Drop-in Decarbonization with Smart Fuel-Switching RTUs

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ABSTRACT

Packaged commercial rooftop units (RTUs) are experiencing a noteworthy shift towards incorporating both electric and fuel-fired technologies. In response to the inherent capacity and efficiency challenges of air-source heat pumps (ASHPs) in cold climates, more than six HVAC manufacturers now offer “dual-fuel” or "hybrid" RTU systems that combine an electric heat pump design with supplemental gas heating in lieu of electric resistance backup heating. These hybrid RTUs present a promising approach for reducing greenhouse gas emissions (GHGs) and utility costs, particularly with enhanced controls.

Hybrid RTU controls commonly feature a static switchover triggered by an outside air temperature sensor, transitioning from heat pump to fuel-fired heating. Advanced systems may base switchover on factors like equipment capacity, efficiency, estimated GHG emissions, or utility pricing, while still ensuring occupant comfort. This paper explores switchover decision strategies using performance results from field applications of hybrid RTUs.

For "smart" controllers, fuel-switching within a hybrid RTU can occur dynamically based on various decision criteria. Exploring the selection of the most emissions-effective or cost-effective energy source to meet building loads is a key focus in this paper. Ahead of field demonstrations, a modeled 40°F switchover point was deemed cost-effective, a finding validated during the demonstration with a 24% shift of the heating load from the gas furnace to the heat pump system while delivering more cost savings than anticipated (15%) and providing immediate decarbonization with 8% GHG reductions. These real-world insights can inform the development of grid-interactive control strategies, addressing emission-based or economic-based objectives.

Introduction

The escalating concern over human-induced climate change has sparked increasing interest in reducing carbon emissions within the building energy sector. In recent years, there has been a notable surge in the adoption of higher efficiency technologies, alongside initiatives to transition to electrification, implement peak shaving strategies, bolster resilience, and more. These trends have received significant support from the HVAC industry, which continues to offer emerging technologies with higher performance, more sophisticated controls algorithms, and varying fuel choices. In parallel, opportunities for decarbonization are complicated by wide variations in regional source energy emissions, high upfront costs for higher efficiency equipment, and the considerable learning curve required to effectively operate emerging technologies.

Despite these challenges, building owners continually seek ways to reduce the cost of building ownership without reducing occupant comfort or increasing tenant turnover. Fluctuations in energy prices create challenges for building owners to control energy costs. Natural gas prices have experienced notable increases in recent years with significant volatility.

While annualized electricity prices have generally had more stability than natural gas prices over the last few years, regional and temporal variations exist, particularly on hourly pricing rate structures. In addition, fuel sources for electricity generation also vary regionally, and can fluctuate on an hourly basis due to the intermittent availability of renewable energy sources like solar and wind. Demand costs for electricity energy sources can vary significantly at smaller time frames. Significant variations in real-time electricity costs and source emissions mean that the cheaper or cleaner fuel source for equipment operation at the point of use can change rapidly. These constraints can lead building owners to a crucial question: which fuel type is preferred in each region, and at different times to facilitate decarbonization, while also not substantially increasing operating costs? One solution that can solve this question is the adoption of emerging HVAC technologies with smart fuel-switching capabilities.

Technology Overview

One of the most ubiquitous HVAC technologies for light commercial buildings are packaged rooftop units (RTUs); with 37% of commercial buildings using RTUs (representing 50% of the total commercial floor space) (DOE 2018). There are approximately 15 million RTUs on commercial buildings in the U.S. (Deru et al. 2020). Meanwhile, a much smaller market share is held by heat pumps, at 11% (representing 15% of the total floor area) predominantly in warmer climates. RTUs are packaged forced air units integrating heating, cooling and ventilating equipment to serve a specific zone or tenant space. RTUs typically incorporate an air handler to distribute conditioned air through building ductwork, along with an electrically-powered compressor with direct expansion (DX) coil to provide cooling. Heating is provided by either a natural gas-fired furnace or various electric heating methods, including resistance heaters or heat pumps. RTUs that combine a heat pump, which are highly efficient electrical systems, along with a natural gas-fired furnace as heating backup, present a promising option to reduce the overall cost of building ownership, potentially lowering energy consumption and GHG emissions in light commercial buildings while maintaining occupant comfort.

RTUs equipped with natural gas-fired furnaces typically meet minimum federal efficiency standards, with an AFUE (annual fuel utilization efficiency) of about 81% (DOE 2014), but rarely exceed that. While there are more efficient condensing furnaces available, their adoption is uncommon due to limited suppliers, higher installation costs and complexity, and increased maintenance requirements. RTUs with heat pumps use the same DX system with electric compressors to provide cooling in the summer months, operating them in reverse during winter to provide heating. While heat pumps demonstrate high efficiency in warmer weather conditions , they generally tend to deliver less heat at lower efficiency as outdoor temperatures decrease (Schoenbauer et al 2016).

To meet high heating loads during extreme cold weather, many heat pump RTUs rely on supplemental electric resistance heaters. Electric resistance heat is highly inefficient, earning the lowest possible COP[3] of 1.0. Some manufacturers activate backup heat when the thermostat setpoint is typically 2°F or more above the indoor temperature after the unit has been operating for 15 minutes or more, indicating that the system needs more heating capacity than the heat pump can deliver. Heat pumps should be properly sized, installed, and operated so that supplemental heat is rarely used, because even occasional use of electric resistance heat can significantly increase monthly electricity demand, usage, and associated expenses. Unexpectedly high utility bills due to the use of supplemental electric resistance heat can be an unwelcome surprise at facilities owners with heat pumps.

In response to fluctuations in energy prices, and heat pump capacity and efficiency losses during cold weather, several HVAC manufacturers now offer “hybrid” or “dual fuel” systems. Hybrid RTUs are packaged systems that include both a gas furnace and a heat pump. Instead of using electric resistance heaters at low ambient temperatures, a hybrid RTU runs the gas furnace to deliver supplemental heating as the heat pump capacity drops. This system design also offers greater heating system flexibility compared to AC-only/gas furnace or heat pump-only systems. In the event of a failure in either heating system, the other system remains operational to provide heating, or at least partial heating, to the building. Hybrid or dual-fuel system controls incorporate a “change-over” temperature setting, also referred to as "crossover" or “switch-over” by manufacturers. This temperature represents an outdoor threshold above which the system will prioritize running the heat pump if all other conditions are favorable, and below which it will activate the gas furnace.

Smart Fuel-Switching RTUs

While the dual-fuel switching capability of Hybrid RTUs is crucial for decarbonization potential, the dual-fuel system controls are just one component of the full controls strategy of the RTUs. To operate in compliance with code and standards, the RTUs must employ a variety of other sophisticated controls to optimize space conditions and introduce outside air ventilation to the conditioned space. Then, dynamic fuel-switching can add an additional layer of control.

Occupancy/Ventilation Control

Occupancy of each conditioned space is typically determined by either an installed CO_2 sensor located in the return air duct, or by a manual override occupancy button on the local thermostat. The controls of the RTU will change based on the presence or absence of occupancy. This controls strategy functions similarly to a set-back that conserves energy to maintain minimal ventilation and space temperature when the space is unoccupied.

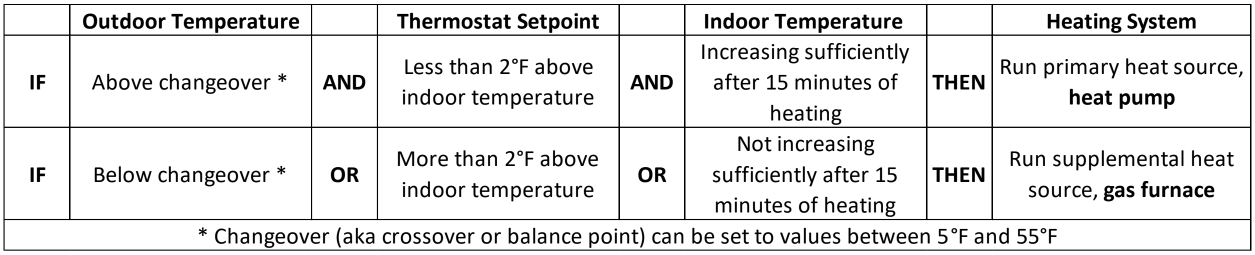
During periods of occupancy, the OA damper and airflow is configured to meet the minimum required airflow of as required to maintain building positive pressure by ANSI/ASHRAE Standard 62.1-2013, up to a maximum outdoor airflow as required by ASHRAE 62-2001 and ASHRAE 55-2004 for ventilation and indoor air quality.

Space Conditioning Fan Control

Local thermostat heating calls will be sent to the RTU controller, with the 2000 CFM supply fan modulated to maintain the supply air (SA) temperature at 105° F. The fan speed is modulated to meet the load. Local thermostat cooling calls will be intercepted by the RTU controller. The RTU will turn on compressors and modulate the indoor supply fan and compressor speeds to maintain the room temperature set point.

Switchover Point Operating Protocol

To determine whether the RTU operates in conventional natural gas furnace heating or heat pump heating, the unit first must determine if all other conditions are favorable. If so, then using an installed outside air temperature (OAT) sensor, the unit determines if the OAT is above or below a “change-over” temperature set on the controller. Figure 1 shows the generic control logic used by one HVAC manufacturer’s Hybrid RTU to decide whether to run the gas furnace or heat pump. For some manufacturers, the default “change-over” is the outdoor temperature where the heat pump capacity and the building load match. Therefore, change-over point is a function of the equipment, building and the climate. If the outdoor temperature is higher than the change-over point, equipment can provide extra capacity to the building. If the outdoor temperature is lower than the balance point, equipment has shortage of heat pump capacity to meet the load.

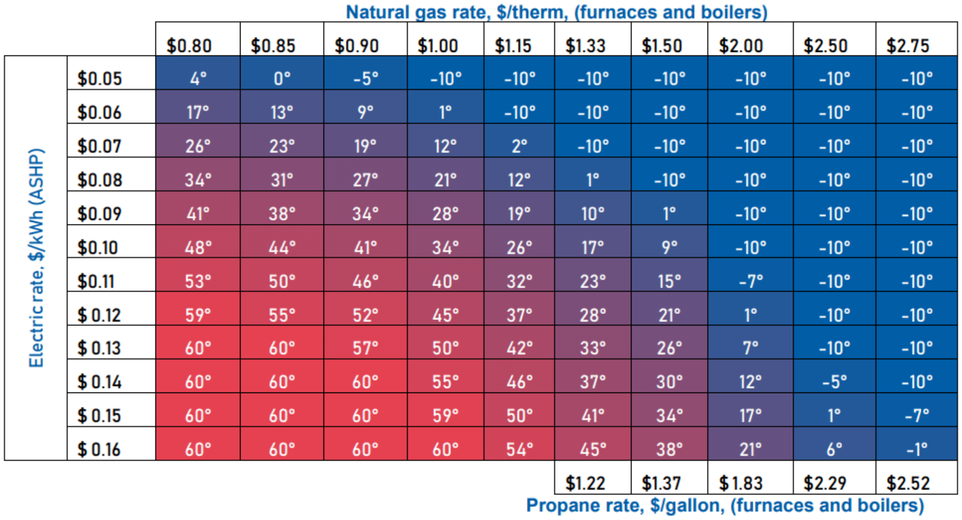


	Outdoor Temperature		**Thermostat Setpoint**		**Indoor Temperature**		**Heating System**
IF	Above changeover *	**AND**	Less than 2°F above indoor temperature	**AND**	Increasing sufficiently after 15 minutes of heating	**THEN**	Run primary heat source, **heat pump**
IF	Below changeover *	**OR**	More than 2°F above indoor temperature	**OR**	Not increasing sufficiently after 15 minutes of heating	**THEN**	Run supplemental heat source, **gas furnace**
* Changeover (aka crossover or balance point) can be set to values between 5°F and 55°F							

Figure 1: Example of hybrid RTU switchover controls sequencing. *Source:* Trane

While the change-over point can be changed from a wide range of OATs, some manufacturers have set the default changeover temperature to 40°F since it allows for heat pump heating operation to occur when efficiency is highest and does not allow for it when its performance decreases. A change-over point of 55°F would result in the RTU almost exclusively using the gas furnace for heating calls, and a change-over point of 15°F would result in the RTU using the heat pump as much as possible until conditions were too cold for it to meet loads. At colder temperatures, the heat pump capacity and performance typically decreases, even if variable speed (Marsik et al 2023).

This switchover setpoint is the focal point in optimizing the tradeoff between operational costs and GHG emissions since each of these results is based on different variables (equipment capacity and efficiency, regional energy source emissions and local utility costs). To help determine the most economical heating source, some energy programs and utility websites offer static calculator tools to determine what ambient outdoor temperature should be used to switchover from heat pump to furnace operation, based on local utility rates. One sample decision matrix for a static switchover setpoint, assuming the heat pump can meet the load, is shown in Figure 2 for varying electric rates, gas rates, and propane rates:



Natural gas rate, $/therm, (furnaces and boilers)

Electric rate, $/kWh (ASHP)	$0.80	$0.85	$0.90	$1.00	$1.15	$1.33	$1.50	$2.00	$2.50	$2.75
$0.05	4°	0°	-5°	-10°	-10°	-10°	-10°	-10°	-10°	-10°
$0.06	17°	13°	9°	1°	-10°	-10°	-10°	-10°	-10°	-10°
$0.07	26°	23°	19°	12°	2°	-10°	-10°	-10°	-10°	-10°
$0.08	34°	31°	27°	21°	12°	1°	-10°	-10°	-10°	-10°
$0.09	41°	38°	34°	28°	19°	10°	1°	-10°	-10°	-10°
$0.10	48°	44°	41°	34°	26°	17°	9°	-10°	-10°	-10°
$0.11	53°	50°	46°	40°	32°	23°	15°	-7°	-10°	-10°
$ 0.12	59°	55°	52°	45°	37°	28°	21°	1°	-10°	-10°
$ 0.13	60°	60°	57°	50°	42°	33°	26°	7°	-10°	-10°
$ 0.14	60°	60°	60°	55°	46°	37°	30°	12°	-5°	-10°
$ 0.15	60°	60°	60°	59°	50°	41°	34°	17°	1°	-7°
$ 0.16	60°	60°	60°	60°	54°	45°	38°	21°	6°	-1°
Propane rate, $/gallon, (furnaces and boilers)						$1.22	$1.37	$1.83	$2.29	$2.52

Figure 2: Dual fuel switchover setpoint at various fuel costs *Source:* MN ASHP Collaborative

Two crucial metrics for Hybrid RTU technology are the energy cost sensitivity per utility region and associated GHG emissions for each fuel source. To enhance heating performance incrementally by comparing heat pump heating to gas furnace heating, the relative costs and GHG emissions of electricity versus natural gas must be sufficiently favorable. If natural gas is excessively cheap or electricity overly expensive, Hybrid RTU implementation becomes economically unfeasible. To facilitate comprehension of utility costs most favorable to Hybrid RTU retrofit, the Utility Cost Ratio (UCR) metric is calculated and compared.

$$UCR = \frac{Gas\ Cost\ \left(\frac{\$}{therm}\right)}{Electricity\ Cost\ \left(\frac{\$}{kWh}\right)}$$

For equivalent gas and electricity usage, the UCR determines the significance of overall energy cost savings that result. When replacing a conventional RTU, it is important to recognize that a Hybrid RTU heat pump operation uses electricity when heating compared to the baseline gas furnace, and with the heat pump operating more, electricity usage will increase, while gas use will decrease. In order to maximize the cost savings, the UCR can be used to help inform the cost effectiveness of varying switchover points. Figure 3 below shows the range in switchover points desired given different UCR’s. Assuming no reduction in heat pump capacity and performance, a UCR of 9 would indicate an optimal switchover temperature is 20°F.

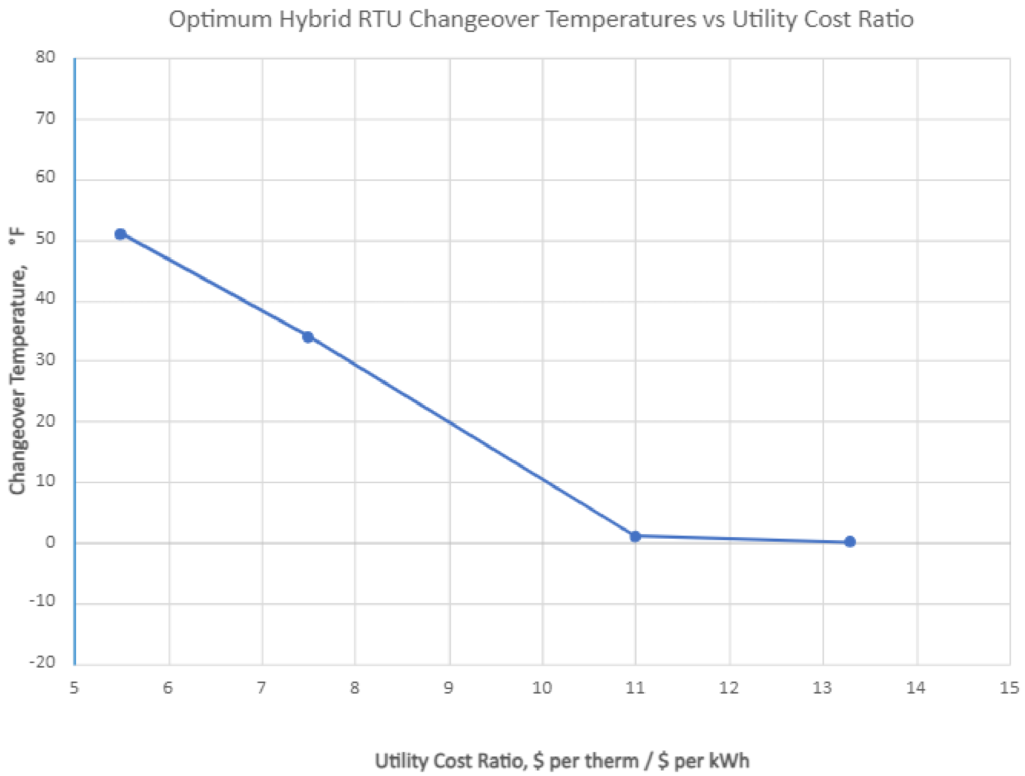


Figure 3: Switchover setpoints based on UCR for Illinois utility rates. *Source:* GTI Energy

While cost effectiveness drives many decisions, Hybrid RTUs bring decarbonization potential as well. The extent of GHG savings achievable with a retrofit Hybrid RTU heavily depend on the source energy and emissions factor of the fuel and regional electricity. In regions with extensive renewable energy adoption and coal-fired generation retirement, electricity tends to be cleaner with lower GHG emissions. Understanding these factors for natural gas and electricity in a given region clarifies the extent of GHG savings.

A recent development is the prevalence of internet-enabled communications being deployed on standalone RTU systems as a general industry trend. When cloud-connected capability is added to a Hybrid RTU there is added potential to create an interactive system capable of looking at dynamic grid emission rates and electrical pricing in real-time, and determining which fuel source to use for heating. This technology has been developed and is in a pre-commercial stage with some technology providers, but offers promise for cloud-connected smart Hybrid RTUs.

Modeling Scenarios to Optimize Cost and/or GHG Emissions Savings

As the market for Hybrid RTUs increases, particularly in retrofit applications, and the overall knowledge of their installations increases, the ultimate decision on “change-over” set-points typically lies with the facility or with the commissioning agent. For the facility, the set-point can be chosen to minimize operational energy costs to condition the space. With a smart fuel-switching controller in the future, there is a potential scenario where controlling the fuel source may be in the electric utility’s best interest to help dynamically manage winter peaks during periods of high energy demand, and/or to somewhat optimize reducing GHG emissions. The decision between low-cost and low-carbon control strategies have the potential to create tension as lower-cost may result in more GHGs if marginal electricity generation is met with fossil fuel power generation.

With multiple Hybrid RTU pilot demonstrations being retrofitted on a commercial office building in southern IL, modeling was performed for a conventional gas furnace RTU and a Hybrid RTU based on Typical Meteorological Year (TMY) Hourly Normal data, the operation and performance of each RTU was determined. The conventional RTU was modeled using a simple load-based approach using hourly OATs and specific performance ratings, while the Hybrid RTU followed a similar approach filtering for OATs above and below a "change-over" set-point using two performance ratings for natural gas heating, and heat pump heating. Other inputs include the gas furnace heating capacity and heat pump heating capacity.

The following section uses the modeling used in a previous section of this paper to illustrate the wide range of outcomes for the demonstration building manipulating the change-over" set-point. The two scenarios were assessed:

1. Baseline Gas Furnace RTU
2. Retrofit Hybrid RTU with 40°F OAT "switch-over" based on fuel cost-effectiveness

Modeling was based on TMY hourly outside temperature data for Southern IL Airport (ASHRAE Climate Zone 4) leveraging a dataset from a recent field demonstration of a Hybrid RTU for heating delivered and OATs. The Table 1 below highlights the two RTU scenarios and their inputs to the modeling.

RTU:	Gas Heating Output Capacity (MBH)	Gas Thermal Efficiency (%)	Heat Pump Heating Output Capacity (MBH)	Heat Pump COP at 47°F
Baseline Gas Furnace	96	80%		
Retrofit Hybrid	96	80%	51.5	3.98

Table 1: Baseline and retrofit RTU specifications

First, Figure 4 shows the baseline modeling illustrated a scenario for a conventional gas furnace heating RTU.

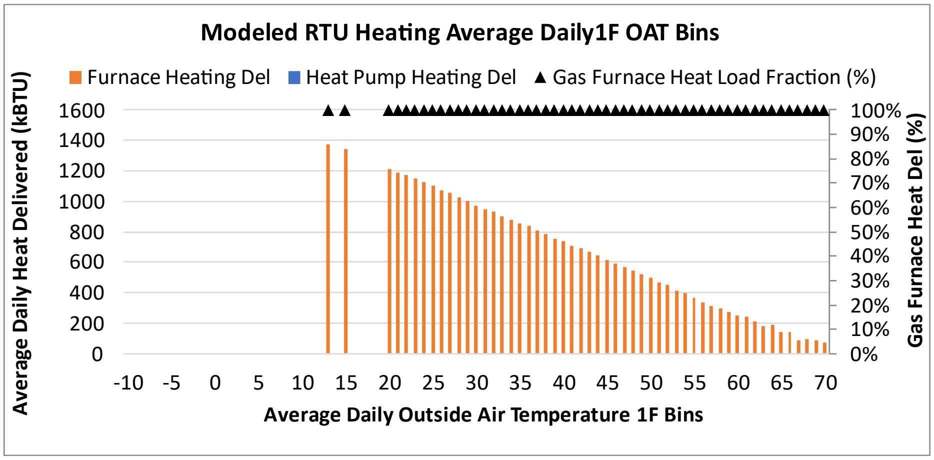


Figure 4: Conventional Gas Furnace RTU Cold Climate Daily Heating Delivered Runtime and % of load, segmented in 1°F Outside Air Temperature Binned Modeling (Climate Zone 4) *Source:* GTI Energy

As expected, the above plot illustrated performance at the rated 80% TE, and an increasing daily heating runtime and load at colder OATs, with 100% of heating load served by the gas furnace. The retrofit modeling in Figure 5 illustrates the scenario for a Hybrid RTU with heat pump and gas furnace heating, using the cost-effective 40°F switchover setpoint.

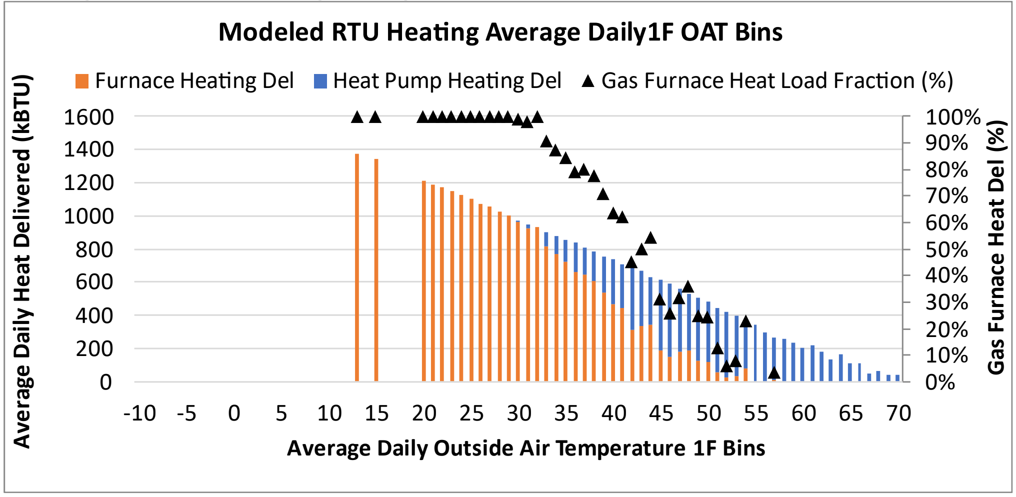


Figure 5: Hybrid RTU 40° F OAT Switchover Set-point impact on projected Daily Average Heating Delivered (L) and Gas Heating load (%) (R) at 1°F Outside Air Temperature Binned Modeling. *Source:* GTI Energy

In Figure 5, performance at the rated 80% efficient gas furnace is for OATs below the "switchover", with gas furnace usage decreasing above that point, but not completely disappearing. Note the average daily energy use occurs in both heating system modes for those days with temperatures both above and below the crossover setpoint of 40°F. Like the baseline modeling, the Hybrid RTU daily heating runtime and heating load increases at colder OATs. The heating load decreases as OAT rises, but due to a dependence of heat pump performance and capacity on OAT, the runtime increases from OAT of 40°F to 45°F, then falls to 0 as the heating load goes to 0. What if we change the switchover setpoint? For comparison, the same model was run for the Hybrid RTU with a lower 30°F OAT switchover setpoint, shown in Figure 6.

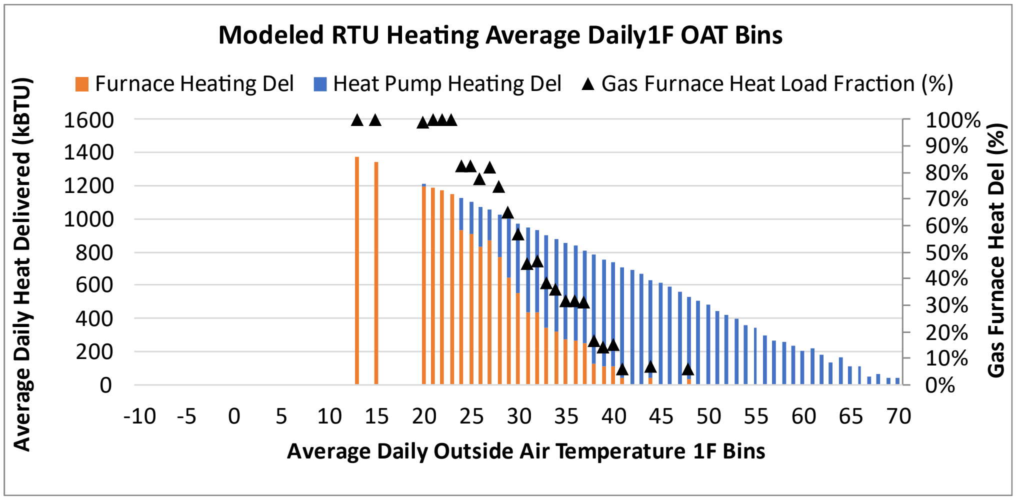


Figure 6: Modeled Hybrid RTU 30° F OAT switchover setpoint impact on daily average heating delivered (L) and gas heating load (%) (R) at 1°F OAT binned data (Climate Zone 4) *Source:* GTI Energy

Using the results of the two modeling scenarios, Table 2 below illustrates the energy use, cost[1], and GHG emissions[2]. Note that the analysis below focuses on heat pump compressor electricity usage as the incremental consumption for a Hybrid RTU and does not include other RTU electricity consumption including the supply fan, combustion fan, etc. These assumptions carry over to the cost and GHG analyses illustrating the decarbonization potential for Hybrid RTUs.

Scenario:	Gas Use (therm)	Heat Pump Electricity Use (kWh)	Total Cost ($); [Savings]	Total GHG Emissions (1000lb CO_2e); [Savings]
Baseline RTU	1761	0	$1,550	25.6
40°F OAT “Switchover”	1072	2,619	$1,196 [$354]	20.9 [4.8]
30°F OAT “Switchover”	493	5,574	$972 [$578]	18.4 [7.3]

Table 2: Modeled scenarios for baseline and Hybrid RTU located in Climate Zone 4

Comparing Table to the modeling of the baseline conventional gas furnace RTU, we can then calculate the annual energy, cost, and GHG emissions savings relative to the baseline. The incremental savings are shown in brackets in Table 3, with GHG emission rates were used for the electric grid serving the southern Illinois demonstration site. Local utility pricing for natural gas and electricity varies across markets in the U.S. and the potential avoided gas and electricity

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[1] Utility costs utilized from CMIC Source Energy and Emissions Analysis Tool SRMW 2021 Non-baseload as $.88/therm and $.0965/kWh (GTI Energy 2024)

[2] Composite GHG Emission Factors for eGRID subregion SRMW used based on eGRID 2021’s non-baseload generation dataset used in CMIC Source Energy and Emissions Analysis Tool. (GTI Energy 2024)
CO2e emission factor for Non-baseload Electricity of 2,006 lb/MWh and for Natural Gas of 145.68 lb/MMBtu.

use varies as the UCR is changed. This underscores how the Hybrid RTU's capacity to save on energy costs is notably influenced by regional utility expenses.

Case Studies of Hybrid RTU Retrofits

Multiple case studies on Hybrid RTU systems will now be presented to consolidate concepts. Ahead of the 2023-24 heating season, small-scale field demonstrations of Hybrid RTUs were implemented across three Illinois Army National Guard facilities serving as offices. The demonstration sites spanned two climate zones in Illinois (ASHRAE climate zones 4 and 5), offering diverse operating conditions. The Daikin Rebel series Hybrid RTU was installed on five RTUs across three buildings, with heating and cooling capacities ranging from nominal 4 tons to 7.5 tons. Primarily serving classrooms, offices, and similar spaces, these RTUs maintained adequate space heating, cooling, and ventilation loads. Conventional natural gas RTUs were retrofitted with drop-in Hybrid RTUs in all cases.

Each RTU was instrumented and monitored for durations of 1-3 years, depending on the field site, to quantify baseline RTU energy consumption and performance. Detailed instrumentation monitored most aspects of the Hybrid RTU system performance and energy inputs. At one site, airflow monitoring enabled comprehensive assessment of delivered energy.

After monitoring at least one full heating season, installing contractors replaced each baseline RTU with a Hybrid RTU of similar airflow and capacity (Figure 7). Installation lasted several months across each of the field sites due to installation and commissioning issues that were presented with these newer dual-fuel RTUs.

Figure 7: Daikin Rebel 4-ton Hybrid RTU demonstrations *Source:* GTI Energy

Experiences from installing and commissioning these five demonstration Hybrid RTUs highlights the criticality of their proper operation. While controls are important for all RTUs to effectively condition and ventilate spaces, the replacement of these units with Hybrid RTUs places greater emphasis on precise commissioning to ensure desired performance and load sharing. During initial data quality control processes, the research team observed and compared the retrofit against the baseline using input-output correlations. Issues emerged related to commissioning and control items such as setting an improper deadband, confirming the switchover temperature. Adding to the complexity, the chosen RTU for retrofitting is among the limited options on the market capable of operating in both gas-fired and heat pump modes simultaneously for space heating, a condition observed in initial data sets.

Following successful service and re-commissioning, the Hybrid RTUs operated as intended. Figures 8 through 10 illustrate the field demonstration of one baseline and retrofit Hybrid RTU at a field site in Marion, IL for an RTU providing space conditioning to multiple office spaces.

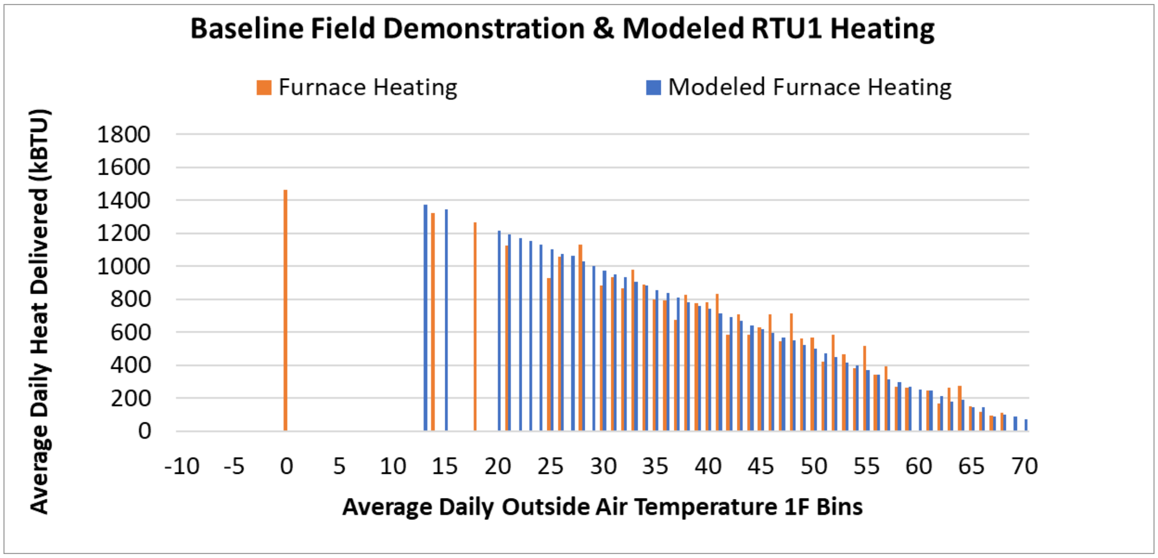

Figure 8: Baseline gas furnace only RTU: field vs modeled data, at 1°F binned dataset. *Source:* GTI Energy

Figure 8 can be compared to the earlier Figure 4 modeled projection, but with the addition of field monitoring data overlaid on the projected modeled data, enhancing confidence with the methodology by corroborating with field demonstration data. In both datasets, the heating load increases from no load at mild OATs to a peak load close to 1,400 kBTU near 0°F.

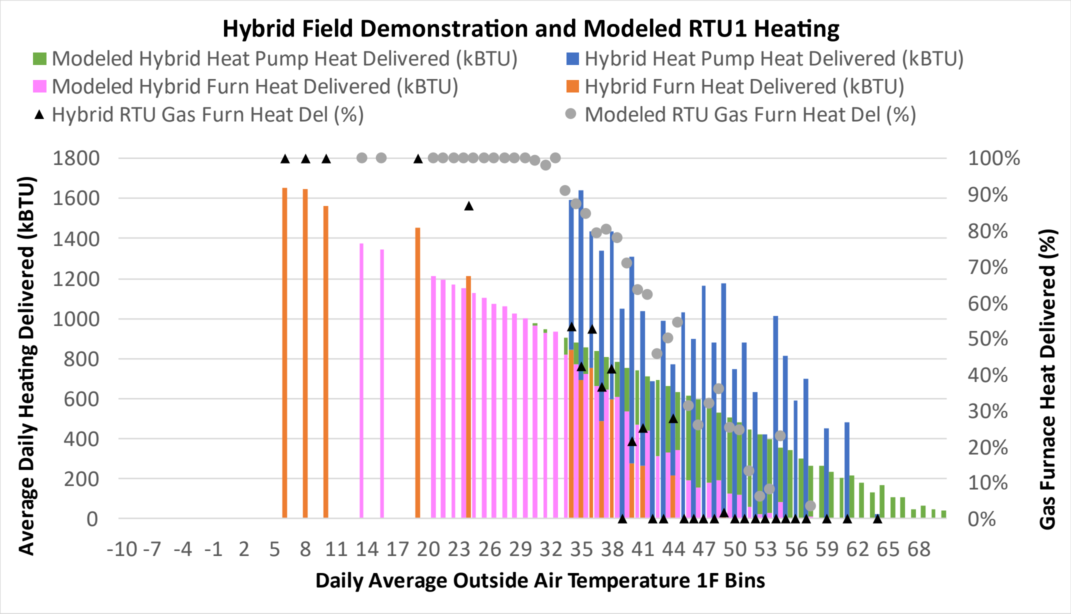

Figure 9: Retrofit Hybrid RTU: field vs modeled data, at fractional 1°F OAT binned data, with 40° F switchover setpoint. *Source:* GTI Energy

Figure 9 re-plots the modeled data in Figure 4 with the additional field demonstration results for comparison over the heating season. Variability in the field test data was a result of installation, commissioning, and controls issues discussed previously. While the heating load was comparable between modeled and actual performance below 32°F, there were inconsistencies at warmer temperatures. This is likely the result of continued commissioning of controls on the Hybrid RTU and related to possible changes in the magnitude of outside air mixing that occurred at the field site and simultaneous furnace and heat pump operation. In any event, both results agree on an incremental drop in gas furnace heating delivered percentage at and above OAT close to the 40°F switchover point, with the field data illustrating a slower transition to 100% gas furnace heating, in part due to the efficient heat pump technology.

Figure 10 below illustrates the daily gas and electricity equivalent GHG emissions per daily heating degree day (base 65). Above the switchover point of 40°F (below HDD65=25), the Hybrid RTU generally emitted less CO2e (gas and electricity), while below 40°F (above HDD65=25), the Hybrid RTU emitted similar GHGs to conventional gas-fired RTUs.

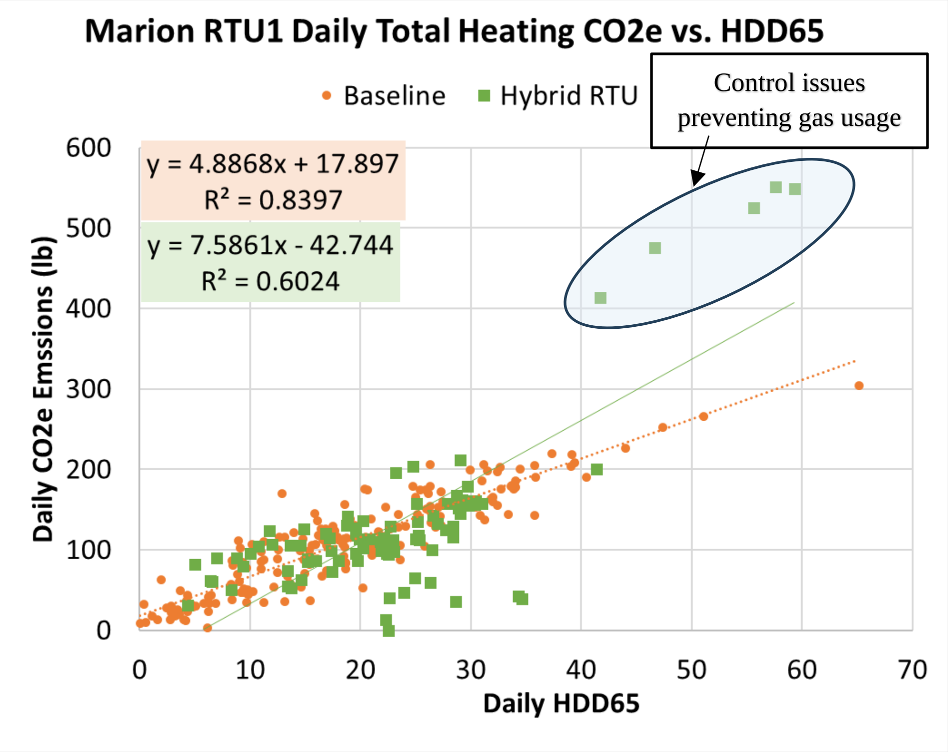

Figure 10: Comparison of Hybrid RTU and baseline gas furnace RTU daily heating GHGs vs. daily HDD65 at 40°F switchover setpoint, in Marion, IL (Climate Zone 4) *Source:* GTI Energy

The demonstration site is located in the SERC Midwest / Eastern Power Grid (SRMW) grid subregion. The emission results are mixed at lower HDD65, in part because non-baseload grid mix was used to generate the emission comparisons here, which uses an averaged out annual emissions value from eGRID. A few of the days monitored with outlier data circled above at cold OATs (HDD65 > 40) occurred when the Hybrid RTU coincided with controls issues requiring re-commissioning. It is interesting to note that the heat pump running at these cold average temperatures resulted in higher source-based GHG emissions than the gas furnace. With the switchover correction recommissioned, it can be anticipated that on days where OATs remain consistently below the switchover point throughout the day, the daily GHG emissions are likely to align closely with baseline gas furnace consumption, as only the gas heating will occur.

To calculate savings for the Hybrid RTU, the gas and electricity usage was compared to a modeled scenario of operation for the baseline RTU, given its input/output linearizations of gas use and electricity use with the heating demand, in Table 3 below.

	Gas Use (therm)	Electricity Use (kWh)	Total Cost ($) [Savings]	Total GHG Emissions (1000lb CO2e)3 [Savings]
Baseline RTU Modeled Data	681	1209	$716	12.34
Hybrid RTU Field Data	359	3,052	$611 [15% savings]	11.36 [8% savings]

Table 3: Comparison of measured Hybrid RTU energy usage and modeled baseline RTU at 40°F switchover

While the earlier section in this paper on modeling Hybrid RTU highlighted the potential energy, cost, and GHG emissions savings that are possible when retrofitting Hybrid RTUs, the modeling results are not always reflected in measured performance outcomes. Table 3 illustrates that even though the use of the Hybrid RTU over 90 days lead to shifting 24% of the load from gas furnace to heat pump heating, the added electricity usage at the site's utility rates delivered energy cost savings, resulting in a 15% savings. A slightly lower switchover setpoint than 40°F could result in a cost-neutral result with more gas load shifted to the heat pump.

Additionally, Table 3 shows that due to the regional source emissions from the SRMW grid, the Hybrid RTU emission reductions of 8% were not as high as expected, due to the prevalence of coal-fired generation. Having realtime grid emission data from power generation would be the best-case scenario for emission-driven goals, particularly if a Hybrid RTU system was cloud connected and could access third-party datasets. Alternatively, hourly electricity pricing compared to natural gas pricing may drive an alternative switchover point for a hybrid RTU.

Market adoption of Hybrid RTUs

Market dynamics pose challenges for Hybrid RTUs due to their typically higher costs compared to standard efficiency RTUs. Planned replacement presents a hurdle as up to 65% of the commercial HVAC market for RTUs involves replacing units only upon failure (Cornejo, 2013). Studies indicate that higher performance RTUs can cost 2-6 times more than baseline RTUs (Gantman et al., 2022). Broader discussion of market barriers and challenges facing Hybrid RTUs are an important consideration for wider adoption, but beyond the scope of this paper to assess.

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[3] Composite GHG Emission Factors for eGRID subregion SRMW used based on eGRID 2021's non-baseload generation dataset used in GTI Energy's CMIC SEEAT calculator https://cmicseeatcalc.gti.energy/CommercialBuildings.aspx , Accessed March 2024.
CO_2e emission factor for Non-baseload Electricity of 2,006 lb/MWh and for Natural Gas of 145.68 lb/MMBtu.

Potential for Grid-interactive Hybrid RTUs

While the Hybrid RTU control strategies previously discussed have focused on outcomes from selecting a static switchover setpoint (e.g. 40°F), the equipment has significant potential when paired with intelligent software controls to provide grid services with the dual-fuel infrastructure. Hybrid RTUs have the flexibility to react to those changes and keep utility costs as low as possible, with that mitigation potentially justifying their cost premium. Advanced controllers capable of pulling in real-time data leverage the dual-fuel platform to:

- Respond to electric grid signals in times of winter peak demand.
- Dynamically control switchover setpoints to transition heating based on cost-effectiveness, leveraging real-time or near-term forecasted electricity rates
- Dynamically control switchover setpoints to transition heating based on lowest source energy emissions, leveraging real-time or projected grid emission rates now available
- Limit electric-based heating during times of facility peak demand

To assist with equipment cost effectiveness, the last point above could allow a Hybrid RTU to have more attractive economics for cost effectiveness. The potential for a facility level control (such as through a BAS) to adapt the switchover so that peak demand charges are not incurred could be valuable in those electric utility service areas with high peak demand charges.

While this control technology is not commercially available at the type of writing, discussions with several manufacturers confirm they are evaluating the space. There are some novel third-party controllers that have been developed for a dynamically-controlled hybrid system as well. In laboratory settings, GTI Energy has implemented a separate cloud control platform to add adaptive controls such as real-time utility costs, and GHG factors. Moreover, the adaptive controls can be configured so facility managers can exercise local authority.

Conclusions

By allowing users to define an operational switchover point where the fuel input can be changed, Hybrid RTU operators can lower operational costs and GHG emissions when properly commissioned. The market for commercial RTUs for space conditioning is vast and can allow for a transition to greater decarbonization. The ability to operate using duel fuels also allows for resiliency in the event of a component failure.

While the specific performance and expected operation of Hybrid RTUs have the potential to lower energy costs and GHG emissions as illustrated in the modeling of this paper, actual field demonstrations have illustrated that beneficial results should not be assumed. Attention to installation and commissioning tasks must first be completed to ensure the units operate as intended, and the switchover point is correctly informed by the UCR or GHG emissions and chosen to optimize the cost or decarbonization goals.

Taking a modeled approach to projected savings for cost effectiveness based on UCR was done to inform a 40°F switchover setpoint for field demonstrations. Once operating as intended, the Hybrid RTUs validated this setpoint achieving operating cost savings of 15% and emission reductions of 8%, while shifting 24% of the heating load from the RTU's gas furnace to the heat pump.

Future opportunities for Hybrid RTUs include exploring the role of these systems at scale to provide grid services where RTUs can shed electrical load and switch to the fuel-fired equipment, minimizing winter peak electric demand and contributing to grid-interactive efficient buildings. This added value could help reduce payback periods. In the least, Hybrid RTU technology still offers potential for immediate decarbonization in commercial buildings by shifting gas heating load to heat pumps, and provide a flexible future for electrification.

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