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Field Demonstration of High-Efficiency Gas Heaters

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The Better Buildings Alliance is a U.S. Department of Energy (DOE) effort to promote energy efficiency in U.S. commercial buildings through collaboration with building owners, operators, and managers. Members of the Better Buildings Alliance commit to addressing energy efficiency needs in their buildings by setting energy savings goals, developing innovative energy efficiency resources, and adopting advanced cost-effective technologies and market practices.

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I. Executive Summary

For many buildings that do not require space cooling, non-centralized equipment such as unit heaters provide space heating to building occupants. Unit heaters are a major source of energy use nationally, accounting for nearly 18% of primary space heating energy use for commercial buildings, and most prominently appear in warehouses, distribution centers, loading docks, etc.[1] Several high-efficiency gas-fired space heating, or gas heater[2], technologies exist that consume significantly less energy than a conventional gas heater and can produce substantial energy savings if widely adopted. This report discusses a field demonstration to analyze the energy savings for one of these technologies, 100% outside air, high discharge temperature heating and ventilation (HTHV) direct-fired gas heaters, under normal use conditions at a warehouse outside of St. Louis, MO.

The project successfully demonstrated the energy savings of 100% outside air, HTHV direct-fired gas heaters from improved thermal efficiency, reduced temperature stratification, higher discharge temperature, and positive pressurization over a standard-efficiency unit heater meeting federal and state appliance standards. We conducted the demonstration over the majority of the 2013–2014 heating season (October 2013 through mid-March 2014) at a single-story warehouse with approximately 41,667 sq.ft. of heated warehouse and loading space and approximately 24 ft. high ceilings. We monitored new high-efficiency and existing standard-efficiency units operating side-by-side in alternating months to better understand how site-specific attributes affect energy consumption. We collected data including equipment operating hours, temperatures throughout the building, door openings, and other factors.

Table 1 summarizes the results of the demonstration and the estimated savings for natural gas consumption, source energy consumption, and utility cost. Because the energy consumption of heating equipment depends on outdoor conditions, we normalized the energy consumption (in therms) over the monitoring period according to the number of heating degree days (HDD) in each monitoring period, such that technologies are compared on a therms/HDD basis. After accounting for rooftop unit consumption of a small office space, the building consumed 1.67 therms/HDD when operating the new gas heaters and 2.10 therms/HDD when operating the existing gas heaters on a normalized basis over the monitoring period, resulting in an average gas savings of approximately 20%. Because the new gas heaters utilize a high-pressure blower to reduce stratification, increased fan electricity consumption offsets the thermal savings, resulting in source energy savings of 15%. Despite higher electricity consumption, converting to the new, high-efficiency gas heaters would save the demonstration site $965, or 15% of their heating-related utility costs for an average year, at average utility rates for the site of $0.8/therm and $0.08/kWh. The natural gas savings provided by the new gas heaters would result in a system payback of approximately 7–8 years over standard efficiency equipment in a new construction or replace-on-burnout scenario, with an effective useful lifetime of approximately 15–20 years.

[1] U.S. Department of Energy. DOE Unit Heater Spreadsheet. November 2001. http://www1.eere.energy.gov/buildings/appliance_standards/commercial/docs/doe_heaters.xls
[2] Gas heater is a generic term referring to several categories of non-centralized heating equipment. Within this categorization, indirect-fired, non-condensing unit heaters represent the baseline technology with several options representing higher efficiency technologies.

Table 1. Summary of Demonstration Results

	Units	New, High Efficiency Gas Heaters	Existing Gas Heaters	% Savings
Gas Consumption	Therm/HDD	1.67	2.10	**20%**
Source Energy Consumption	MBtu/HDD	0.19	0.22	**15%**
Seasonal Utility Costs	$/Year	$4,955	$6,227	**15%**

This field study successfully demonstrated the energy savings and operational benefits of 100% outside air, HTHV direct-fired gas heaters. As evidenced by the temperature readings near the floor and ceiling, the new gas heaters reduced stratification and maintained more uniform temperature distribution. Because heated air naturally rises to the ceiling, conventional technologies create a temperature gradient in high-bay buildings. When this occurs, the occupied areas near the floor take longer to reach their designated temperatures, increasing equipment runtime and energy consumption. High-pressure blower fans found in HTHV direct-fired technologies more readily circulate the heated air to the floor, reducing the temperature gradient between floor and ceiling. In addition to space heating savings, by bringing in 100% outside air, the technology could also satisfy minimum ventilation requirements for high-performance buildings.

If deployed widely, high-efficiency gas heaters would significantly decrease natural gas consumption related to space heating for semi-conditioned spaces such as warehouses, loading areas, distribution centers, and manufacturing facilities. As evidenced this field study demonstrates, high-efficiency gas heaters could save from 11%[3] or more in space heating energy consumption. Applied to the national existing unit heater stock, higher efficiency models could save 0.03–0.04 quads[4] of source energy once accounting for increased electricity usage[5]. While installation costs, utility rates, thermostat settings, and climate region may vary these payback estimates, the results of this demonstration suggest relatively good payback periods in moderate or cold climates.

Because unit heaters and other non-centralized heating systems offer low upfront cost and easy installation compared to central heating systems, building owners, heating, ventilation, and air conditioning (HVAC) contractors and design professionals commonly use the systems throughout semi-conditioned spaces. Nevertheless, the attributes that make this equipment segment so popular (i.e., low cost, easy installation, long lifetime of 15–20 years) encourage professionals into only considering first cost, and pose a barrier to more expensive, higher efficiency options. Raising awareness of the availability and the potential lifetime energy savings of high-efficiency gas heaters may encourage more industry professionals to evaluate high-efficiency gas heaters for their buildings, and determine whether the systems offer an acceptable payback based on climate, operations, building design, etc. Additionally, system designers have difficulty using popular building modeling tools to evaluate strategies that affect outside air infiltration, temperature stratification and other features. By

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[3] 11% savings from thermal efficiency of >90% vs. standard efficiency of 80% for gravity-vent units. Field test results showed gas savings of 20% and source energy savings of 15% once accounting for increased electricity consumption.

[4] Quadrillion (10^{15}) Btu

[5] Commercial space heating consumption in 2013 estimated at 2.2 quads/yr. from the Energy Information Administration's (EIA) Annual Energy Outlook (AEO) 2010. Unit heater consumption estimated to be 18% of all commercial space heating consumption, and 65% of the floor area served by unit heaters, uses gas-fired equipment (ADL. 2011. "Energy Consumption Characteristics of Commercial Building HVAC Systems- Volume I: Chillers, Refrigerant Compressors, and Heating Systems."). Assumes 11-15% source energy savings as detailed in Footnote 3.

failing to capture these additional benefits, the modeling programs limit the savings potential of these technologies for potential projects.

We recommend the following actions promoting adoption of high-efficiency products, including:

For Developers of Building Energy Modeling Tools

- *Design specific equipment modules for high-efficiency products or include high-efficiency as a standard option within the modeling software*
- *Improve software capabilities to more effectively model the energy impacts of building stratification and infiltration to better predict the energy savings of 100% outdoor air, direct-fired heating technologies.*

For DOE and Other Efficiency Organizations

- *Assess further the energy impact of 100% outdoor air, direct-fired technologies when used as combination ventilation and space heating device for high-performance buildings.*
- *Facilitate quick energy savings calculations by developing a simple set of regional climate maps estimating equipment runtimes for different scenarios including new construction/replace-on-burnout or early-replacement scenarios, various thermostat temperature settings, as well as high/medium/low estimate for equipment sizing and placement relative to heating loads.*
- *Develop best practice guides for non-centralized heating strategies based on evaluations of available high-efficiency heating products (e.g., condensing gas heaters, direct-fired heaters, infrared heaters6) against different baseline equipment and building types.*

For Natural Gas Utilities

- *Educate commercial customers on the life-cycle cost of different space heating technologies and include high-efficiency non-centralized heating technologies in available grant, incentive, or financing programs.*

[6] AHRI Standard 1330P is currently under review to provide a test method to calculate the relative radiant factor for gas-fired infrared heaters. Along with other metrics of performance, this radiant factor can help system designers identify high-efficiency products. Once available, this equipment category should be evaluated further through field demonstrations.

II. Introduction

A. Problem Statement

For many buildings that do not require space cooling, non-centralized equipment such as unit heaters provide space heating to building occupants. Unit heaters are a major source of energy use nationally, accounting for nearly 18% of primary heating energy use, especially for warehouses, loading docks, etc.[7] Several high-efficiency gas-fired space heating, or gas heater[8], technologies exist that consume significantly less energy than a conventional gas heater and could produce substantial energy savings if widely adopted. This report discusses a field demonstration to analyze the energy savings for one of the high-efficiency gas heater technologies, 100% outside air, high discharge temperature heating and ventilation (HTHV) direct-fired gas heaters, under normal use conditions at a warehouse outside of St. Louis, MO. This technology provides savings through higher thermal efficiency, thermal destratification, reduced outdoor air infiltration, and higher discharge temperatures. This study evaluated the operation, performance of both conventional and high-efficiency technologies in the test location operating in alternating months to provide independent information for building owners, design professionals, and contractors with regard to energy savings, comfort, and other benefits.

We conducted this project as part of the Better Buildings Alliance, an initiative within the Better Buildings Program of the U.S. Department of Energy (DOE), Energy Efficiency & Renewable Energy Program. The Better Buildings Alliance brings together commercial building owners, operators, and experts across multiple industries to share best practices, incorporate energy efficiency into financial and leasing decisions, develop high-performance equipment specifications, and other activities. Several of the Better Buildings Alliance Technology Solutions Teams have developed technical specifications for commercial equipment categories where efficient products are available, but often underutilized. This report documents the results for the demonstration project for products meeting the Gas Heater Procurement Specification. This specification outlines energy-related product requirements for building owners, so they can ensure they procure a high-efficiency, high-quality product from manufacturers when developing purchasing specifications.

B. Opportunity

High-efficiency gas heaters reduce natural gas consumption while maintaining heating performance by increasing the natural gas combustion efficiency, reducing off-cycle heating losses, and/or transferring the latent heat of flue gases to the building space. By using strategies such as intermittent ignition devices, separated combustion, power venting, condensing heat exchangers, or direct-fired combustion, high-efficiency gas heaters offer increased steady-state thermal efficiency over conventional unit heaters. For many buildings with low space-cooling loads, non-centralized equipment such as unit heaters provide space heating loads. Unit heaters supply upwards of 10% of commercial floor space nationally, resulting in approximately 18% of total commercial space heating energy[7,9]. In 2013, natural gas consumption for gas-fired unit heaters resulted in 0.26 quads[10]

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[7] U.S. Department of Energy. DOE Unit Heater Spreadsheet. November 2001. http://www1.eere.energy.gov/buildings/appliance_standards/commercial/docs/doe_heaters.xls

[8] Gas heater is a generic term referring to several categories of non-centralized heating equipment. Within this categorization, indirect-fired, non-condensing unit heaters represent the baseline technology with several options representing higher efficiency technologies.

[9] ADL. 2011. "Energy Consumption Characteristics of Commercial Building HVAC Systems- Volume I: Chillers, Refrigerant Compressors, and Heating Systems." Arthur D. Little, Inc. April 2001.

[10] Quadrillion (10^{15}) Btu

nationally[11]. As discussed in the following sections, natural gas consumption by unit heaters can be decrease by 11% or greater by replacing a conventional unit heater with a high-efficiency gas heater. Installing high-efficiency gas heaters could save an estimated 0.03 quads per year nationally at 11%[12] savings, with significantly higher percentages for some buildings with high-bay ceilings and large doors frequently open to outdoor conditions.

Despite the large energy use of this equipment, several barriers exist that have limited the adoption of high-efficiency gas heaters to date.

- In many cases where the equipment purchaser is often not the same as the one paying utility bills, conventional unit heaters are purchased to heat an area at the lowest first cost with little consideration given to energy efficiency or whole building impacts. This split-incentive arrangement poses an issue to any efficiency project that carries a substantial first cost premium.
- Especially for retrofit applications, high-efficiency gas heaters may pose installation issues due to the requirements of additional building envelope penetrations, proper condensate removal, and other issues.
- As non-centralized systems in large open spaces, system designers follow industry best practices on equipment placement, but can result in substantially different energy consumption depending on building openings and internal barriers. Because two pieces of equipment may have drastically different energy consumption due to their placement, building owners can obtain the best economics by targeting the highest-running units for replacement with more efficient products.
- Finally, little independent data exist on energy use to help purchasers make informed decisions where energy efficiency is concerned.

We conducted this field demonstration to mitigate some of these barriers by showcasing the energy savings that can be achieved with high-efficiency gas heaters. The results of the demonstration will provide more information to purchasers for whom energy efficiency is a consideration. In cases of split incentives, the demonstration results may help the facility owner encourage the purchaser to buy high-efficiency equipment, potentially by offering an incentive commensurate with the expected long-term cost savings.

C. Technical Objectives

The technical objectives of this demonstration were to measure field energy use of selected high-efficiency gas heater models and to compare the energy use to that of similar, standard-efficiency models in a side-by-side comparison. One goal was to evaluate whether the high-efficiency models used less energy than standard models under field conditions to either support or refute the claims that these models were significantly more efficient than the average model. A second goal was to collect operational characteristics of each gas heating technology in relation to its placement within the building to better understand the unit placements that would most readily benefit from high-efficiency equipment.

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[11] Commercial space heating consumption in 2013 estimated at 2.2 quads/yr. from the Energy Information Administration's (EIA) Annual Energy Outlook (AEO) 2010. Unit heater consumption estimated to be 18% of all commercial space heating consumption, and 65% of the floor area served by unit heaters, uses gas-fired equipment (ADL 2001).

[12] 11% savings from thermal efficiency of >90% vs. standard efficiency of 80% for gravity-vent units, with negligible differences in fan electricity consumption.

D. Technology Description

This demonstration is intended to provide a better understanding for a non-centralized space heating by highlighting the key differences in technology, efficiency, and best applications for high-efficiency gas heater technologies. When devising a non-centralized space heating strategy, two initial considerations affect energy consumption: technology efficiency and operating hours.

D.1 Technology Efficiency

Non-centralized space heating equipment is classified based on the type of combustion process, how heat from the combusted natural gas reaches the space, and how the exhaust gases are handled. As described in Table 2, three general categories exist for non-centralized gas-fired space heating equipment:

- Unit heaters
- Direct-fired heaters
- Infrared heaters.

Table 2. Classification of Non-Centralized Gas-Fired Space Heating Equipment

Category	Combustion/ Exhaust Type	Heat Transfer Type	Exhaust Type	Description
Unit Heater	**Indirect:** Combustion products *do not* enter building	**Fan Convection**	**Flue through wall or ceiling**	• Natural gas is combusted and exhaust gases are piped through a heat exchanger before exiting through a flue • Fan circulates air across the heat exchanger, warming the space
Direct-Fired Heater	**Direct:** Combustion products *do* enter building[13]	**Fan Convection**	**Directly into heating space**	• Fan propels products of natural gas combustion into the space • Uses either indoor and/or outdoor air to heat the space
Infrared Heater	**Indirect:** Combustion products *do not* enter building	**Thermal Radiation**	**Flue through wall or ceiling**	• Natural gas is combusted and exhaust gases are piped through a heat exchanger space exiting through a flue • High-temperature exhaust gases generate thermal radiation which is reflected to the objects within the space by mirrors

Seasonal efficiency largely drives annual energy consumption for both conventional and high-efficiency gas heaters, and includes both steady-state thermal efficiency and the associated flue losses at start-up, shut-down,

[13] All direct-fired heaters must comply with ANSI Z-83.4 Non-recirculating Direct Gas-Fired Industrial Air Heaters and related standards that limit the output of carbon monoxide and other combustion byproducts to safe levels and specifies gas-ignition, combustion-air, and flame control measures to safeguard against improper operation.

and standby. Table 3 summarizes thermal efficiency and seasonal efficiency estimates for conventional and high-efficiency gas heaters. There is currently no standardized laboratory test method for measuring seasonal efficiency, but this estimated value incorporates seasonal flue losses not captured in the steady-state thermal efficiency test.[14][15] This analysis assumes that conventional heaters have a thermal efficiency of 80%, and high-efficiency heaters have a thermal efficiency of 90% or greater. The demonstration quantified the energy savings of direct-fired heating equipment from improved thermal efficiency and other causes such as reduced stratification, higher discharge temperature, positive pressurization, etc. Electricity consumption for both conventional and high-efficiency gas heaters is small compared to gas consumption but does vary between technology types. To help understand how electricity consumption affects potential payback times, we measured electricity consumption during the demonstration to quantify the difference between gas heater technologies.

Table 3. Summary of Thermal and Seasonal Efficiency for Gas-Fired Heaters

Technology	Thermal Efficiency	Seasonal Efficiency	Technology Category	Source
Pilot Light, Gravity Vent	78%-82%	63%	Indirect-Fired Unit Heater	Sachs. 2003[14]
Intermittent Ignition Device, Gravity Vent	78%-82%	66%		Davis Energy Group. 2004[15]
Intermittent Ignition Device, Power Vent	80%-83%	80%		Sachs. 2003[14]
Separated Combustion	80%-83%	80%		Sachs. 2003[14]
Condensing Heat Exchanger	>90%	90%		Sachs. 2003[14]
Direct-Fired Heater *	>90%	90%	Direct-Fired Heater	Cambridge Engineering, Inc.2011[16]

Note – these values represent current range of efficiencies offered by manufacturers.

D.2 Operating Hours

The seasonal runtime or operating hours of a gas heater generally reflects its energy consumption, and can predict the potential savings from high efficiency options. Without runtime data from previous heating seasons, estimating operating hours relies on high-level approximations by location. The actual number of hours a unit heater will operate depends on the following:

- Building loads (determined by Heating degree days (HDD), building size/orientation, construction characteristics (insulation, infiltration, windows, etc.) and site characteristics
- Temperature setpoint of the building's thermostat(s)

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[14] Sachs, Harvey M. Unit Heaters Deserve Attention for Commercial Programs. ACEEE. April 2003. http://aceee.org/research-report/a031

[15] Davis Energy Group. Analysis of Standards Options for Unit Heaters and Duct Furnaces. Prepared for PG&E. May 2004. http://www.energy.ca.gov/appliances/2003rulemaking/documents/case_studies/CASE_Unit_Heater.pdf

[16] Cambridge Engineering, Inc. 2011. "S-Series." Available at http://www.cambridge-eng.com/.

- Equipment sizing and number of units (usually determined by design heating load)
- Heater placement in relation to infiltration loads (e.g., loading docks, garage doors, roof penetrations, corners of buildings, etc.) and internal barriers (e.g., walls, shelving racks, etc.)

Two previous researchers of high-efficiency gas heaters, Sachs (2003)[14] and Davis Energy Group (2004)[15], both assumed an average number of operating hours based on a 1994 ARI map for the heating load hours of the U.S., shown in Figure 1. Looking at the contour map, space heaters would be expected to operate from approximately 1,500 to 2,000 hours per year at the demonstration host site. In Section IV.H, we compared the results of this demonstration against this high-level estimate and analyzed the relationship between operating hours due to gas heater technology, location within the building, and equipment sizing.

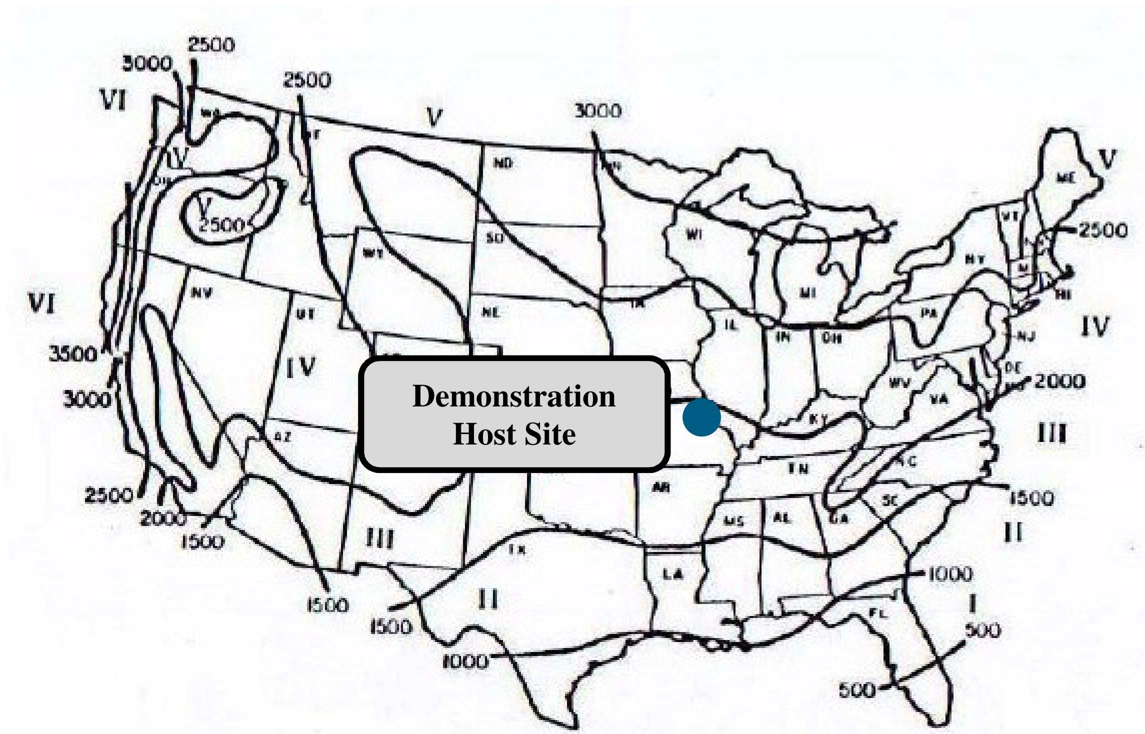


Figure 1. Heating load hours in the United States (1994 ARI map cited in Sachs, 2003)[14]

D.3 Units Analyzed in Demonstration

Table 4 contains the specifications of the standard and high-efficiency gas heaters measured in this demonstration. The existing gas heaters consist of indirect-fired unit heaters that meet federal and state appliance standards with intermittent ignition device and gravity damper. Although unit heaters with powered exhaust systems are increasingly common and offer higher thermal efficiency, the gravity damper units better represent the installed base. The new, high-efficiency gas heaters in this demonstration consist of 100% outside air, HTHV direct-fired heaters from Cambridge Engineering, Inc. The designation HTHV refers to the high discharge temperature of the product that helps to minimize the required outside airflow to satisfy conduction heating loads, the high velocity of the airflow that can help generate vertical circulation throughout the building, reducing temperature stratification, and the fact that the technology provides space heating and ventilation air. Direct-fired heaters can serve as a one-for-one replacement for unit heaters in most situations, but contractors must accommodate the required outdoor airflow either through a wall or roof penetration.

Table 4. Summary of Existing and New Heating Equipment

	Existing Gas Fired Rooftop Unit (Unchanged)	Existing Unit Heaters		New Gas Heaters
Space Served	Office	Warehouse, Loading Area		
Approximately Sq.ft.	8,333	41,667		
Gas Heater Type	Indirect-fired	Unit Heater, Gravity-Vent		Direct-Fired
Manufacturer	Carrier	Janitrol		Cambridge Engineering
Model Number	48TJD008	WH-350	WH-100	SA-250
Number of Units	2	2	4	4
Rated Input Capacity (Btu/hr. per unit)	125,000	350,000	100,000	250,000
Rated Output Capacity (Btu/hr. per unit)	100,000	273,000	80,000	225,000-230,000
Total Rated Input Capacity (Btu/hr.)	250,000	700,000	400,000	1,000,000
Total Rated Output Capacity (Btu/hr.)	200,000	546,000	320,000	920,000
Thermal Efficiency	80%	78%	80%	92%
Airflow (CFM)	6,100	9,639	2,469	1,200
Total Airflow (CFM)	12,200	29,154		4,800
Maximum Temperature Rise °F	50	80	80	160
Electrical Consumption per Unit (kW)	n/a	0.44	0.21	1.41

Direct-fired heating equipment can supply both ventilation and space heating airflow to maintain comfortable conditions for occupants in commercial buildings. By bringing in outside air, direct-fired equipment does not increase the amount of air entering the building, rather the airflow brought in by the direct-fired equipment creates a slight positive pressurization and offsets the infiltration that would normally enter through building seams. Through this method, the amount of air entering the building and the related infiltration heat load remains the same. Ventilation-only products, often called make-up air units, replace exhaust air by conditioning outdoor air only to indoor ambient temperatures, and thus require a separate space heating system to satisfy the conduction heating load of the building. Direct-fired space heating products supply outdoor air at sufficiently high temperatures to not only supply heated ventilation air, but also satisfy conduction heating loads.

The total output capacity for the new gas heaters is slightly more than the sum of the existing unit heaters while serving the same space heating load. In theory, one would anticipate somewhat shorter duty cycle for the new gas heaters compared to the existing equipment (i.e., higher capacity equipment satisfies the heating load in less time). In practice, the direct-fired heaters modulate their output based on the entering outdoor air temperature, so the duty cycle varies with outdoor conditions. Additionally, the airflow rate through the new gas heaters is significantly lower than the existing equipment. Direct-fired gas heaters provide a higher discharge temperature and temperature rise that reduces the airflow required to deliver heat to the space.

III. Methodology

A. Demonstration Site Description and Technology Installation

Non-centralized space-heating equipment is commonly used within warehouses, distribution centers, loading docks, multi-line retail, garages, and other large, open buildings and typically includes multiple gas-fired unit heaters. The demonstration was conducted at the single-story warehouse of Langendorf Supply Co., Inc., an distributor of heating, ventilation, and air conditioning (HVAC) equipment located in Bridgeton, MO, a suburb of St Louis, MO. The building consists of a loading docks, warehouse space, and office space. Figure 2 provides an aerial view of the building and the rear loading docks. The new gas heaters replaced a collection of conventional unit heaters throughout the heated warehouse and loading space (approximately 41,667 sq.ft.) with approximately 24 ft. high ceilings.

Figure 2. Aerial view of demonstration site (color enhanced)

Source: Microsoft Corporation (2014), Nokia (2013)

Figure 3 provides the internal floor plan for the building, including the placement of internal barriers and shelving racks. The remainder of the space is dedicated to offices and is served by two indirect gas-fired packaged rooftop units (RTUs). The office space is a self-contained area within the larger warehouse featuring a drop ceiling covered with sheets of fiberglass insulation. The office's RTUs connect to the drop-ceiling registers through insulated flexible and sheet-metal ductwork. Warehouse spaces 1 and 2 are separated by a floor-to-ceiling wall except for an approximately 12x12ft. opening that allows forklifts to carry material between the two spaces. Each warehouse space contains one or more aisles created by approximately 20 ft. tall shelving racks.

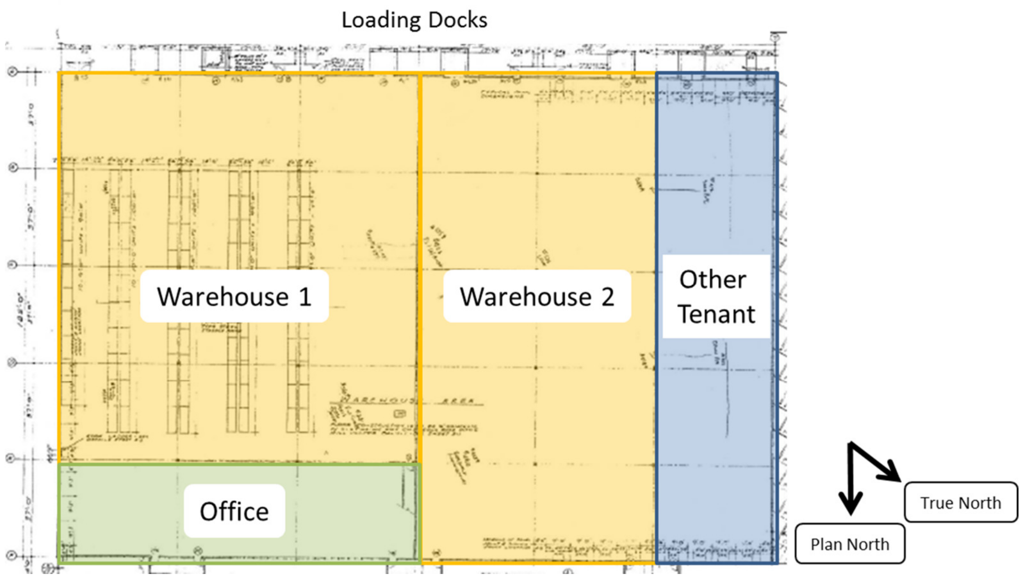


Figure 3. Internal floor plan of demonstration site

Langendorf Supply Co. upgraded the space heating system from conventional unit heaters to 100% outside air HTHV direct-fired heaters as an energy savings measure. Figure 4 provides a schematic for the placement of the new and existing heaters within the building. The new heaters were placed within the same general area as the existing units and oriented such that warm air traveled down the relevant aisle. Each set of gas heaters is controlled by a separate Wi-Fi thermostat mounted on the nearest ceiling support, approximately 5 ft. above the floor, and set to 60°F for the duration of the monitoring period. Note – Warehouse 2 contains two sets of unit heaters (UH-3, UH-4) with each set containing two small 100,000 Btu/hr. units controlled by a shared thermostat, such that each set functions as one larger 200,000 Btu/hr. product.

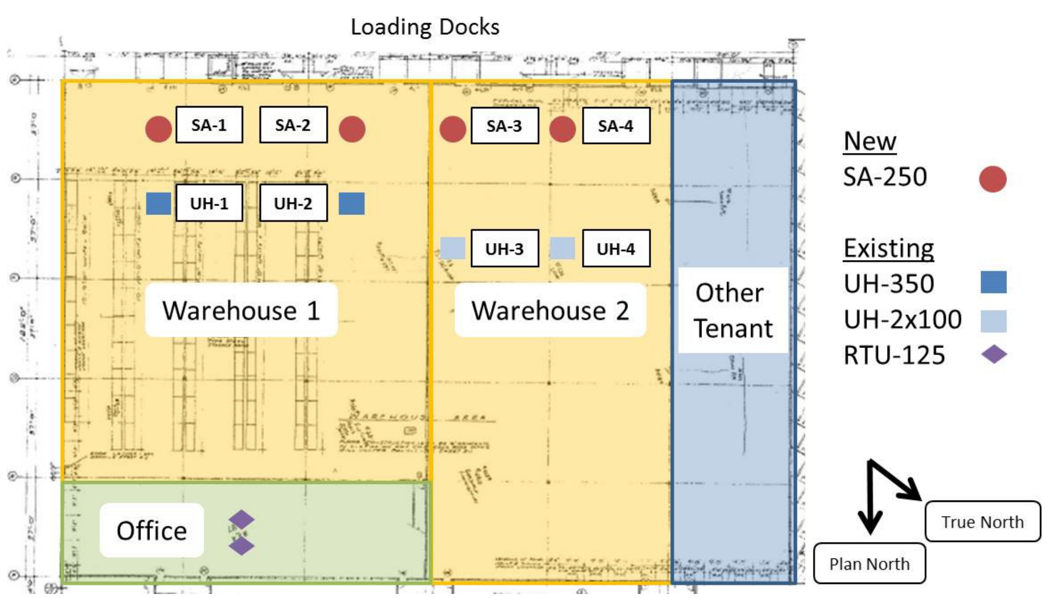


Figure 4. Placement of heating equipment at demonstration site

Langendorf Supply Co. agreed to join this demonstration study as an additional element to an installation already in progress and covered all purchase and installation costs for the new equipment. The key differences from a normal installation were the additional installation of monitoring equipment, keeping the existing gas heaters in place through the duration of the heating season, and operating the existing and new equipment in alternating months. DOE provided funds to Cambridge Engineering Inc. for the installation and use of monitoring equipment and submission of data collected at the project site. Installation of monitoring equipment and data gathering was performed by specialists at Cambridge Engineering, Inc. who have performed over 200 monitoring projects for their equipment types. Navigant observed the initial installation of the monitoring equipment as well as equipment operation through the web interface of the Wi-Fi thermostats.

B. Measurement and Data Collection Plan

We monitored several data sources over a portion of the heating season to evaluate the relative performance of new and existing gas heaters. Table 5 summarizes the key monitoring points, and Table 6 outlines the other information sources we used in the data analysis. The technology demonstration commenced in October 2013 after the installation of the new, high-efficiency equipment, and ran over a portion of the 2013–2014 heating season (October 2013 through mid-March 2014). To provide a more equitable comparison over the 2013–2014 heating season, the new gas heaters were installed alongside the existing gas heaters and operated in alternating months. Switch-over from old to new, and vice versa, each month occurred using Wi-Fi enabled thermostats. At the start of the monitoring period, all equipment and controls were operating correctly and no equipment malfunction was reported during the period.

Table 5. Key Monitoring Points for Analysis

Name of Monitoring Point	Number of Sensors
Temperature at ground (5ft.) and ceiling (20ft.) heights	2 each x 10 zones[17]
Runtime of new gas heaters	1 each x 4 heaters
Runtime of existing gas heaters	1 each x 4 heaters
Runtime of existing rooftop units	1 x 2 rooftop unit
Operation of loading doors	1 x 6 doors
Operation of ceiling lighting	1 x 1 lighting areas
Thermostat set-points	1 x 8 thermostats
Other relevant measures of interest as needed	-
Estimated Total Number of Monitoring Points	**45**

[17] We monitored the temperature at 5ft. and 20ft. in ten zones throughout the warehouse to understand how different gas heater technologies affect thermal stratification and infiltration. The zones are spaced approximately 40-60 ft. apart and cover the four corners and primary length of the building.

Table 6. Additional Data Sources for Analysis

Item	Note
Natural gas utility bills and thermal coefficients	Monthly for 2011 through 2014 heating seasons
Annual heating degree day information	2012–2013, 2013–2014, and annual average

Appendix A contains further details about the instrumentation and data collection methodology.

Figure 5 provides a schematic for the relative placement of sensors throughout the building. We connected each thermostat to a wireless internet network to remotely control the temperature settings, and to view or download through an internet browser the operating state (i.e., runtime), temperature, and other information. The thermostats took measurements every 15 seconds, and reported measurements every 5 minutes. For example, a data point contained the average temperature over a 5 minute period and the equipment runtime to a resolution of 15 seconds. We placed each temperature logger on a building support column or shelving rack for the duration of the study and recorded the ambient temperature (in °F) at 30 minute intervals. The light loggers recorded the ambient light intensity (in lumens/sq.ft.) at 30-minute intervals. The state loggers recorded the operating time of both the loading dock doors and office RTUs by recording a time stamp each time an action occurred. Operating runtime can be measured by taking the difference between the two timestamps. For the loading dock doors, we attached a magnetic strip to the door and a sensor to the frame such that each time the magnetic strip passed over the sensor (signaling a door opening or closing), time was recorded. For the RTUs, we tied the logger into the thermostat line, so when the thermostat signaled for the start or end of a heating cycle, time was recorded.

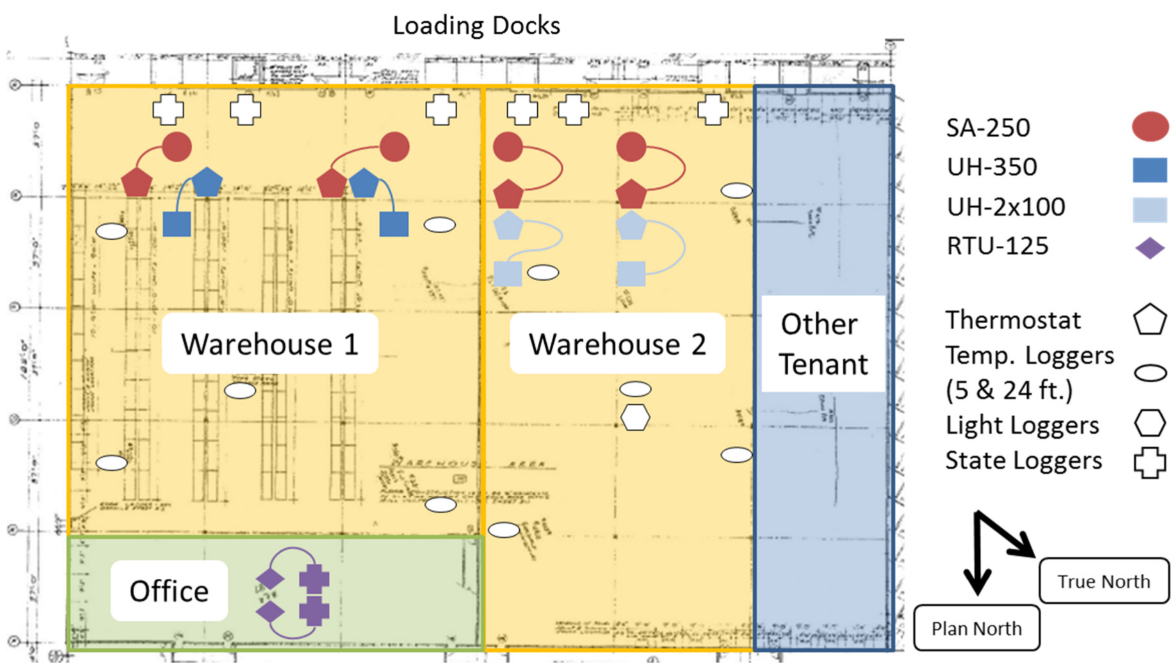


Figure 5. Placement of monitoring equipment at demonstration site

Note – a malfunctioning gas meter compromised the collection of gas consumption data for the period 1/1/2014 through 2/5/2014, and is not included in the evaluation period. During a periodic site visit, one of the gas utility meters was found to have malfunctioned and stopped recording gas consumption sometime during the latter half of January. The meter reading at the end of January matched that of a meter reading in the middle of January which indicated the presence of an error. The fact that the meter reading increased from the start of January to mid-January indicates that the issue occurred within the month of January and did not affect prior results. Laclede Gas, the local utility, replaced the malfunctioning gas meter, and the monitoring period continued on 2/5/2014.

Because the energy consumption of heating equipment depends on outdoor conditions, we normalized the energy consumption (therms) over the monitoring period of the new and existing gas heaters as well rooftop unit according to the HDD of their monitoring period, such that technologies are compared on a therms/HDD basis. Daily heating degree days for the site were determined using available weather data from the nearby St. Louis International Airport:

$$Daily\ Heating\ Degree\ Days\ (HDD\ 60°F) = 60°F - 24Hr\ Average\ Air\ Temperature\ °F$$

Because the two gas meters record the consumption of all gas-fired equipment within the building, each monthly meter reading includes both the consumption of the warehouse's gas heaters and the office's RTUs. The existing rooftop units are recirculating systems that do not modulate their consumption rate during operation such that operating time corresponds directly with consumption for a given unit's heating capacity. To isolate the consumption of the warehouse heating equipment, we estimated RTU operating hours vs. daily HDDs by plotting the available data and then developing a linear-fit model to complete the missing data. Using this model, we can project the contribution of the RTU consumption to the utility meter readings and subtract that out from the gas heater analysis.

$$Gas\ Consumption\ (Therms) = Heating\ Capacity\ \left(\frac{Btu}{Hr}\right)\ x\ Operating\ Time\ (Hr)\ x\ \frac{1\ Therm}{100{,}000\ Btu}$$

The data loggers monitoring the RTUs often reached their capacity in between periodic site visits, creating gaps within the data. Appendix B provides additional details on this estimate and Appendix C provides details on estimating consumption from utility meter readings.

In addition to outdoor weather, the building's heating load can be affected by other factors not captured by HDDs, including occupancy, as well as frequency and duration of door openings. We attempted to account for occupancy by measuring the operating schedule of each loading dock as well as light levels within the building. For example, if the loading dock doors remained open for an exceptionally long period of time on a cold day, any increased consumption would not reflect a difference in technology, but rather a difference in occupancy-generated heating load. If major differences occurred between the operating period of the new and existing gas heaters, an adjustment might be necessary to account for this factor.

Both lighting and loading dock schedules followed similar patterns during the operation of both gas heaters so we concluded that an adjustment in seasonal gas consumption was not necessary. Average daily light output and weather-adjusted loading dock operation remained consistent between the monitoring periods. For days where equipment runtimes seemed unusually long, we cross-referenced the equipment runtimes against these two data sets to identify a cause. In each case we investigated, loading dock and lighting schedules were normal and the increased runtimes could be associated with a sudden drop in outdoor temperature or extended period of below-freezing temperatures. The state logger for Door 3, closest to SA-2 and UH-2 failed during monitoring and was not included in the analysis.

IV. Results

A. Gas Consumption Results Without Adjusting for RTU Consumption (Gross Savings)

Table 7 compares the average gas consumption per HDD for the entire building during the operation of the new and existing gas heaters, using unadjusted values from the utility meter. Without accounting for RTU consumption, the building consumed 2.00 therms/HDD when operating the new gas heaters compared to 2.42 therms/HDD operating the existing gas heaters on a normalized basis over the monitoring period. This results in savings of approximately 17%.

Table 7. Gas Consumption Savings of New and Existing Gas Heaters without RTU Adjustment

Month	HDD (Base 60 F)	Utility Meter Values (Therms)	Consumption per HDD (Therms/HDD)
October	146	30	0.21
November	490	571	1.17
December	819	2,308	2.82
February–March	1,011	2,434	2.41
Existing Heaters (October & December)	965	2,338	2.42
New Heaters (November & February/March)	1,501	3,005	2.00
		% Savings	**17%**

B. Gas Consumption Results Adjusting for RTU Consumption (Net Savings)

Table 8 compares the average gas consumption per HDD for only the warehouse space during the operation of the new and existing gas heaters, using utility meter values and subtracting the modeled RTU consumption. After accounting for RTU consumption, the building consumed 1.67 therms/HDD when operating the new gas heaters compared to 2.10 therms/HDD operating the existing gas heaters on a normalized basis over the monitoring period. This results in savings of approximately 20%. With no other loads connected to the gas meter, this estimate represents the gas savings from upgrading to higher efficiency equipment for the demonstration warehouse.

Table 8. Gas Consumption Savings of New and Existing Gas Heaters with RTU Adjustment

Month	HDD (Base 60 F)	Utility Meter Values (Therms)	Modeled RTU Consumption (Therms)	Adjusted Utility Meter Values (Therms)	Consumption per HDD (Therms/HDD)
October	146	30	39	-9	-0.06
November	490	571	159	412	0.84
December	819	2,308	273	2,035	2.49
February–March	1,011	2,434	338	2,096	2.07
Existing Heaters (October & December)	965	2,338	311	2,027	2.10
New Heaters (November & February/March)	1,501	3,005	497	2,508	1.67
				% Savings	**20%**

C. Electricity Consumption

Table 9 compares the estimated electrical consumption (kWh) per HDD of the new and existing gas heaters based on rated power consumption and measured operating hours. On a normalized basis, the new gas heaters consumed 1.44 kWh/HDD compared to 0.40 kWh/HDD for the existing heaters during the monitoring period. This represents an increase in fan consumption of approximately 260%. This increase was expected because the new gas heaters operate with a more powerful, high-pressure supply fan to deliver the heated air to the floor and create vertical circulation that can reduce temperature stratification between the floor and ceiling.

Table 9. Electricity Consumption of New and Existing Gas Heaters

Gas Heater		Operating Hours	HDD 60 F	Amps	Volts	Number of Units	kW	kWh	kWh/HDD
New	SA 1	295	1,501	12.3	115	1	1.41	417	1.44
	SA 2	549		12.3	115	1	1.41	777	
	SA 3	85		12.3	115	1	1.41	120	
	SA 4	597		12.3	115	1	1.41	844	
Existing	WH 5	442	965	3.8	115	1	0.44	193	0.40
	WH 6	24		3.8	115	1	0.44	10	
	WH 7	358		1.8	115	2	0.41	148	
	WH 8	5		1.8	115	2	0.41	2	
								% Increase	**260%**

D. Combined Energy Impacts

Table 10 compares the estimated natural gas and electrical consumption per HDD in terms of both site and source Btu. On a site energy basis, the new gas heaters consumed a combined 172,064 Btu/HDD compared to 211,445 Btu/HDD for the existing gas heaters during the monitoring period, representing a savings of 19%. Assuming site-to-source[18] ratios of 1.05 for natural gas and 3.31 for electricity, the new gas heaters consumed a combined 190,922 Btu/HDD compared to 224,870 Btu/HDD for the existing gas heaters during the monitoring period. On a source energy basis, the new gas heaters would offer approximately 15% source energy savings.

[18] Primary energy accounts for the losses in generation, transmission, and distribution. Primary energy does not account for the losses associated with extraction. Site-to-source ratios assumed as 3.14 for electricity and 1.05 for natural gas, determined from https://portfoliomanager.energystar.gov/pdf/reference/Source%20Energy.pdf?cb28-29dd.

Table 10. Combined Energy Impacts of New and Existing Gas Heaters

		Gas Heater		% Savings	Notes
		New	Existing		
Natural Gas Consumption	Therms/ HDD	1.67	2.10	20%	-
	Btu/HDD (Site)	167,158	210,080		100,000 Btu per Therm
	Btu/HDD (Source)	175,515	220,584		Natural gas site-to-source ratio of 1.05*
Electricity Consumption	kWh/HDD	1.44	0.40	-260%	-
	Btu/HDD (Site)	4,907	1,365		3412 Btu per kWh
	Btu/HDD (Source)	15,407	4,285		Electricity site-to-source ratio of 3.14*
Combined Energy Consumption	Btu/HDD (Site)	172,064	211,445	19%	-
	Btu/HDD (Source)	190,922	224,870	15%	-

*Site-to-source ratios assumed as 3.14 for electricity and 1.05 for natural gas, determined from https://portfoliomanager.energystar.gov/pdf/reference/Source%20Energy.pdf?cb28-29dd.

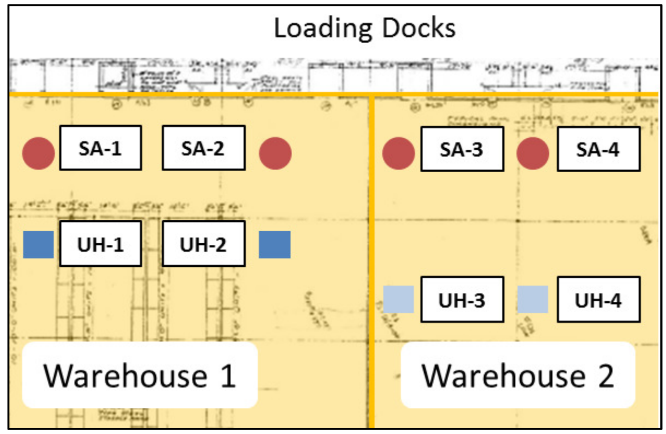
E. Equipment Placement and Operating Time

Table 11 summarizes the runtimes for each of the new and existing gas heaters during their respective monitoring periods. Surprisingly, the relative operating hours for a given warehouse location switched during the operation of each technology. Some of this variability can be explained by placing the new units further away from the shelving racks or door opening schedules[19], but there is no clear contributing factor(s) that caused this change.

[19] As noted previously, the state logger for Door 3 failed during the monitoring period and the operating schedule for this door is unknown. Door 3 is located closest to SA-2 and UH-2 While the other door openings schedules were generally consistent on a per HDD basis, Door 3s operation may have contributed to the difference in runtime between SA-2 and UH-2

Table 11. Operating Runtimes of New and Existing Gas Heaters

Gas Heater		Operating Hours	Relative Vertical Position
New	SA-1	295	Low
	SA-2	549	High
	SA-3	85	Low
	SA-4	597	High
Existing	UH-1	442	High
	UH-2	24	Low
	UH-3	358	High
	UH-4	5	Low



F.Thermal Stratification and Infiltration

Figure 7 displays the difference in temperature near the floor (5 ft. off the floor) and at the ceiling (20 ft. off the floor) during the monitoring period. For buildings with high ceilings, such as the warehouse in this demonstration, warm air naturally rises to the ceiling and can raise the average ceiling air temperature 10–20°F above the thermostat set-point. Because of this temperature gradient, the heating system must run longer and consume more energy to meet the needs of the building's occupants near the floor. As displayed in Figure 7, the new gas heaters operating in January display a much smaller temperature difference than the existing unit heaters operating in December. Generally, the existing gas heaters exhibited vertical temperature differences of more than 5°F higher than exhibited by the high-efficiency gas heaters.

This observation demonstrates the ability of destratification technologies to reduce the large temperature differences between operating heights and the ceiling of high-bay buildings. HTHV direct-fired gas heaters and other destratification technologies increase air circulation and provide more uniform temperature distribution throughout the space. Additionally, because the roof is typically the largest area for heat transfer in a warehouse, lowering the temperature of the interior ceiling decreases the heat loss through the roof.

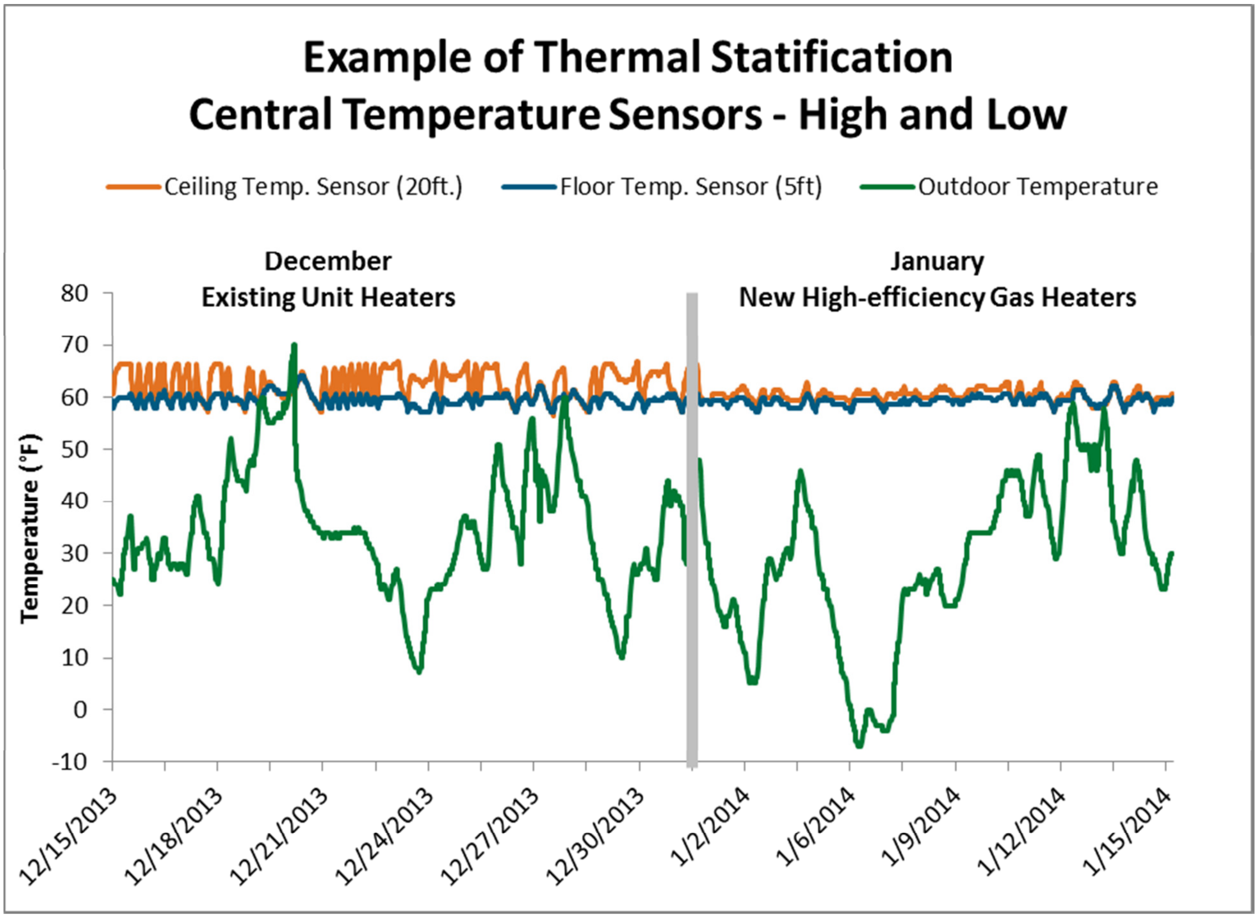


Figure 6. Temperature readings at various heights

G. Economic Analysis

High-efficiency gas heaters carry a substantial cost premium over conventional equipment so determining an expected payback is key to their further adoption by building owners. This section presents payback calculations for both the 2013–2014 heating season and the average heating season at the location.

G.1 Estimated Annual Operating Cost by Fuel Type

We estimated annual natural gas and electricity consumption by multiplying the fuel consumption per HDD values for each technology by the HDD values for the entire heating season[20]. Table 12 provides a summary of natural gas costs associated with operating the new and existing gas heaters over the 2013–2014 and average heating seasons. Fuel cost for natural gas ($0.8/therm) estimated from past utility bills of host site and electricity cost ($0.08/kWh) estimated from average rates for commercial customers in Missouri[21]. This estimate assumes 20% gas savings using the utility meter values and subtracting out RTU consumption as described in Section III.B.

[20] 2013-2014 HDD (60°F) values provided by www.degreedays.net and projected for April/May based on annual average values. 70-year average HDD (60°F) values provided by High Plains Climate Center for years 1941-2012.

[21] Obtained from EIA Table 5.6.A. Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State for February 2014.

For an average year, natural gas consumption would decrease by 1,590 therms and $1,272 through use of the new gas heaters.

Table 12. Estimated Annual Operating Cost – Natural Gas

Heating Season	HDD (60 F)	Existing Gas Heaters			New Gas Heaters			Annual Gas Savings ($)	
		Therms / HDD	Therms / Yr.	Gas Cost ($/Yr.) @ $0.8/therm	Therms / HDD	Therms / Yr.	Gas Cost ($/Yr.) @ $0.8/therm	Therms	$
2013–14 Season	4,188	2.10	8,798	$7,039	1.67	7,001	$5,600	1,797	$1,438
70–Year Average	3,705		7,783	$6,227		6,193	$4,995	1,590	$1,272

Table 13 provides a summary of electricity costs associated with operating the unit heaters and high-efficiency gas heaters over the 2013–2014 and average heating seasons. This estimate assumes a 175% increase in the electricity cost for the heating system. For an average year, site electricity consumption would increase by 3,846 kWh and $308.

Table 13. Estimated Annual Operating Cost – Electricity

Heating Season	HDD (60 F)	Existing Gas Heaters			New Gas Heaters			Annual Electricity Increase	
		kWh/ HDD	kWh / Yr.	Electricity Cost ($/Yr.) @ $0.08/kWh	kWh / HDD	kWh / Yr.	Electricity Cost ($/Yr.) @ $0.08/kWh	kWh	$
2013–14 Season	4,188	0.4	1,675	$134	1.4	6,023	$482	4,348	$348
70–Year Average	3,705		1,482	$119		5,328	$426	3,846	$308

Table 14 provides a summary of the total fuel costs, natural gas and electricity, associated with operating the unit heaters and high-efficiency gas heaters over the 2013–2014 and average heating seasons. For an average year, converting to high-efficiency gas heaters would save the demonstration site $965 or 15% of their heating-related utility costs.

Table 14. Estimated Annual Operating Cost and Savings

Heating Season	Existing Gas Heater Utility Costs ($)			New Gas Heater Utility Costs ($)			Net Cost Savings	
	Natural Gas	Electricity	Total	Natural Gas	Electricity	Total	$	%
2013–2014 Season	$7,039	$134	$7,173	$5,600	$482	$6,082	$1,091	15%
70–Year Average	$6,227	$119	$6,346	$4,955	$426	$5,381	$965	

G.2 Payback for Early-Replacement Scenario (Full Cost)

Where high-efficiency units are replacing standard-efficient equipment in working condition, such as this demonstration, the building owner may consider the full cost of the high-efficiency products depending on the age of the equipment. Table 15 provides a payback estimate of 13–15 years for an early-replacement project including the full retail price for the high-efficiency products in the demonstration, as well as the associated fuel costs and savings. Note – this estimate does not include the installation cost of the units including any additional roof or wall penetrations required for installation, as they can vary significantly from site to site. In some instances, installation will be similar to conventional unit heaters by using the existing roof penetrations.

Table 15. Payback Analysis for Early-Replacement Scenario

Timeframe	Full Retail Price ($)*	Therm Savings ($/Yr.) @ $0.8/therm**	Electric Increase ($/Yr.) @ $0.08/kWh**	Net Savings ($/Yr.)	Simple Payback (Yr.)
2013–2014 Season	$14,466	$1,438	$348	$1,090	13.3
70–Year Average	$14,466	$1,272	$308	$965	15.0

*Retail price for 4 x 250,000 Btu input units ($3,617 each, total output 920,000 Btu/hr. @ 92% thermal efficiency) from Cambridge Engineering in Fall 2013.

**Fuel cost for natural gas ($0.8/therm) estimated from past utility bills of host site and electricity cost ($0.08/kWh) estimated from EIA data for commercial customers in Missouri from February 2014.

G.3 Payback for New Construction or Replace-on-Burnout Scenario (Incremental Cost)

Where high-efficiency units are installed in a new building or replacing standard-efficiency equipment that has failed or are at the end of their useful life in an existing building, the building owner may consider only the incremental cost of the high-efficiency products compared to new standard efficiency units. Table 16 provides a payback estimate of 7–8 years for a replacement project over a baseline system with an effective useful lifetime of approximately 15–20 years. Note – this estimate does not include the installation cost of the units including any additional roof or wall penetrations required for installation, as they can vary significantly from site to site. In some instances, installation will be similar to conventional unit heaters by using the existing roof penetrations.

Table 16. Payback Analysis for New Construction or Replace-on-Burnout Scenario

Timeframe	Incremental Retail Price ($)*	Therm Savings ($/Yr.) @ $0.8/therm**	Electric Increase ($/Yr.) @ $0.08/kWh**	Net Savings ($/Yr.)	Simple Payback (Yr.)
2013–2014 Season	$7,426	$1,438	$348	$1,090	6.8
70–Year Average	$7,426	$1,272	$308	$965	7.7

*Retail price for 4 x 250,000 Btu input units ($3,617 each, total output 920,000 Btu/hr. @ 92% thermal efficiency) from Cambridge Engineering in Fall 2013. Retail price for standard efficiency, gravity vent unit heaters estimated as $7,040 for 4 x 250,000 Btu input units ($1,760 each, total output of 800,000 Btu/hr. @ 80% thermal efficiency) from eComfort.com, accessed Spring 2014.

**Fuel cost for natural gas ($0.8/therm) estimated from past utility bills of host site and electricity cost ($0.08/kWh) estimated from EIA data for commercial customers in Missouri from February 2014.

H. Evaluating Runtime Estimates

Section II.A discussed the pre-demonstration estimate of 1,500 to 2,000 equipment operating hours at the host site using a 1994 ARI map of heating load hours for the U.S. cited by previous studies[14,15]. Table 17 provides a summary of the projected equipment operating hours for the new and existing gas heaters over the 2013–2014 and average heating seasons. The variability of these results suggest that while a simplified location-based approach may provide some regional indication of expected operating hours, site-specific equipment sizing and placement relative to heating loads and temperature settings are better indicators of equipment runtime and potential savings from higher efficiency equipment.

Table 17. Projections of Seasonal Equipment Operating Hours

Gas Heater		Operating Hours	Partial Season HDD	Hr./HDD	Full Season HDD		Projected Operating Hours	
					2013–14 Season	Annual Average	2013–14 Season	Annual Average
New	SA-1	295	1,501	0.20	4188	3705	823	728
	SA-2	549	1,501	0.37			1,532	1,355
	SA-3	85	1,501	0.06			237	210
	SA-4	597	1,501	0.40			1,666	1,474
Existing	UH-1	442	965	0.46			1,918	1,697
	UH-2	24	965	0.02			104	92
	UH-3	358	965	0.37			1,554	1,374
	UH-4	5	965	0.01			22	19

V. Summary Findings and Recommendations

A. Overall Technology Assessment at Demonstration Facility

This field study successfully demonstrated the energy saving and operational benefits of 100% outside air, HTHV direct-fired gas heaters and accomplished the technical objectives of this project. Over the course of the side-by-side monitoring period, the new gas heaters provided 20% natural gas savings when normalized for HDDs. This value exceeds the expected energy savings values of 11%[22] when evaluating the technologies on a thermal efficiency basis. In addition to improved gas burner efficiency, the new gas heaters demonstrated the ability to reduce stratification and maintain more uniform temperature distribution between the operating space and ceiling. Although not monitored in this study, direct-fired technologies using 100% outdoor air also pressurize the space, such that the additional air creates a slight pressurization within the building and limits the effect of infiltration through building seems, cracks, or open dock doors. While the specific savings due to each of these additional factors is difficult to estimate, previous claims have attributed 10–15% savings based on previous claims of reduced stratification over unit heaters in available literature[23]. By bringing in 100% outside air while heating the space, the technology could also satisfy minimum ventilation requirements while providing space heating for high-performance buildings.

Projected over an average heating season for the host site in Bridgeton, MO (3,705 average HDD–60°F), the new gas heaters would save approximately 15% on utility costs related to space heating. Despite higher electricity consumption, the substantial natural gas savings provided by the new gas heaters would result in a system payback of approximately 7–8 years in a new construction or replace-on-burnout (incremental cost) scenario and approximately 13–15 years in early-replacement (full cost) scenario[24]. While installation costs, utility rates, thermostat settings, and climate may vary these payback estimates, the results of this demonstration suggest relatively good payback periods in moderate or cold climates.

B. Market Potential and Recommendations

If deployed widely, high-efficiency gas heaters would significantly decrease natural gas consumption related to space heating for semi-conditioned spaces such as warehouses, loading areas, distribution centers, etc. and manufacturing facilities. Depending on the exact configuration, high-efficiency gas heaters could save at 11%[22] or more in space heating energy consumption and utility costs as shown in this demonstration. Opportunities for deployment include new construction as well as replacements for failing equipment. Applied to the national existing unit heater stock, higher efficiency models could save 0.03–0.04 quads of source energy, once accounting for increased electricity usage[25].

The actual utility bill savings for a building owner will depend on a number of factors, most notably the building's climate region and regional utility rates. A moderate climate such as Bridgeton, MO, can experience

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[22] 11% savings from thermal efficiency of >90% vs. standard efficiency of 80% for gravity-vent units. Field test results showed gas savings of 20% and source energy savings of 15% once accounting for increased electricity consumption.

[23] Aynsley, Richard. 2005. "Saving Heating Costs in Warehouses." ASHRAE Journal. December 2005. www.ashrae.org/File%20Library/docLib/Public/200512265816_886.pdf.

[24] Assumes $0.8/therm, $0.08/kWh, $14,466 for 4x250,000 Btu/hr. high-efficiency units, $7,064 for 4x250,000 standard efficiency units.

[25] Commercial space heating consumption in 2013 estimated at 2.2 quads/yr. from the Energy Information Administration's (EIA) Annual Energy Outlook (AEO) 2010. Unit heater consumption estimated to be 18% of all commercial space heating consumption, and 65% of the floor area served by unit heaters, uses gas-fired equipment (ADL 2001). Assumes 11-15% source energy savings. 11% savings from thermal efficiency of >90% vs. standard efficiency of 80% for gravity-vent units. Field test results showed gas savings of 20% and source energy savings of 15% once accounting for increased electricity consumption.

payback periods from 7–8 years if the project is new construction or replace-on-burnout scenario. Colder regions will have the highest cost savings potential and shortest payback periods due to the higher number of HDDs they experience each year. If the building owner can identify the most active heaters by either observation or a monitoring system, such as an advanced thermostat, they could achieve quicker paybacks by targeting those heaters with the highest runtimes.

The suitability and economics of high-efficiency gas heaters will vary from site to site for several reasons, including:

- Standard-efficiency unit heaters are relatively inexpensive and commonly installed in places where they operate only a few hours a year.
- Regions with milder heating seasons may not consume enough natural gas to make the efficiency measure attractive.
- Installation costs may be significantly higher for certain situations where direct-fired heating equipment would require additional roof or wall penetrations or condensing, indirect-fired heating equipment would require complicated condensate drainage strategies.

Increasing the adoption of high-efficiency gas heaters will require a change in the way HVAC contractors, design engineers, and building owners and operators consider non-centralized heating equipment. Because unit heaters and other non-centralized heating systems offer low upfront cost and easy installation to reach minimum heating requirements, higher efficiency options are often not considered due to their upfront cost premium. Raising awareness of the availability and the potential lifetime energy savings of high-efficiency gas heaters may encourage more industry professionals to evaluate the high-efficiency gas heaters for their buildings, and determine whether the systems offer an acceptable payback based on climate, operations, building design, etc. Additionally, system designers have difficulty using popular building modeling tools to evaluate strategies that affect outside air infiltration, temperature stratification and other features. By failing to capture these additional benefits, the modeling programs limit the savings potential of these technologies for potential projects.

We recommend the following actions promoting adoption of high-efficiency products, including:

For Developers of Building Energy Modeling Tools

- *Design specific equipment modules for high-efficiency products or include high-efficiency as a standard option within the modeling software*
- *Improve software capabilities to more effectively model the energy impacts of building stratification and infiltration to better predict the energy savings of 100% outdoor air, direct-fired heating technologies.*

For DOE and Other Efficiency Organizations

- *Assess further the energy impact of 100% outdoor air, direct-fired technologies when used as combination ventilation and space heating device for high-performance buildings.*
- *Facilitate quick energy savings calculations by developing a simple set of regional climate maps estimating equipment runtimes for different scenarios including new construction/replace-on-burnout or early-replacement scenarios, various thermostat temperature settings, as well as high/medium/low estimate for equipment sizing and placement relative to heating loads.*

- *Develop best practice guides for non-centralized heating strategies based on evaluations of available high-efficiency heating products (e.g., condensing gas heaters, direct-fired heaters, infrared heaters26) against different baseline equipment and building types.*

For Natural Gas Utilities

- *Educate commercial customers on the life-cycle cost of different space heating technologies and include high-efficiency non-centralized heating technologies in available grant, incentive, or financing programs.*

[26] AHRI Standard 1330P is currently under review to provide a test method to calculate the relative radiant factor for gas-fired infrared heaters. Along with other metrics of performance, this radiant factor can help system designers identify high-efficiency products. Once available, this equipment category should be evaluated further through field demonstrations.

VI. Acronyms

AEO	Annual Energy Outlook
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
HDD	Heating degree days
HTHV	High discharge temperature heating and ventilation
HVAC	Heating, ventilation, and air conditioning
RTU	Rooftop unit

VII. References

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Appendix A Instrumentation Summary

Name of Monitoring Point	Number of Sensors	Manufacturer	Model Number	Frequency of Measurement	Limit of Error
Temperature at ground (5ft.) and ceiling (20ft.) heights	2 each x 10 zones	Onset	HOBO H08-001-02	Every 30 minutes	± 1.5°F
Runtime of existing rooftop units	1 x 2 rooftop unit	Onset	HOBO H06-001-02	Irregular: timestamp recorded to nearest second when activated	±25ppm (0.003%)
Operation of loading doors	1 x 6 doors	Onset	HOBO H06-001-02	Irregular: timestamp recorded to nearest second when activated	± 100ppm (0.01%)
Operation of ceiling lighting	1 x 1 lighting areas	Onset	HOBO H08-004-02	Every 30 minutes	±20% of reading
Runtime of new gas heaters	1 each x 4 heaters	ecobee	Energy Management System	Reported in 5 minute intervals with resolution of 15 seconds	±15 seconds
Runtime of existing gas heaters	1 each x 4 heaters	ecobee	Energy Management System	Reported in 5 minute intervals with resolution of 15 seconds	±15 seconds
Thermostat set-points	1 x 8 thermostats	ecobee	Energy Management System	Every 5 minutes	±1°F

Appendix B Methodology to Estimate Rooftop Unit Consumption

Described in Section III.B, the state loggers monitoring the operation of the RTUs reached their capacity faster than expected, creating gaps within the data. To try and isolate the consumption of the warehouse heating equipment, we estimated RTU operating hours vs. daily HDDs by plotting the available data and then developing a linear-fit model to complete the missing data. Using this model, we can project the contribution of the RTU consumption to the utility meter readings and subtract that out from the gas heater analysis.

Figure 8 provides the available RTU operating time data plotted against the corresponding HDDs for those days. Data for RTU-1 covered the periods 10/1/2013 through 12/3/2013 and 1/21/2014 through 2/1/2014. Data for RTU-2 covered the period 10/1/2013 through 2/9/2014. Using the equation for the linear-fit curves and the daily HDD values for each day in the full monitoring period, we projected the RTU consumption during the study, and included this data for the rest of the analysis.

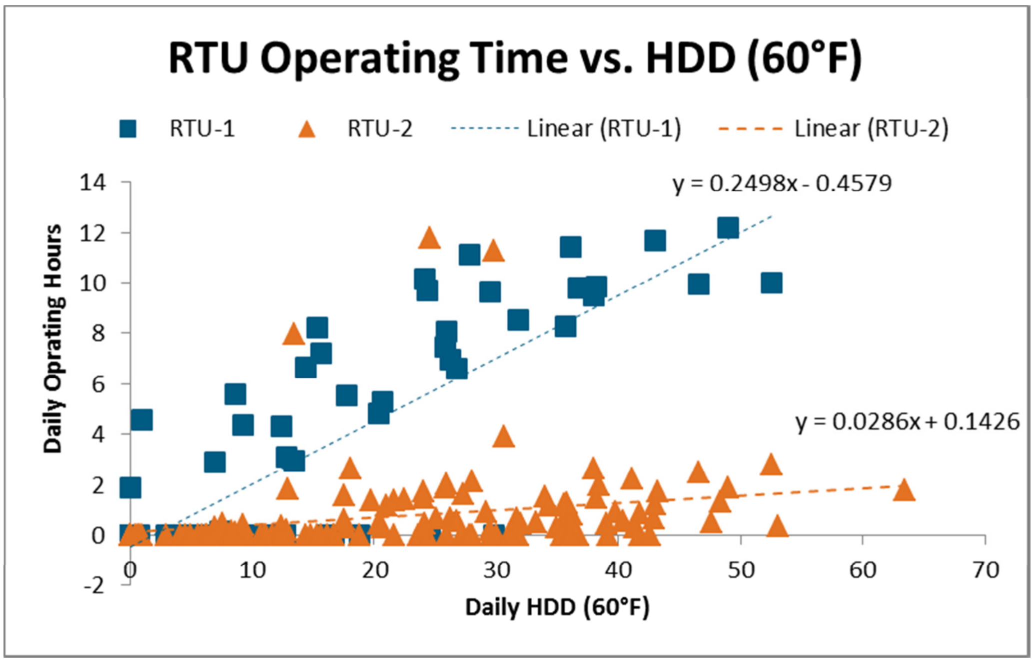

Figure 7. RTU operating time vs. HDD data

Appendix C Methodology to Estimate Consumption from Utility Meter Readings

Table 18 provides a summary of the utility gas consumption values and necessary conversions. Natural gas consumption was measured through visual readings of the on-site utility meters. The utility meters measure consumption according to volume in hundred cubic feet (ccf) and must be converted to a thermal consumption value (therm) in order to compare consumption against the thermal consumption estimated equipment runtimes and rated thermal output. The local gas utility, Laclede Gas provided the necessary conversion factor, which equates to the average heat content of natural gas delivered to the site in that month.

Table 18. Summary of Utility Gas Consumption Values

Date	Meter / Meter Readings (ccf)			Gas Use (Volume)	Thermal Value Coefficient	Gas Use (Heat)	Month	Gas Heating Equipment
	1505290	1523074	1523367	ccf Used	Therm/ccf	Therms		
9/30/13	938	381	n/a	-	-	-	-	n/a
10/31/13	967	381	n/a	29	1.025	30	October	Existing
12/1/13	1,335	568	n/a	555	1.028	571	November	New
1/1/14	2,922	1,224	n/a	2,243	1.029	2,308	December	Existing
1/15/14	3,621	1,404	n/a	879	1.029	904	n/a	n/a
1/31/14	4,518	1,404	n/a	897	1.024	919	n/a	n/a
2/5/14	4,928	n/a	58	468	1.024	479	n/a	n/a
3/10/14	6,370	n/a	988	2,372	1.026	2,434	February-March	New

As noted in Section III.B, a malfunctioning gas meter compromised the collection of gas consumption data for the period 1/1/2014 through 2/5/2014, and is not included in the evaluation period. Laclede Gas, the local utility, replaced the malfunctioning gas meter, and the monitoring period continued on 2/5/2014.