

New boiler control system means big savings in commercial space heating

Are you ready to take a big bite out of your hot water space-heating costs without replacing your boiler? If your annual natural gas heating/reheating fuel bills are greater than \$25,000, a new control system offers you an excellent chance of reducing your annual fuel consumption by as much as 20% to 50% with a simple payback period of 2.0 to 3.0 years. A new company called Thermodynamic Process Control (TPC) has developed an innovative approach to boiler control that measures the building load in real time and signals the boiler system to output only as much energy as the building load requires. Although field data are limited so far, the system has cut energy use in one independently verified application by 49%, with a payback period of only 2.4 years.

Energy and cost savings

The economics of a TPC installation depend on many factors, including the boiler's size, how poorly it is being controlled, how oversized it is for the load, whether it has modulation capability, and the size of the annual cooling load it is serving. The average installed cost of the TPC control system, for retrofit or new construction, ranges from \$27,000 to \$35,000, depending on the number and type of boilers. This cost includes all of the data acquisition and control devices as well as installation and commissioning. If the boiler or boilers do not have a low enough output to match the lowest expected building load, it may be necessary to purchase an additional small modulating boiler to meet low building load conditions. A typical 2,000-MBH (million Btu per hour) modulating boiler will cost from \$17,000 to \$35,000 depending on the turndown ratio, heat exchanger type, and whether it is noncondensing or condensing. A simple rule of thumb to help determine if TPC's control system will be cost-effective is to look at the annual fuel consumption. In general, if a customer's heating fuel bills are greater than \$25,000 per year, then there is a good chance that TPC's control system will yield a two- to three-year simple payback period.

All types of boilers, both high and standard-efficiency, have the potential to benefit from a TPC control system. Data from TPC show an average annual fuel consumption savings of about 33% at a Midwestern university dormitory served by two 2,000-MBH high-efficiency condensing boilers (Figure 1, see reverse). Even though the baseline system is highly efficient, the TPC controls still save energy by delivering only as much heat as the building requires, which reduces loss from overheating spaces and boiler on/off cycling, called short-cycling. Additionally, by measuring and recording the actual building load over the course of a year, the TPC system can help determine whether the boiler plant is oversized and, in multiple boiler installations, select the most efficient boiler to run for the given conditions.

One independently verified study, conducted by the Wisconsin Energy Conservation Corp. for Vectren Energy's custom efficiency incentive rebate program, supports TPC's savings claims. The TPC control system installed at Madison Junior High School in Madison, Indiana, reduced boiler plant energy use from about 39,000 therms per year to nearly 20,000 therms per year—a 49% reduction. TPC's installed cost for this project was \$29,500, which yielded a simple payback calculation of 2.4 years. Vectren Energy paid an incentive of \$8,850, which lowered the payback period to 1.4 years. The key to energy savings is to deliver only as much heat as the building requires, minimizing losses from short-cycling and overheating.

Short-cycling and overheating losses

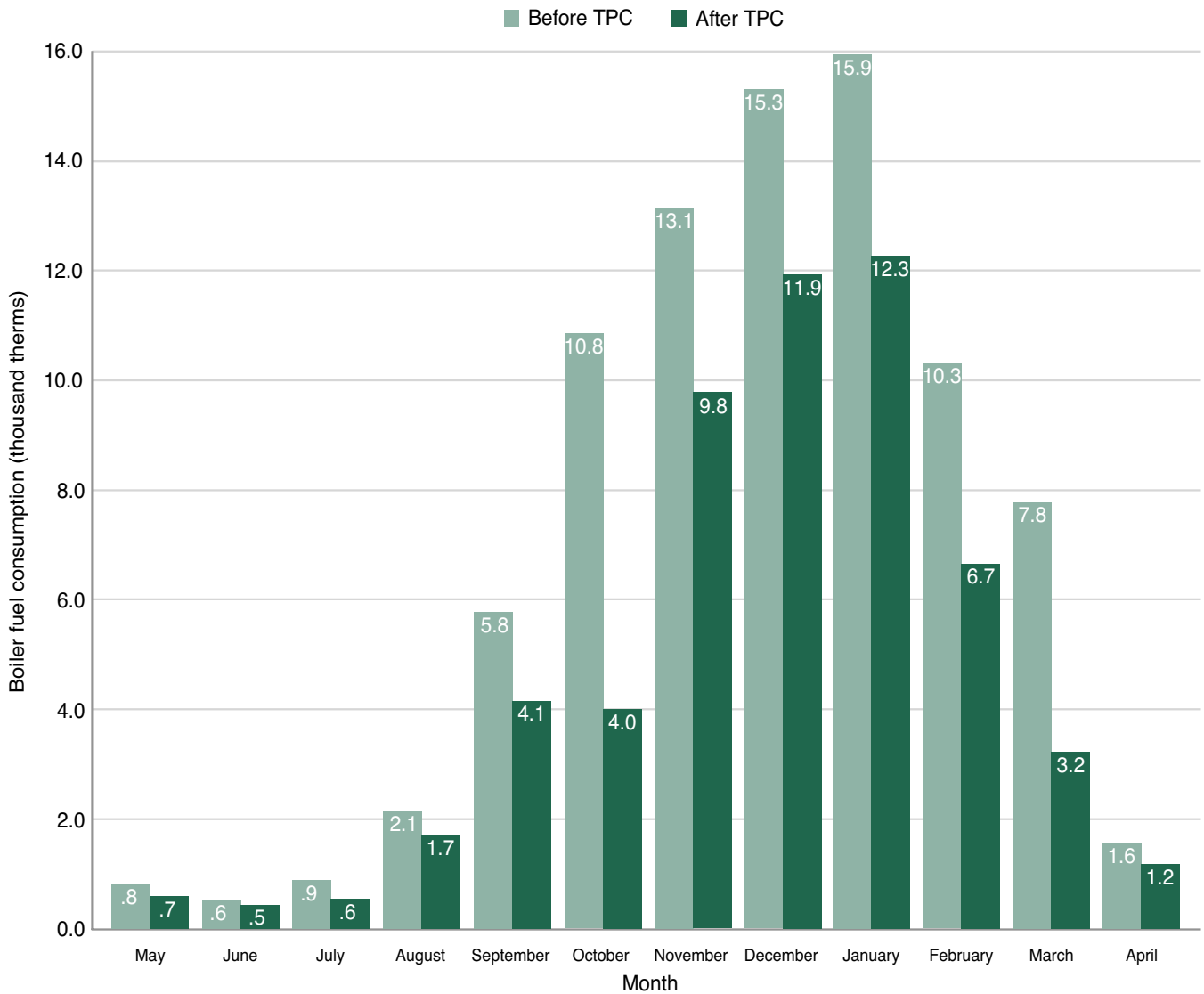
Short-cycling occurs when a boiler fires at a high rate, producing more Btu than are required to satisfy the building load at that time. When too much energy is supplied, the space heats quickly and the thermostat shuts the boiler off. Once the room cools, the thermostat calls for heat and the boiler turns back on. Compared to continuous, steady-state operation,
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in which the boiler output just matches the building heat loss, this frequent on/off cycling wastes energy and causes harmful wear and tear on the boiler. Each time the burner is turned on, the combustion chamber is purged with ambient air to ensure that no explosive gases can accumulate. This process, called a purge cycle, removes heat that must be replaced before the boiler does any useful work, and causes thermal stress. It is generally accepted that short-cycling boilers are around 30% less efficient than boilers that operate continuously at steady-state conditions.

Overheating occurs when the distribution system delivers more heat than the conditioned space requires. The room heats up quickly, satisfying the temperature setpoint, and the thermostat signals the valve to close. However, there is still considerable residual heat in the pipes that continues to be transmitted to the space through the heat emitters, overheating the space.

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Figure 1: Annual fuel consumption is reduced by more than 28,000 therms or about 33%.
 A TPC boiler control system earned substantial fuel savings in a Midwestern university dormitory with relatively small-capacity (4,000 MBH), high-efficiency condensing boilers.



Note: MBH = million Btu per hour.

Current boiler control strategy

To understand why short-cycling and overheating spaces are an ever-present condition of boiler operations, we need to examine outside air reset control, the predominant strategy for controlling large hot water space-heating boilers. The outside air reset function uses a ratio, uniquely calculated for each building, to determine the required rise in boiler supply temperature for each one-degree drop in outside air temperature. This strategy assumes that the change in outside air temperature is proportional to the change in building heat loss. This was a good assumption in the past, when buildings had high rates of infiltration due to poor-quality windows and minimal insulation. More recently, however, as building envelope efficiency has improved and the amount of heat generating electronic devices per square foot has increased, this assumption has become less accurate. Increasing internal heat gains act to reduce the overall building heat loss to a point significantly below the building's original design conditions. Boilers are sized to meet the building design's heat loss rate on the coldest day of the year, which accounts, on average, for only about 1% of a boiler's total operating time. For the remaining 99% of the operating time, they are oversized. Because outside air reset control is based on temperature alone and is unable to take reductions in building load into consideration, it is frequently signaling the boiler to deliver more heat than the building actually requires (Table 1).

In the scenario outlined in Table 1, the building load decreased by 50% over the space of three hours, due to the internal heat gains from occupants, electronic loads, and solar gain; but the boiler reset temperature decreased by only 1% because the outside air temperature stayed nearly the same. As a result, at 10 a.m. the boiler would provide far more heat than required and would quickly cycle on and off. If the building load had been monitored and used to control the boiler's firing rate and the hot water supply flow rate, little or no overshoot would occur, and short-cycling would be reduced.

If the trend toward using more office equipment continues, and if building envelopes become more energy efficient, then the influence of internal heat loads on overall building heat loss will continue to grow, exacerbating boiler short-cycling and overheating spaces. One method that could minimize this condition would be to measure the building load in real time and incorporate it as a control system feedback variable.

TPC boiler control strategy

The founders of TPC understood the potential for energy savings if the boiler output could track the building heat loss. With the advent of relatively inexpensive solid-state controls and flow-measurement devices, they set out to solve the problems of short-cycling and overheating spaces by creating a control system that uses real-time building load measurement as the feedback variable.

Table 1: Outside air reset control misses the importance of changing building loads.

Outside air reset control is not sophisticated enough to incorporate measured building load as a variable in its reset strategy and thus is unable to capture all of the available savings. In this example from an Indiana high school in winter, it's easy to see that outside air reset control is insufficient because it could detect only the minor change in outside air temperature and not the major change in building load.

Time	Outside conditions	Outside air temperature (°F)	Percentage of designed maximum building load	Boiler supply temperature (°F)
7 a.m.	Dark	2	76	178
10 a.m.	Sunny	4	38	176

Note: F = Fahrenheit.

On the surface, the TPC system seems relatively simple: Calculate the building's heat loss rate from measurements with a flow meter and a supply and return-temperature sensor, and use that information to modulate the boiler, combustion air dampers, pumps, and three-way valves to match just that amount of energy in real time. The complexity becomes evident in TPC's software, which incorporates a complex mathematical analysis that includes the boiler's operating characteristics, the energy flow interactions between the boiler and the building demand, the outside air temperature, and the ability to accurately determine the rate of heat loss from the building.

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Based on the calculation of the energy that is being lost in the distribution system, the TPC controller directs the boiler plant to replace just that amount of energy. For example, in Table 1, at 10 a.m., the TPC system would still be supplying hot water at 176° Fahrenheit (F), but the flow rate of that water and the firing rate of the boiler to heat the water would be reduced to the point that the amount of energy delivered to the distribution system at 176° F matched the amount of energy being lost. Despite the complexity, the TPC control system is an off-the-shelf product that doesn't require a custom installation above the normal commissioning process. The TPC system can control single boilers or multiple and mixed boilers (condensing and noncondensing) in a boiler plant. In a multi-boiler installation, the TPC system selects the appropriate boiler according to size, type, and hours of run time to make sure that the load is met by the boiler that will operate most efficiently at the required firing rate.

Best applications

Any existing boiler system that meets TPC's annual fuel bill criteria is a good candidate for an upgrade to the TPC control system. Given the cost of the TPC control system, users considering boiler replacement may think it's best to wait to install the new control system with the new boiler. Our suggestion is: don't wait. By installing the control system before replacing the boiler, the actual building load—both winter heating and summer reheating—and boiler system characteristics will be measured over an entire calendar year. These data will assist designers in selecting the size and type of replacement boilers needed to satisfy the building load most efficiently instead of simply replacing an old boiler with a new

boiler of the same capacity. The resized boiler will likely be smaller, and the savings in equipment cost can be used to defray the cost of the TPC control system. Ongoing savings also will accrue from lower radiative losses from the smaller boiler. The TPC control system is currently available for both hot water and steam commercial and industrial space-heating applications across North America.

For more information

TPC: www.thermodynamicprocesscontrol.com

Please remember:

- This control system is most cost effective for customers using more than \$25K annually in heating fuel costs (not just total gas bill).
- Unlike outside air reset controls, it uses actual building loads (heat gain) as a feedback variable.
- System may be eligible for a custom incentive from Focus on Energy (requiring that the customer or their contractor work with Focus before purchasing or installing the system).

Need more help?

Need help getting started? Contact an MGE account manager at (608) 252-7007. Find more operating tips and free equipment guides at mge.com/business/saving.

Financial incentives for selected energy efficiency improvements are available from **Focus on Energy**, Wisconsin's statewide program for energy efficiency and renewable energy. See focusonenergy.com/incentives for more details.

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