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Energy Modeling
Warehouse Heating Systems

Energy Performance Guidelines

Utility Rebate Programs

ASHRAE 90.1 Comparisons

EPAct Federal Tax Deductions

Certified LEED Building Projects

Energy Efficient Heating Equipment

Introduction

This white paper summarizes the approach, results and conclusions of the first published energy modeling analysis documenting predicted energy performance for six types of gas fired heating systems commonly used in warehouses and commercial/industrial buildings with large open spaces.

Space heating and lighting consume most of the energy in non-refrigerated warehouses. Installing more efficient lighting to save electrical energy has been well documented by computer modeling. But what about energy modeling guidelines for selecting more efficient gas-fired heating/ventilating equipment that accounts for 75% to 95% of the gas used at these facilities? This white paper summarizes the approach, results and conclusions of the first published energy modeling analysis documenting predicted energy performance for six types of gas fired heating systems commonly used in warehouses and commercial/industrial buildings with large open spaces. The computer simulation analysis includes a comparison to the ASHRAE 90.1 baseline heating system used to determine utility rebates, government tax deductions, energy points for LEED certified buildings and other incentives for using energy efficient heating equipment. A set of Best Practices Guidelines is provided at the end of the paper.

Consultant and Software

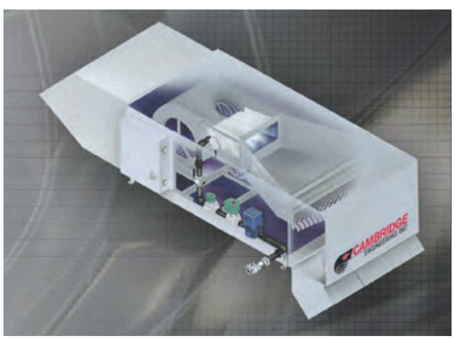
Independent Consultant

GARD Analytics (Chicago, IL) performed the energy modeling analysis and wrote a detailed 18 page report summarizing their methods and conclusions. They are a consulting service with prior experience in energy modeling and doing evaluations of technologies for providing energy efficient heating services to buildings. GARD was on the team that helped the U.S. Department of Energy (DOE) develop and test the internationally recognized EnergyPlus energy modeling software used for this analysis.

Roger L. Hedrick –Report Author
GARD Principal Engineer
B.S. Mechanical Engineering
Master of Environmental Engineering
ASHRAE 62.1 Standing Standards Subcommittee member

Energy Modeling Software

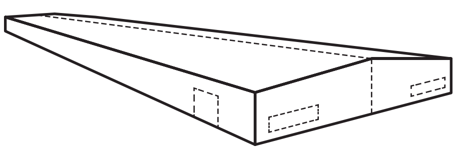
EnergyPlus building simulation software developed by DOE was used for this project. It offers simultaneous calculation of envelope and space loads and is able to simulate the energy performance for all seven heating systems. EnergyPlus meets the requirements of the U.S. Green Building Council (USGBC) for determining LEED energy credit points. It conforms to the modeling requirements of ASHRAE Standard 90.1 and is an IRS approved energy modeling software for obtaining Energy Policy Act (EPAct) federal tax deductions.



Blow Thru® S-Series Space Heater
Energy modeling results from this study found direct fired blow-thru type heating systems always used the least amount of energy.

Heating/Ventilating Systems

Seven different natural gas-fired heating/ventilating systems were sized and modeled. The first complies with the specifications in Appendix G of ASHRAE Standard 90.1-2004. The other six are common types of heating equipment used for warehouses and commercial/industrial buildings with large open spaces. Equipment sizing was done by the EnergyPlus program.



A 200,000 ft^2 generic storage warehouse/distribution center type facility was developed for this study. Building dimensions are 1000′ by 200′. Long sides of the building are 30′ high. The roof peak running the long direction is 36′ high. There are 34 dock doors and the interior of the building is open. The warehouse is constructed and insulated to meet ASHRAE 90.1-2004 guidelines for Columbus, OH (climate zone 5). Internal loads include 50 workers, ten forklift trucks and lighting based on ASHRAE 90.1. Steel products are assumed to be the type of stored materials. Typical warehouse occupancy, dock door activity, equipment operation, lighting and infiltration schedules were all simulated on an hourly basis. No office or cold storage areas were included in the analysis in order to focus on just the warehouse heating/ventilating systems.

Equipment efficiency and operating characteristics

ASHRAE 90.1 baseline – Indirect fired boiler supplying water reheat for VAV system

Output – 180°F max water temperature

Boiler – 80% efficiency

Provides required ventilation air

Direct fired, high temperature rise blow-thru heating system

Output - 160°F max temperature rise

Burner – 92% efficiency, variable capacity, modulating control

Provides required ventilation air

Direct fired, lower temperature rise draw-thru make-up air heating system

Output - 120°F max temperature rise

Burner – 92% efficiency, variable capacity, modulating control

Provides required ventilation air

Direct fired, recirculation heating system

Output – 49°F max equivalent temperature rise (required by ANSI Standard Z83.18)

Burner – 92% efficiency, variable capacity, modulating control

Provides required ventilation air

Indirect fired, power vented unit heater system

Output - 50°F max temperature rise

Burner – 80% efficiency, single capacity, o n/off control

Indirect fired make-up air heater provides required ventilation air

Indirect fired, air turnover (air rotation) heating system

Output - 35°F max temperature rise

Burner – 80% efficiency, single capacity, on/off control

Indirect fired make-up air heater provides required ventilation air

Infrared (radiant), high efficiency (condensing tube) heating system

Output – auto-sized by EnergyPlus program to meet heating load

Burner – 92% efficiency, single capacity, on/off control

Direct fired make-up air heater provides required ventilation air

Standard Conditions

Stratification Results

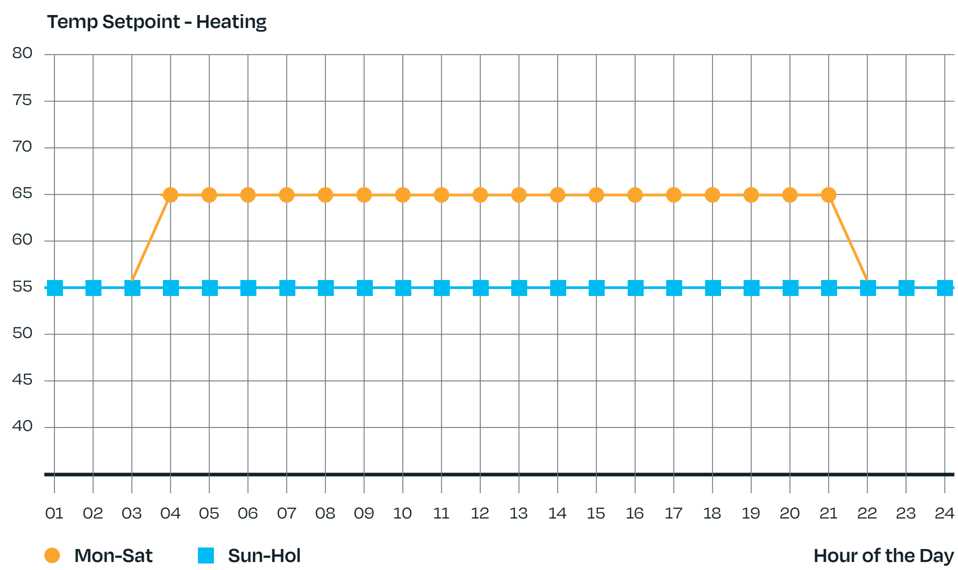
Heating: 65°F during occupied hours; 55°F night/weekend/holiday temperature setback

Ventilation: 0.06 cfm/ft^2 during occupied hours (to meet ASHRAE Standard 62.1-2007)

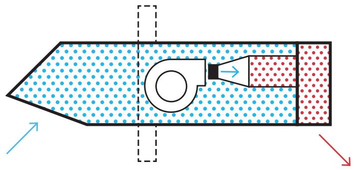
Stratification: 4°F

Air Conditioning: Not included in the analysis

Heating Operating Schedule



Standard Conditions



Blow-Thru Space Heater

More energy efficient

Burner is downstream of blower

Components in the cold air stream

160˚F max temp rise/discharge temp

Highest Btu/cfm ratio

Blow-thru heaters used 35% less natural gas and 93% less fan electricity than the ASHRAE 90.1 baseline heating system.

Blow-thru heaters used the least amount of total energy. Using any other heater type increased total therms required to heat the warehouse by 24% to 59%

Infrared heaters were auto-sized by EnergyPlus to handle the total heating load. Analysis and load did not incorporate the practice of keeping the space thermostat set 15-20% lower in order to save energy.

Computer Modeling Results

Energy Comparison for Heating Systems Standard Conditions

Equal Stratification for All Systems (4°F), ASHRAE 62.1 Ventilation (0.06 cfm/ft^2)

Energy Consumption	Gas (therms)	Fan Electric (kWh)
ASHRAE 90.1 Baseline	30,907	76,733
Blow-Thru	20,220	5,758
Draw-Thru	25,052	7,317
Recircultation	25,910	52,644
Unit Heater	30,481	16,289
Air Turnover	26,822	17,153
Infared	32,156	11,164
% Savings vs. 90.1 Basline		
Blow-Thru	34.6%	92.5%
Draw-Thru	18.9%	90.5%
Recirculation	16.2%	21.4%
Unit Heater	1.4%	78.8%
Air Turnover	13.2%	77.6%
Infrared	-4.0%	85.5%
% Increase vs. Blow-Thru		
Draw-Thru	23.9%	27.1%
Recirculation	28.1%	814.2%
Unit Heater	50.7%	182.9%
Air Turnover	32.6%	197.9%
Infrared	59.0%	93.9%

Electrification Considerations

Emission Analysis of Electric Resistive Heat for High Bay Spaces

Electrification has been a growing trend as many stakeholders strive to reduce their carbon footprint. In addition, many localities are enacting legislation and corporations are setting policies that would prohibit natural gas heating. This results in many building owners providing electric resistive heat due to it being the lowest first cost option for heating high bay spaces using electricity. This typically results in a large increase in total carbon emissions as most electrical grids in the United States are still largely reliant on fossil fuels to generate electricity.

Cambridge Air Solutions has performed the following analysis in 2024 as an addendum to the study to compare the emissions that would be generated if some of the technologies in this study were revised from indirect fired gas heat to electric resistive heat.

Compare direct gas fired, high temperature rise blow-thru heating system to commonly used electric resistive heating options

Assume equal heating output for electric resistive option compared to the equivalent indirect fired system from GARD Analytics study.

Corrected for efficiency difference between indirect gas fired technology and 100% efficient electric resistive heat

Total MWh includes electricity usage from supply fan(s) and the electric heating element

Assuming National Average Emission Rate of 852.3 lb CO2/MWh*

System	Total Therms	Total MWh	Carbon Emissions (lbs.)	Increased Carbon Emissions Scaled to Direct FIred Blow-Thru
Direct Fired Blow-Thru	20220	6	241168	1x
Electric Unit Heater	0	731	622832	2.58x
Air Turnover w/ Electric Heat	0	646	550469	2.28x
Electric Infrared Heater	0	765	651927	2.70x

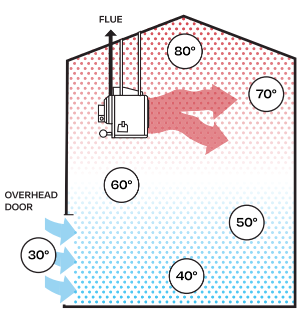
Conclusion

Because electricity generation in the US relies heavily on fossil fuels, simply switching to an electric resistive heating system was shown to greatly increase the total amount of carbon emissions. Gas fired heating equipment is a historically reliable and effective means of decarbonization. It is important to understand the total effects of electrification when determining if it is the right fit for your building. For more information on this topic please reference Cambridge Air Solutions White Paper *Electric vs. Gas Heat* which dives deeper into this topic.

Stratification

Analyzing Energy Efficiency with Destratifying Systems and Fans

A potentially important energy issue for warehouse heating is temperature stratification. Warehouses typically have high open ceilings where significant differences in air temperature can occur between floor level and the ceiling due to lack of adequate air movement. High levels of stratification will waste energy. Reduced stratification is a claimed benefit of destratifying ceiling fans and three of the heating systems modeled in this analysis (Blow-Thru, Air Turnover and Infrared). Energy modeling software, including EnergyPlus, cannot predict the amount of stratification created by each heating system but it can determine the additional energy used for specific levels of stratification. Therefore each heating system was first modeled using just 4°F stratification and then a second set of modeling results were obtained for 10°F stratification to determine the predicted amount of additional energy used for those buildings that do not use a destratifying heating system or fans.



Blow-Thru Heaters Reduce Stratification
Building studies show small blow-thru type space heaters reduce stratification with their high velocity vertical throw diffusers. They achieve 3°F to 5°F temperature variation, which is the same or better than large air turnover systems while using much less energy.

Computer Modeling Results

Stratification Comparison

4°F Stratification for Blow-Thru, Air Turnover*, Infrared
10°F Stratification for all other systems
ASHRAE 62.1 Ventilation (0.06 cfm/ft^2)

Energy Consumption	Gas (therms)	Fan Electric (kWh)
ASHRAE 90.1 Baseline	30,907	76,733
Blow-Thru	20,220	5,758
Draw-Thru	25,052	7,317
Recircultation	25,910	52,644
Unit Heater	30,481	16,289
Air Turnover	26,822	17,153
Infrared	32,156	11,164
% Savings vs. 90.1 Basline		
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% Increase vs. Blow-Thru		
Draw-Thru	23.9%	27.1%
Recirculation	28.1%	814.2%
Unit Heater	50.7%	182.9%
Air Turnover	32.6%	197.9%
Infrared	59.0%	93.9%

* Low velocity constant air turnover units require 2-3 building air turnovers per hour to minimize stratification.

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Ventilation Rate

Meeting ASHRAE 62.1 Ventilation Standards

ASHRAE Standard 62.1 requires a continuous supply of ventilation air at the minimum rate of 0.06 cfm/ft^2 for warehouse applications during periods of occupancy. This is a prerequisite for all LEED projects and is also required by many local codes. All seven heating systems were modeled to meet this ventilation requirement. A 30% higher ventilation rate of 0.078 cfm/ft^2 will earn an indoor environmental quality credit point for LEED projects. An additional set of modeling results was obtained for this condition to determine its impact on energy use.

Indoor Environmental Quality (Indoor Air Quality – IAQ)

Minimum IAQ Performance (Prerequisite)
Intent - LEED Certified buildings must meet the minimum requirements of Sections 4 through 7 of ASHRAE Standard 62.1 or applicable local code whichever is more stringent. ASHRAE 62.1 requires a continuous ventilation rate of 0.06 cfm/ft^2 during occupied periods for most warehouse applications.

EQ Credit 2: Increase Ventilation (Potential Points: 1)
Intent - Provide more outdoor air ventilation than that required by ASHRAE 62.1 to improve indoor air quality. For mechanically ventilated spaces this means increasing the ventilation rate by at least 30%. For most warehouse applications this would require a continuous ventilation rate of 0.078 cfm/ft^2 during occupied periods.

Warehouse Heater Contribution
Direct gas-fired heaters certified to ANSI Standard Z83.4 can help meet this requirement because they use only 100% non-recirculated outside air. Consult with the heater manufacturer to explore the best options for this credit. This may be a "free point" if the heating equipment already has the capability to provide 0.078 cfm/ ft^2. However, it may not make sense to increase the continuous ventilation rate for large unoccupied warehouse areas because this will increase operating costs and energy use without a significant benefit to the building's occupants.

Computer Modeling Results

Combined Increased Ventilation & Stratification Comparison
4°F Stratification for Blow-Thru, Air Turnover*, Infrared
10°F Stratification for all other systems
30% higher than required ASHRAE 62.1 Ventilation (0.078 cfm/ft^2)

Energy Consumption	Gas (therms)	Fan Electric (kWh)
ASHRAE 90.1 Baseline	35,608	78,483
Blow-Thru	22,435	7,350
Draw-Thru	29,214	8,950
Recirculation	27,805	52,644
Unit Heater	36,344	19,636
Air Turnover	29,802	32,256
Infared	34,978	14,514
% Savings vs. 90.1 Basline		
Blow-Thru	37.0%	90.6%
Draw-Thru	18.0%	88.6%
Recirculation	21.9%	32.9%
Unit Heater	-2.1%	75.0%
Air Turnover	16.3%	58.9%
Infrared	1.8%	81.5%
% Increase vs. Blow-Thru		
Draw-Thru	30.2%	21.8%
Recirculation	23.9%	616.2%
Unit Heater	62.0%	167.6%
Air Turnover	32.8%	338.9%
Infrared	55.9%	97.5%

Conclusions

Blow-Thru Space Heaters

Figure 1
Computer Modeling
Predicted Energy Savings with
Blow-Thru Space Heater

Other Industrial Heating Systems	Energy Savings w/ Blow-Thru Space Heaters
Indirect Gas-Fired Systems	
Boilers	53%
Unit Heaters	51%
Air Turnover	33%
Infrared (Radiant)	59%
Direct Gas Fired Systems	
Draw-Thru (Make Up Air)	24%
Recirculation	28%

1 Direct gas-fired, high temperature rise blow-thru space heaters used 35% to 38% less gas (therms) than the ASHRAE 90.1 baseline heating system for all cases included in this computer analysis. Using any other heater type increased the total therms required to heat the facility by at least 24% to 59% as shown in Figure 1. Blow-thru heaters use the least amount of energy to heat/ventilate large warehouses based on the following advantages of their design:

- Higher 92% efficiency vs. 80% rating for all indirect gas fired systems
- More efficient, variable capacity, modulating control burner
- Better performance from dual 160°F maximum temperature rise/ discharge temperature capability providing a high Btu/cfm ratio, which reduces the effective heating load relative to other direct fired heating systems.
- Electrical energy use is reduced by small blower motor, lower static pressure and ability to provide both space heat and tempered ventilation using the least amount of outside air.

2 Air turnover, draw-thru make-up air and recirculation type heating systems outperformed the ASHRAE 90.1 baseline heating systems by only 13% to 22%.

3 Power vented unit heaters are a common way to heat warehouses and were found to virtually match the ASHRAE 90.1 baseline heating system for natural gas use.

4 Although infrared (radiant) heating is a good way to heat stationary objects and small facilities with open spaces, these computer simulation results indicate it to be a poor performer for large buildings that require both space heating and mechanical ventilation. Some manufacturers of infrared heaters recommend using their systems with a rated output 80% to 85% lower than the heat loss calculated by the ASHRAE Handbook or by turning down the room thermostat by an equivalent amount. This analysis did not incorporate either approach.

5 The ASHRAE 90.1 boiler baseline heating system had much higher fan (electrical) energy use due to the significant static pressure associated with using a ducted heating system for a large open area.

6 The combined effects of ceiling stratification and increased ventilation beyond ASHRAE 62.1 requirements can result in a significant 10% to 25% energy increase.

Best Practices Guidelines

The following guidelines are recommended for the selection of energy efficient space heating equipment used in warehouses and commercial/ industrial buildings with large open spaces.

Direct-Fired Blow-Thru Heaters

- 100% combustion efficiency (Ec)
- 92% thermal efficiency (Et)

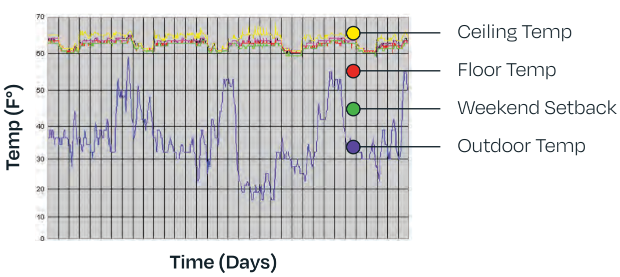
90+% Efficient Heaters

Select space heaters with energy efficiency ratings above 90% to get every possible Btu out of the fuel as usable heat.

Consider Ventilation and IAQ

Be sure the heating system accounts for the facility's ventilation and indoor air quality requirements. The use of direct gasfired, non-recirculating heating equipment certified to ANSI Standard Z83.4 is an energy efficient solution.

Building Temperature Data Logging Graph



Reduce Stratification

Reduce temperature stratification in buildings with high ceilings. Options include: small blow-thru space heaters with their high velocity vertical throw diffusers; large, low velocity constant air turnover heating units that provide two to three building air-volume turnovers per hour; infrared heating; or the use of ceiling fans.

Be ASHRAE 90.1 Compliant

Heating equipment should, at a minimum, be compliant with ASHRAE Energy Building Standard 90.1. As shown by this energy modeling report, this does not necessarily assure you are getting the most energy efficient heating equipment. But it is a requirement for many government tax incentives and utility rebate programs. It is also a prerequisite for LEED buildings. The heater manufacturer should have this stamped on their nameplate.

Document Energy Savings

Since actual energy savings are the real goal, use a proven technology from an experienced manufacturer that can document energy savings with studies of existing buildings and energy modeling.

For More Information:

Cambridge Engineering, Inc.

760 Long Road Crossing Dr.

Phone: 800-899-1989

Fax: 636-530-6133

www.cambridge-eng.com