Programming Interfaces (APIs) would unlock innovative solutions for advanced controllers, followed by new demonstrations to verify implementation results.

Finally, most commercial cost optimization routines lack user input options for demand charges and actual equipment performance curves. Machine learning algorithms that adapt to actual energy usage of installed equipment could address the efficiency discrepancy and continually improve energy use predictions. Algorithms incorporating demand charges would benefit from the addition of a power demand switchover setpoint to alleviate potential for heating demand charges in excess of typical summer A/C peaks. Modeling studies with the gas and heat pump characterizations could quantify demand charges avoided. While the demonstration site had minimal demand charges, these costs can range up to 20 times higher across other locations in the USA.

The project successfully demonstrated the potential of retrofit dynamic control systems to adjust the controller switchover temperature using actual utility rates via cloud integration. Using the measured field data, the project team identified key parameters for optimal algorithms with methods to identify ideal locations to implement the advanced controls. Continued development with the recommendations discussed would enhance the feasibility and performance of efficient and hybrid RTUs, advancing smarter, more adaptive HVAC technologies aligned with variable energy pricing and evolving emissions standards.

Acknowledgements

These and the Reference headings are in bold but have no numbers. Text below continues as normal.

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