

HVAC&R ENGINEERING

# update

Make a building-system investment that can cut greenhouse-gas emissions and recoup the cost with energy savings



## Introduction

Many building owners and system designers are interested in reducing greenhouse-gas emissions. They may want to boost their facility's green-building rating, create a more progressive corporate policy, and/or attract tenants who want to occupy a green building. In addition, various private and public initiatives are addressing the environmental consequences of current trends in greenhouse-gas emissions, chiefly CO<sub>2</sub>, associated with high consumption of fossil fuels.

That's why it pays facility owners to understand how the selection of one of their building's major energy users – HVAC equipment – impacts not only their utility bills, but also their share of greenhouse-gas emissions.

The challenge is identifying affordable equipment options to make reduced emissions practical. As a leader in building efficiency, Johnson Controls offers several technologies that respond to building owners' concerns about how the greenhouse-gas issue affects both the planet and their pocketbook. Often, the very same technology that reduces greenhouse-gas emissions also produces energy savings to help pay for the equipment investment.



BY JOHNSON CONTROLS

### Scope of the Problem

In the U.S., commercial buildings consume 20% of the total electricity produced. Most is generated by coal-fired power plants, which discharge CO<sub>2</sub>. The 12 quadrillion BTUs of electricity used by the commercial-building sector produces 200,000,000 metric tons of CO<sub>2</sub> emissions.<sup>1</sup>

To produce 1.00 kWh of electricity using the U.S. national mix of fuel sources, a power plant produces 1.30 pounds (0.65 kg) of CO<sub>2</sub>.<sup>1</sup> Unfortunately, most of a power plant's energy output is wasted. There are significant inefficiencies inherent in producing and delivering electricity. 64% of the source energy consumed is lost as heat, and 9% is lost in transmission. So, by the time electricity reaches a building's HVAC equipment, only about 27% of the energy remains to do useful work (Figure 1). These losses increase the greenhouse-gas emissions attributable to building equipment powered by electricity.

For example, a medium-sized hospital, with peak loads of 2,500 tons (8,800 kW) of electric-drive cooling, 15 million BTU/hr (4,400 kW) of heating, and 5 megawatts of power may well be responsible for emitting 17,000 tons of CO<sub>2</sub> annually. At \$0.12/kWh electricity and \$1.00/therm gas, it could have an annual utility bill of \$4,000,000. Reducing this level of consumption can yield substantial economic and environmental savings.

Using low-energy light bulbs is often the first step in cutting building electricity consumption. But many building owners realize the need for further reductions. HVAC equipment typically uses as much as half of the energy in commercial buildings – and it is usually concentrated in a few areas. That makes it easy to change equipment and make a big impact on building energy consumption.

CO<sub>2</sub> generated by HVAC equipment can be reduced in two ways: First, by reducing the electricity consumed by electric-drive equipment. Second, by utilizing equipment that uses an energy source that generates less CO<sub>2</sub> emissions than electricity production. This Update evaluates commercial HVAC equipment in terms of its energy efficiency *and* the energy sources it utilizes.

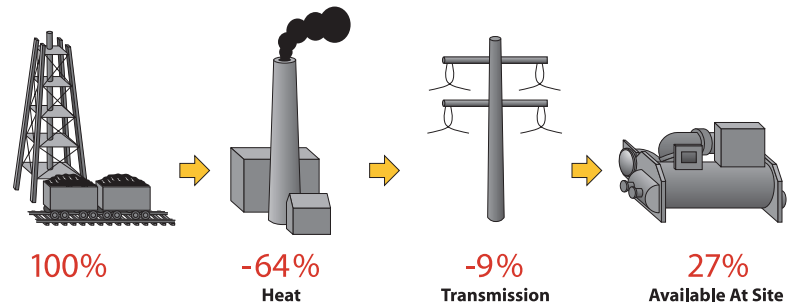


Figure 1: Source-energy utilization – electric-drive chiller<sup>2</sup>.

### Assessing the Technologies

The HVAC industry is looking closely at how energy inefficiencies in equipment contribute to greenhouse-gas emissions. The goal is to identify technologies that help reduce CO<sub>2</sub> emissions and provide a reasonable payback when implemented.

To reach this goal, Johnson Controls has identified several technologies that help building owners and system designers reduce CO<sub>2</sub> emissions, which is a greenhouse-gas reduction (GGR). These technologies are either more energy-efficient, meaning they consume less electricity and produce fewer emissions than conventional equipment, or they are driven by an energy source other than electricity. Because these technologies also reduce energy costs, we have also identified their return on investment (ROI).

These two factors – ROI and GGR – are useful values for assessing the different technologies. When multiplied by each other, they result in a value that we call the Carbon Cost Coefficient (C<sup>3</sup>). The calculation is a simple one: ROI% x GGR% = C<sup>3</sup>. The Carbon Cost Coefficient provides a shorthand measure of a technology's economy and ecology benefits. We have coined this measurement to help building owners make an equipment selection that will be a win-win environmentally and economically.

Four different HVAC technologies will be examined: gas-fired chillers, electric chillers with variable-speed drives, water-to-water heat pumps, and combined-cooling-heating-and-power plants.

### Base Plant

In the following example, a Base Plant with a  $C^3 = 0$  (0% ROI x 0% GGR) is used as a reference point. The Base Plant is comprised of electric-drive chillers, a natural-gas boiler, and the utility power supply (Table 1).

The four alternative HVAC technologies will be compared to the Base Plant. They will be evaluated in terms of their  $C^3$ . In each scenario, the quantities of cooling, heating, and power remain constant.

The economics and environmental impact of each technology depends on the specific application. Each building has a unique load profile, and energy costs will vary. Therefore, numbers shown indicate a range of likely outcomes, and should be treated as a starting point for a specific building analysis.

### Scenario 1: Gas-fired Chillers

This strategy avoids much of the energy loss incurred in electricity production by using gas-fired chillers. The loss in transportation of the gas to the chillers is similar to electrical transmission – about 9%. So, 91% of the source energy is available for use in the building (Figure 2). This solution reduces the utility-power requirement to 80%, because the chillers are gas-driven. Energy utilization is further improved when the heat generated by gas combustion is recaptured. In fact, gas-fired chillers can easily meet part of the heating load when the recovered heat is reused for heating. The more-efficient utilization of the source energy quickly offsets the higher cost of the gas-driven chillers, resulting in a 25% ROI.

Because of these efficiencies, the greenhouse-gas emissions are reduced 5%. The result is a Carbon Cost Coefficient of 125 (Table 2).

Building Infrastructure	Load	Simple Payback	ROI	GGR	$C^3$
Electric Chillers	100%	0 years	0%	0%	0
Heating Boiler	100%				
Utility Power Supply	100%				

Table 1: Carbon Cost Coefficient of Base Plant.

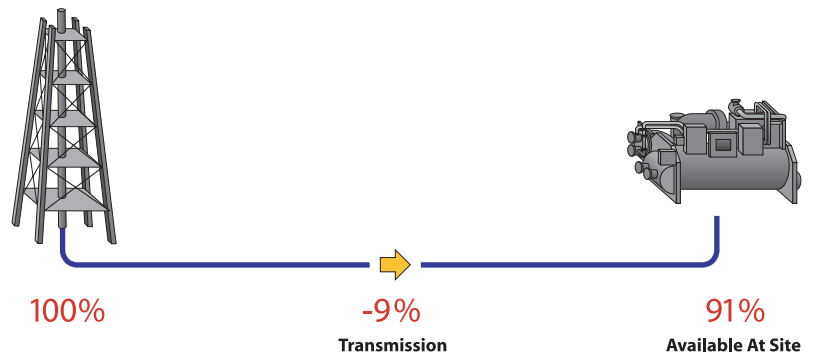


Figure 2: Source-energy utilization – gas-driven chiller.

Building Infrastructure	Load Compared to Base Plant	Simple Payback	ROI	GGR	$C^3$
Gas-engine Chillers	100%	3–5 years	25%	5%	125
Heating Boiler	60%				
Utility Power Supply	80%				

Table 2: Carbon Cost Coefficient of using gas-fired chillers.

### Scenario 2: Variable-speed Drives Applied to Electric-drive Chillers

The strategy in this scenario is to reduce the electricity consumption of the Base Plant by maximizing the chiller’s energy efficiency. Today, centrifugal chillers remain the most efficient means of producing chilled water for most buildings. But as referenced earlier, they rely on an inefficient energy source, namely electricity.

To get more useful work from the electricity delivered to the chillers, a variable-speed drive (VSD) is added to each centrifugal chiller. Compared to the constant-speed chillers in the Base Plant, the variable-speed chillers save 30% of the annual cooling energy (Figure 3).

The first cost of the VSDs is relatively low and energy savings are high, so the payback occurs very fast – in 1 to 3 years. Consequently, the ROI is also high – an average of 50%. But from the standpoint of greenhouse-gas reduction, this scenario only impacts the building’s cooling, not its heating or power. As a result, the GGR is only 5%, resulting in a C<sup>3</sup> of 250 (Table 3).

### Scenario 3: Water-to-water Heat Pump

The strategy in this scenario is to reduce the consumption of gas for heating by recycling low-grade heat using heat-pump technology. In this case, the heat source is the year-round cooling requirement of the building core. The heat pumps can generate hot water far more efficiently, and with lower CO<sub>2</sub> emissions, than a fossil-fuel boiler, which results in about 18% lower CO<sub>2</sub> emissions.

The heat pumps can do both heating and cooling, so the size of the boiler and the chiller plant are reduced. Combined with the energy savings, this results in a typical ROI of 50%.

Although this scenario is also driven entirely by electricity, because of the high GGR and higher ROI, the Carbon Cost Coefficient of this Scenario is 900 (Table 4).

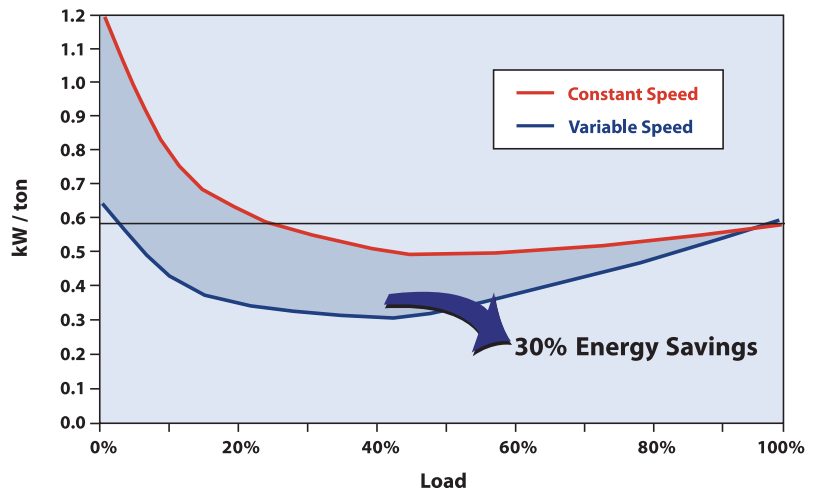


Figure 3: Performance of variable-speed chillers compared to constant-speed chillers.

Building Infrastructure	Load Compared to Base Plant	Simple Payback	ROI	GGR	C <sup>3</sup>
Variable-speed Electric Chillers	100%	1-3 years	50%	5%	250
Heating Boiler	100%				
Utility Power Supply	100%				

Table 3: Carbon Cost Coefficient of adding variable-speed drive to the chillers.

Building Infrastructure	Load Compared to Base Plant	Simple Payback	ROI	GGR	C <sup>3</sup>
Electric Heat Pumps/ Electric Chillers	50%/50%	1-3 years	50%	18%	900
Heating Boiler	40%				
Utility Power Supply	110%				

Table 4: Carbon Cost Coefficient of using electric heat pumps to do portion of cooling and heating (Note: Utility power is 110% because heat pumps are designed to do both heating and cooling, which slightly increases the building electrical requirement, but significantly reduces the gas consumption).

**Scenario 4: Combined Cooling, Heating, and Power**

This strategy generates electricity on-site and uses the heat by-products of the generation process for facility heating and cooling.

In this scenario, chilled-water production is integrated into a combined-heating-and-power (CHP) solution. As a result, more of the potential energy in the fossil fuel is utilized. This approach produces 50 to 60% less CO<sub>2</sub> emissions.

The key to tapping more of the energy output is to turn the heat into cooling by applying a thermally activated chiller to the system. Thus, the heat from the electric generator can be used for either heating or cooling.

The components of a CHP system vary depending on the available power-production capacity.

Small CHP systems, usually below two megawatts, can use a natural-gas engine to drive a generator. Engine-coolant and engine-exhaust heat are then carried to a heat exchanger where they can be used to heat the facility. The heat can also be employed to drive a hot-water absorption chiller to supply chilled water to the facility. Packaged systems, which minimize the installed cost of such an installation, combine the absorption chiller, piping, heat exchangers, and control system. The ROI on these systems is typically 30%.

Large CHP systems, usually above one megawatt, can use a natural-gas-combustion turbine generator to create electricity. Heat from the turbine exhaust is captured by a heat-recovery steam generator. The steam can be used to heat the facility; it can also be used to drive a steam-turbine chiller to cool the building. The ROI on these systems is typically 25%.

The Carbon Cost Coefficient for both systems is about 1500 (Table 5).

Building Infrastructure	Load Compared to Base Plant	Simple Payback	ROI	GGR	C <sup>3</sup>
Absorption Chiller/ Electric Chillers	25%/75%	2-4 years	30%	50%	1500
Heating Boiler	20%				
Gas-engine Generator/ Utility Power	40%/60%				
Steam-turbine Chiller/ Electric Chillers	40%/60%	3-5 years	25%	60%	1500
Heating Boiler	20%				
Gas-turbine Generator/ Utility Power	40%/60%				

**Table 5: Carbon Cost Coefficient of using CHP system to replace portions of cooling, heating, and power.**

	Base Plant	Scenario 1	Scenario 2	Scenario 3	Scenario 4A	Scenario 4B
	Typical Building	Gas-fired Chillers	Variable-speed Electric Chillers	Water-to-water Heat Pumps	Small CHP System	Large CHP System
Cooling	100% Electric Chillers	100% Gas-fired Chillers	100% Variable-speed Electric Chillers	50% Electric Heat Pumps and 50% Electric Chillers	25% Absorption Chillers and 75% Electric Chillers	40% Steam-turbine Chillers and 60% Electric Chillers
Heating	100% Heating Boilers	100% Heating Boilers	100% Heating Boilers	40% Heating Boilers	20% Heating Boilers	20% Heating Boilers
Power	100% Utility Power	80% Utility Power	100% Utility Power	110% Utility Power	40% Gas-engine Generator and 60% Utility Power	40% Gas-turbine Generator and 60% Utility Power
C <sup>3</sup>	0	125	250	900	1500	1500

**Table 6:** Comparison of Carbon Cost Coefficients for all scenarios.

### Conclusion – Adding Up the Environmental and Economic Benefits

By carefully considering the different HVAC and power equipment choices available today, building owners and designers can address concerns over the cost of energy *and* the environmental consequences of using fossil fuels. Table 6 summarizes pertinent data for all of the scenarios.

Thanks to these technological options, there is no need to worry about a tradeoff between being financially justifiable and environmentally responsible when investing in energy efficiency. That's because equipment choices are available that address both building efficiency *and* greenhouse-gas reduction. As a result, building owners can make a win-win decision that addresses today's economic *and* environmental challenges.

To help you analyze the options that are best for your facility, we developed the concept of the Carbon Cost Coefficient (C<sup>3</sup>). This number is the product of multiplying the return on investment produced by an equipment option's energy savings by its correlative reduction in greenhouse-gas emissions. Of course, the number is a general value. Every installation must be individually assessed to see the specific value of one choice over another. But the C<sup>3</sup> factor does provide a general reference point to show how technology that is good for the planet also produces energy savings that are good for your pocketbook.

### References:

1. U.S. Primary Energy Consumption and Carbon Dioxide Emissions (U.S. D.O.E. Energy Information Administration, 2001 data, <http://www.eia.doe.gov/oiaf/1605/gccebpro/chapter1.html>)
2. U.S. D.O.E. Energy Information Administration

