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MULTIFAMILY

Do Vent Dampers Work in Multifamily Buildings?

by Martha Hewett

While the data are not conclusive, here, finally, is a substantial study of the effectiveness of vent dampers for saving energy in multifamily buildings.

Vent dampers—which seal off chimneys when boilers aren't running—intuitively seem like a good idea for multifamily boilers. After all, many multifamily boilers are physically large and many are operated at high temperatures all winter. The chimneys are massive, too, and could draw a lot of warm air out of the building during the off-cycle. But should you bet the cost of the retrofit on it? As it turns out, relatively little work has been done to answer this question as it applies to multifamily buildings, although a number of studies have analyzed the performance of vent dampers in single-family homes and some have studied the factors that affect savings.[1] When we realized that almost no multifamily data were available, and that single-family homes were too different to make findings there directly applicable, we decided to install vent dampers in a few apartment buildings and see how they performed.

The Size and Shape of Our Guinea Pig Buildings

We picked buildings typical of the multifamily housing in Minneapolis: two- and three-story walk-ups ranging from 15 to 80 years old and from 12,000 to 21,000 square feet (7 to 32 units).

Newer Buildings

The four buildings that were built in the 1960s and '70s have compact, atmospheric, cast-iron boilers that hold

Martha Hewett is technical projects manager for the Center for Energy and the Urban Environment (formerly the Minneapolis Energy Office). *The research discussed in this article was funded by Minnegasco, a subsidiary of Diversified Energies, Inc.*

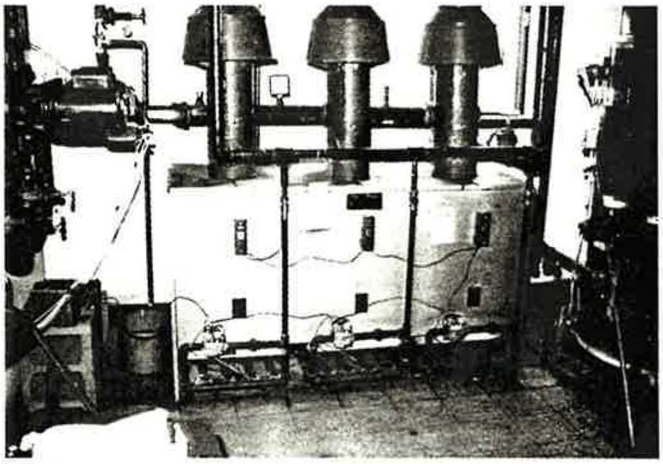

Figure 1. Compact gas-designed boiler of the type tested. This one has three modules and three fixed draft diverters.

less than 20 gallons of water (Figure 1). The boilers are designed to burn gas and have fixed draft diverters. Some were constructed of two boiler modules packaged inside a single sheet-metal casing, and so required a separate vent damper for each module. Total inputs range from 360,000 to 613,000 Btu/hr, and the systems are 50–100% oversized relative to the actual building loads at design conditions (not an unusual degree of oversizing). The buildings have hot water distribution systems with continuous circulation. All four have boiler rooms located on the occupied garden level, but the degree of communication with the living space varies. The boiler room for building D is under the parking lot and has only one wall adjoining the building, while the boiler room for building C is part of the laundry room, and the door is almost always open to the hallway. The other two buildings are more typical, with boiler rooms well closed off by concrete block walls and metal fire doors. All four of these buildings already had outdoor reset and cutout controls, which probably had already reduced the boiler off-cycle losses somewhat.[2] Our goal was to see how much vent dampers would save as a second retrofit in these buildings.

And Older Buildings

The two buildings built before 1921 have large, site-built, atmospheric steam boilers that rest in massive brick

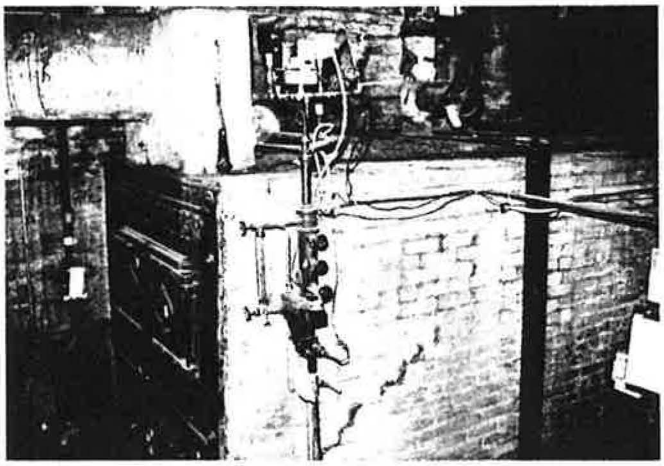

Figure 2. Massive brickset steam boiler at building F. The boiler holds 500 gallons of water. The vent damper is out of the frame to the left.

settings and contain about 500 gallons of water (Figure 2). The boilers have been converted from coal to gas. The boiler in building F has a barometric damper and is 225% oversized, with an input of 1.3 million Btu/hr. The boiler in building E has no draft relief (a code violation) and is 84% oversized, with an input of 1.4 million Btu/hr. Both boilers have motorized secondary air shutters at the burner intake, which are supposed to close during the off-cycle, but only those at building F were properly adjusted. The boilers are in separate boiler rooms in largely unoccupied basements. Both had already received steam balancing services.[3] Each of the six buildings has either one or two conventional tank-type water heaters.

The Test Setup

Since it seemed possible that the savings from vent dampers in the newer buildings might be small (see box on p. 29), we decided to maximize our chance of getting measurable results by going for a top-of-the-line, "Cadillac" installation. We installed redundant gas valves and electronic ignition devices on the boilers so that we could install very tight, quick-closing dampers (see box on p. 31). We even converted the water heaters to 24-volt control and fitted them with redundant gas valves (but not electronic ignition) so that we could install tight, quick-closing dampers on them, too. Not surprisingly, these installations were pricey, due to the cost of numerous new parts and controls and the labor to install them.

For the older buildings we used vent dampers that had been installed on the boilers earlier by the owners, so we didn't have as much quality control, and the dampers were somewhat slower and leakier. With no draft diverters, we expected that the heat saved by the boiler vent damper would be held in the boiler itself rather than spilled into the boiler room, so water heater dampers would be less necessary. As a result, we didn't install dampers on the water heaters until the second year of the tests.

A Vent Damper Refresher

A vent damper is installed in the vent of a furnace, boiler, or water heater, downstream of the draft diverter or barometric damper, and closes automatically when the burner goes off to reduce the loss of warm air up the chimney. How does a vent damper reduce energy use? When an appliance with an atmospheric burner turns off, air continues to flow through the appliance and out the chimney. This air picks up heat as it flows through the heat exchanger. Besides the air that flows through the appliance itself, additional air is drawn out the chimney through the draft diverter or barometric damper. When a vent damper is used, it closes off the venting (at least partially), and reduces the escape of warm air to the outside. Usually air will still flow through the appliance even with the vent damper closed, but instead of going up the chimney, this air will spill out the draft diverter into the area around the appliance. So vent dampers can reduce energy losses in two ways. The first is to reduce heat loss due to air flow over the heat exchanger, either by actually slowing this air flow or by directing it out the draft diverter instead of up the chimney. The second is to cut off a major exfiltration path.

Several characteristics of furnace and boiler venting are important in understanding vent dampers. A furnace or boiler with an *atmospheric* burner relies on the shape of the gas burner and on the natural draft (stack effect) caused by the warm appliance to draw in combustion air. Appliances using natural draft need comparatively large flue gas passages, so often a fairly high volume of air flows through them in the off-cycle, unless dampers are used to reduce the flow. Appliances with atmospheric burners also need some kind of *draft relief.* The draft (or suction) in a chimney varies depending on the temperature difference between the chimney air and outside air, and on the wind speed. But the flame needs a constant draft to burn properly. So a *draft diverter* or *barometric damper* is used to uncouple the combustion area from the variable draft in the chimney. This draft relief is designed so that when the chimney draft increases, more air is pulled through the diverter or barometric damper, but the amount of air pulled through the burner area remains nearly constant. A draft diverter is a fixed opening between the top of the appliance flue and the venting. A barometric damper has the same purpose but consists of an opening in the side of the vent with a weighted damper that swings open or closed as draft increases or decreases.

Codes do not allow *flue dampers,* that is, dampers installed upstream of the draft diverter or barometric damper, as a retrofit, although flue dampers can be installed on some appliances at the time of manufacture (as is done with some commercial water heaters). A vent damper, since it is installed downstream of the draft diverter, allows some warm air to flow through the appliance and out the draft diverter into the boiler room, whereas a flue damper substantially reduces flow through the appliance.

Power burners use a blower to push or pull combustion air into the appliance (forced or induced draft, respectively). Because they rely on the blower, they can have smaller flue gas passages. This, plus the resistance created by the blower itself when it is off, tends to produce relatively low off-cycle flue flow. Furthermore, power burner boilers usually do not have any draft relief, eliminating another source of off-cycle heat loss. For these reasons, power burner appliances seldom, if ever, need vent dampers.

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We alternately activated and deactivated the vent dampers at two-week intervals throughout the heating season. Such a flip-flop design is preferable to before-and-after tests in many cases, because it allows data to be collected in each test mode under comparable conditions of weather, occupancy, maintenance, and so on. During the summer, we only flip-flopped the water heater dampers. (The boiler dampers were deactivated, as they would normally be with power to the boiler turned off.) In the second year we tested three modes in some of the buildings: no damper, boiler damper only, and boiler plus water-heater damper. The data were weather-normalized using the PRInceton Scorekeeping Method (PRISM).[4]

Savings: The Good, the Bad, and the Ugly

The results of our tests can best be summarized by two favorites from the researcher's vocabulary: maybe, and sometimes.

First of all, we saw a fair amount of variation in our year-to-year estimates of normalized consumption for the same building and mode, and a fair amount of year-to-year variation in savings. This variability in the results is probably partly due to real physical changes that were uncontrolled, though to our knowledge these were minimal, and partly due to random error in the statistical estima-

Factors that Affect Vent Damper Performance

Understanding the important factors in vent damper savings that have been identified in single-family homes is a good first step in making educated guesses about how well they might work in the apartment buildings you deal with.

The building

The most critical building characteristic affecting vent damper savings in single-family homes is the extent of communication between the area around the appliance and the rest of the house. Heated air spilled into the area around the appliance is only translated into savings if it is "seen" by the thermostat. One field study found 8 to 14% savings for houses with the best communication, and –3 to 6% for those with the worst.[11] This finding doesn't seem to bode well for vent dampers in apartment buildings, since boiler rooms are typically isolated from the living space by fire-rated walls, ceilings, and doors.

The second building characteristic that is important is the fraction of flow up the chimney that actually contributes to the net air-change rate of the building. Closing off the venting may save a lot if it actually reduces the building air change rate, but if air flow simply directs itself to other exfiltration paths, the damper may provide little benefit.

The boiler and the water heater

Characteristics of the appliance itself also affect the savings from vent dampers. The more oversized the furnace or boiler is, the more time it will spend off, and therefore the greater the total off-cycle losses. A study in the early 1980s showed that furnaces in single-family homes nationwide averaged 125% oversized![12] We are not aware of any comparable data for apartment buildings.

The larger the heat capacity (or thermal mass) of the boiler, the more heat is available to be lost by off-cycle air flow through the heat exchanger. Multifamily boilers do have greater heat capacities than single-family furnaces, though not necessarily proportionately greater. Older multifamily boilers are often physically large, with heavy cast iron sections or massive brick settings, and large volumes of water. Newer boilers are often physically compact, not much larger than residential heating systems in spite of substantially higher firing rates. But in many multizone heating systems, the circulating pump moves the water in the distribution system through the boiler continuously, even during the off-cycle, increasing the effective thermal mass.

The chimney's size and long-term off-cycle temperature are also important. The larger and hotter the chimney, the more off-cycle flow it will induce.[13] In Minneapolis, buildings with boiler inputs over 400,000 Btu/hr are not required to have metal chimney liners, so brick chimneys are the norm. These could be expected to cause higher long-term off-cycle temperatures and more sustained drafts than if metal liners were present.

The water heater can't be overlooked, either. At least in some cases, an open water-heater vent will serve as an alternate escape route. One lab study showed that with a damper on the furnace only, exfiltration was reduced very little compared to having no damper at all. But with a damper on both the furnace and the water heater, exfiltration was reduced substantially. Estimated savings were 0.4% and 8.7% respectively.[14] A field study found savings averaging 5.1% for a vent damper on the furnace alone, and 9–11% for vent dampers on both appliances.[15]

One heating system factor not discussed in the single-family research we have seen is draft relief. Modern, gas-designed atmospheric boilers typically found in newer multifamily buildings have fixed draft diverters similar to those found on residential systems. But older boilers that were converted from coal to gas typically have barometric dampers. When a vent damper installed on such a system closes, the barometric damper swings closed because the draft on it is greatly reduced. This greatly limits spillage from the boiler into the boiler room, and holds more heat in the boiler itself.

As mentioned earlier, boilers with power burners should not need a vent damper.

The damper itself

Not surprisingly, the characteristics of the vent damper itself are also important. Damper closing time can vary from instantaneous for solenoid-operated electric dampers to as much as 13 minutes for some bimetal dampers. How important this is will vary with both the heating system cooling rate ("time constant") and the frequency of heating system cycling, but a slow damper definitely runs the risk of locking the barn after the horse is stolen. Computer modelling of residential furnaces showed that savings were degraded about 33% by a two-minute closure delay.[16]

Physical leakage areas typically range from 2–20%. As a rule of thumb, for small leakage areas the percent energy leakage is about four times the percent physical leakage area.[17] National standards influence the closing time and leakage area of available products (see box, p. 31). Of course, there is no free lunch: tight, fast dampers that can provide greater energy savings have to be installed with two main gas valves, which greatly increases their cost.

After mentally applying all of the above to the multifamily boilers you have come to know and love, you may find yourself confused about whether or not vent dampers are a good idea for apartment buildings. We were at that very point when we decided to put vent dampers to an actual field test.

tion of normalized annual consumption. For our purposes, the implication is that it is probably more meaningful to look at average results for groups of buildings than to try to interpret individual building data.[5]

On this basis, most of the results make sense. For the gas-designed boilers with draft diverters, savings using both boiler and water heater vent dampers averaged 780 therms or 6.5% of total gas use, with a range of –1.5 to 9.5% (see Table 1). The overall mean savings are statistically significant, as are the savings from four of the six tests individually (a fifth is marginally significant). But when two of these buildings were tested with boiler dampers only, "savings" were only 1.6 and 2.1% and were not statistically significant. As we expected, these systems seem to need vent dampers on both appliances to be effective.

For the buildings with massive conversion boilers, savings from vent dampers on the boiler alone averaged a statistically significant 1,440 therms or 8.5% of total gas use, with a range of 5.7 to 11.7%. Two of the individual tests were statistically significant and two were marginal. So, as expected, a vent damper on the boiler alone produced savings in these systems, perhaps because the barometric dampers held the heat in the boiler itself. However, inconsistent results were obtained in these buildings in the tests of both boiler and water-heater dampers. One building did substantially better than it had with the boiler damper only, while the other did much worse than it had with the boiler damper only, and essentially saved nothing.

Table 1. Performance of Vent Dampers at Test Sites.

Building ID	Heating Season	Savings, therms/yr	Savings, percent*	Cost, $	Payback, years**
Compact gas-designed boilers with draft diverters					
Damper on boiler and water heater					
A	'84–85	890	9.5	2,200	4.5
A	'85–86	380	4.2	"	10.6
B	'84–85	1,240	9.3	2,720	4.0
B	'85–86	1,250	9.4	"	4.0
C	'85–86	-160	-1.5	1,530	none
D	'85–86	1,100	8.0	2,590	4.3
Damper on boiler only					
A	'85–86	140	1.6	1,630	20.7
B	'85–86	280	2.1	1,260	8.2
Brickset conversion boilers with barometric dampers or no draft relief					
Damper on boiler and water heater					
E	'85–86	160	0.7	2,400	36.9
F	'85–86	1,380	12.1	2,430	3.2
Damper on boiler only					
E	'84–85	1,210	5.7	1,700	3.5
E	'85–86	2,570	11.0	"	1.7
F	'84–85	1,330	11.7	850	1.2
F	'85–86	660	5.8	"	2.3

* Percent of total weather-normalized annual gas use.
** Paybacks calculated based on 1984–86 average marginal cost of gas of $0.55/therm, except $0.40/therm for interruptible service at building E.

With the exception of the last results for conversion boilers, the broad pattern of our findings seems logical and relatively consistent.[6] Still, we are baffled by some of our results. First, the variations from year-to-year in normalized consumption and savings, though similar to those that have been observed elsewhere,[7] are not particularly comforting. Second, results from specific buildings with gas-designed boilers did not come out as we had anticipated. We had thought that building C might do well because the boiler room was in open communication with the rest of the building. We thought building D might do poorly because the boiler room only adjoined the building along one wall, and the chimney was low-mass metal rather than masonry. But in reality, we observed the exact opposite pattern of savings. Perhaps the vent dampers on gas-designed boilers saved energy primarily via their secondary effects on boiler room temperature. Recent measurements have shown that off-cycle *flue* flow (flow through the appliance) is relatively insensitive to *vent* draft in some cases,[8] but we know that flue flow depends on the difference in temperature between the appliance and the boiler room. So perhaps the vent damper warmed the boiler room enough to reduce off-cycle flue and jacket losses in some cases, such as the small, isolated boiler room at D, but not in others, such as the large boiler room at C, which was open to the rest of the building. We took strip-chart recordings of boiler room temperature, but we have not analyzed them yet, so this remains in the realm of speculation. Thus while the buildings with gas-designed boilers did well on average, we cannot yet predict which ones will do better or worse.

The contradictory results for the massive steam boilers are also unsettling. Why did one system do much better with dampers on both the boiler and water heater than with a damper on the boiler only, while the other did much worse? The only idea we have come up with is that for the boiler with no draft relief, closing the water heater venting with a tight damper may have shifted the main off-cycle air flow path back through the boiler, with its leakier damper, undermining the savings.

Digging Deeper

Short-term diagnostic tests conducted at two of the buildings by researchers from Lawrence Berkeley Laboratory (LBL) agreed reasonably well with our findings. At building B, LBL's results support our finding that if the boiler has a draft diverter, vent dampers must be installed on the water heater as well as the boiler to be effective. LBL measured air-flow rates and air temperatures in the venting and chimney in this building for about seven hours in each damper test mode. The graphical data they provided show that the minimum off-cycle air flow through the chimney shared by both appliances was about 410 cubic feet per minute (cfm) with no damper in place. With a boiler damper only, this decreased only modestly to about 320 cfm (and in fact, though flow through the boiler venting decreased by 80%, flow through the water heater venting actually increased by about 35%!). But with both boiler and water heater dampers, the total chimney flow dropped sharply to 120 cfm. Minimum air

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Vent Damper Standards and Products

The construction, performance, and installation of vent dampers are addressed in national standards. These standards are voluntary for the manufacturer, but state and local codes often permit only products with third-party certification to be installed. Even if they are not required in your area, certified products are preferable in terms of safety and liability.

The American National Standards Institute (ANSI) has established standards for electrically-operated and thermally-actuated dampers for use on gas-fired appliances (Z21.66 and Z21.68). The standards are predicated on use of the dampers with certified appliances equipped with draft diverters, and apply to dampers with nominal diameters of 12 inches or less. (They do not cover dampers installed on larger vents or with barometric dampers). American Gas Association Laboratories lists the manufacturers and model numbers of certified vent dampers in its *Directory of Certified Appliances and Accessories.*

The minimum allowable leakage area and closing conditions for vent dampers made for use on gas appliances are spelled out in the ANSI standards. If the manufacturer's installation instructions specify that the vent damper is for use only on appliances equipped with two main gas valves (to provide extra safety), then the damper can be both tighter and faster than if such a "redundant" valve is not specified. For vent dampers of sizes typical in multifamily buildings, the required minimum leakage area with a redundant valve present is less than 2%, and there is no restriction on closing time. Two main gas valves can be provided by installing a second main valve in series with the original, or by installing a replacement with two internal main valves, but either alternative entails substantial extra expense for both parts and labor.

On the other hand, if the manufacturer's installation instructions don't call for two main gas valves, the ANSI standards require the vent damper leakage in the closed position to be at least 10% of the vent area. For electric vent dampers, they further require an integral means to assure that the damper cannot close when the temperature of the air in the damper is above 225°F.

Vent dampers for oil-fired appliances are certified by Underwriters' Laboratory (UL) under UL/ANSI 17, *Standard for Vent or Chimney Connector Dampers for Oil-Fired Appliances.* Since we do not work with oil-fired appliances, we have not studied these standards in detail. Certified products are listed in UL's *Gas and Oil Equipment Directory.* You can use the AGA and UL equipment directories to identify vendors on a national level, then contact them for local representatives or distributors.

temperatures in the chimney were relatively constant at about 95 to 105°F. So the heat loss was reduced much more with dampers on both appliances than with a damper on the boiler only.

At building F, LBL staff found that the vent damper on the boiler alone reduced instantaneous heat loss through the boiler from 32,000 to 24,000 Btu/hr, and reduced instantaneous heat loss from the boiler room via the barometric damper from 37,000 to 25,000 Btu/hr. From these and other measurements, they estimated a 9% savings in space heating energy use.[9] For that same year, we had calculated submetered space heating savings of 12.6%, a good agreement for two such different methods.

Costs and Paybacks

The costs of the installations in our test buildings, shown in Table 1, are based on manufacturers' suggested retail prices and labor at $43 per hour. They are quite high, reflecting the additional gas valves and electronic ignition devices for most of the boilers, changeover to 24-volt controls and redundant valves for the water heaters, and the fact that many buildings had two boiler modules or two water heaters, so that three vent damper systems were needed.

For the boilers with draft diverters, the median payback time for installing dampers on the boiler and water heater was 4.4 years, but the range was from four years to infinite (no payback at all). For the conversion steam boilers, the payback was 1 to 4 years for a damper on the boiler only. For dampers on both appliances, one building showed a payback of 3 years and the other 37 years!

Even the better paybacks we observed are long compared with the 1 to 2-year paybacks that owners in our area, Minneapolis, are looking for. Obviously, vent dampers can be installed at much lower costs if you go for a "Volkswagen" installation instead of a "Cadillac." Table 2 shows the installed costs we currently use in our multifamily program for vent dampers without redundant gas valves and electronic ignition devices. Using this less expensive approach, we could have installed vent dampers on the boilers and water heaters in buildings with gas-designed boilers for only 20 to 30% of the costs of the Cadillacs. Cadillacs had not been installed on the coal-to-gas conversion boilers, since those vent dampers were put in by the owners themselves. On the total installations including water heater dampers, we could have reduced costs in the older buildings to about 60% of the Cadillac price. These cheaper installations would also be simpler for contractors to install and for subsequent contractors to service. Of course, the critical question is: How much would slower, leakier dampers degrade savings?

Conclusions?

Everything that is known about savings from vent dampers in multifamily buildings still leaves us far short of an iron-clad programmatic decision on vent dampers. For now, our office is marketing "Volkswagen" dampers on both appliances when the boiler has a draft diverter, and on the boiler alone when it has a barometric damper. Work is bid using the prices in Table 2. Estimated savings are somewhat arbitrarily deflated from the averages we saw in our research tests to 5% of space heating gas use (about 3.5% of total gas use) in both types of systems. The owner makes his or her own decision based on the resulting payback. If there is more than one boiler module or more than one water heater, costs increase and the economics may not look as good. We don't recommend dampers on boilers with power burners (see box on p. 28) or if the boiler room has a thermostatically controlled fan that brings in outside air when the room gets too warm.

One of the most important conclusions at this point is that we just don't know enough about the seasonal efficiency of multifamily boilers. If we had measured data on

Table 2. Current Installed Costs for Vent Dampers in Minneapolis Multifamily Program.

Vent Diameter, inches	Cost, $, w/tapered fittings	Cost, $, w/flanged fittings
Electric dampers with no redundant gas valves		
4-8	280	n/a
9-12	330	n/a
13-16	800	870
≥17	1,300	1,300
Thermal dampers		
3-5	90	n/a
6-8	110	n/a

the off-cycle stack losses for a good-sized sample of common boiler types, it would be relatively obvious which ones have high enough losses to need a vent damper. So far, relatively little of this type of data has been collected.[10] Our results also point up the limitations of flip-flop tests. These tests are most useful when they show consistently good savings or consistently bad savings from a retrofit. When some buildings do well and others do poorly, flip-flops alone don't provide the details needed to sort out what makes a building a good candidate for the retrofit.

Of course, various retrofits have been installed in literally thousands of buildings with much less measured data to go on. While that may not be too comforting, we hope that this article gives you a better basis on which to decide whether to recommend vent dampers for the multifamily buildings you work with, or perhaps motivates you to field test them for yourself. ■

Endnotes

1. The following are recommended:

Field studies:

T.S. Zawacki, J.T. Cole, V. Huang, and R.A. Macriss, 1982. *Effect of Building Characteristics on Gas-Appliance Performance and End-Use Efficiency.* Institute of Gas Technology, Chicago, IL.

R.A. Macriss, T.S. Zawacki, M.T. Kouo, and P.A. Ketels, 1980. *Analysis and Correlation of Seasonal Performance Data from the Gas Industry's Space Heating Efficiency Improvement Program (SHEIP).* Institute of Gas Technology, Chicago, IL.

L. Berry, J. Bledsoe, T. Vineyard, and D. White, 1987. Evaluation of gas heating system retrofit pilot programs in Minnesota and Kentucky. *Proceedings of the 1987 Conference on Energy Conservation Program Evaluation: Practical Methods, Useful Results.* Vol. 1, p. 209–217. Available from Argonne Na ional Laboratory, Argonne, IL.

P. Witte and M. Kushler, 1987. Results of the Michigan natural gas furnace retrofit pilot for low-income households. *Proceedings of the 1987 Conference on Energy Conservation Program Evaluation: Practical Methods, Useful Results.* Vol. 1, p. 227-236.

Lab study:

R.A. Macriss and F.E. Belles, 1976. *Evaluation of Alternatives for Conserving Fuel Resources.* Institute of Gas Technology, Chicago, IL.

Computer modelling:

U. Bonne and A. Patani, 1982. *Combustion System Performance Analysis and Simulation Study.* Gas Research Institute, Chicago, IL.

2. For more on resets, see *HE,* Nov/Dec '88.
3. Steam balancing was discussed in *Energy Auditor & Retrofitter,* (now called *Home Energy*) Mar/Apr '87.
4. M.F. Fels, 1985. *The PRInceton Scorekeeping Method: an Introduction.* Report No. 163, Center for Energy and Environmental Studies, Princeton University, Princeton, N.J.
5. For complete information on NACs and associated statistics for this study, see M.J. Hewett, T.S. Dunsworth, H.E. Emslander and M.J. Koehler, 1988, *Measured Energy Savings from Vent Dampers in Low Rise Apartment Buildings.* MEO/TR88-2-MF, Minneapolis Energy Office, Minneapolis, MN.

   Ed. note: The buildings are referred to by letters rather than the numbers used in the full report. Building A = building 3033; B is 2600; C is 1910; D is 2002; E is 1518; F is 2317.
6. Vent dampers have also been tested in one apartment building each by St. Paul's Energy Resource Center and Chicago's Center for Neighborhood Technology. Their results are within the same general range as our flip-flop findings. For results of the ERC tests, see D.A. Robinson, G.D. Nelson, and R.M. Nevitt, 1986. *Evaluation of the Energy and Economic Performance of Twelve Multifamily Buildings Retrofitted Under a Shared Savings Program.* Energy Resource Center, St. Paul, MN. CNT data were provided to us by John Katrakis.
7. Center for Neighborhood Technology, 1986. *Space Heating Efficiency Improvements in Multifamily Buildings, Topical Report January to October, 1985,* for Gas Research Institute, and Macriss et al., 1980.
8. R. Nevitt, 1989, *Measured Performance of Water Heater Retrofits to Reduce Standby Losses in a 24-Unit Apartment Building.* St. Paul: Energy Resource Center.
9. M.P. Modera, R.C. Diamond, and J.T. Brunsell, 1986. *Improving Diagnostics and Energy Analysis for Multifamily Buildings: A Case Study.* LBL-20247. Lawrence Berkeley Laboratory, Berkeley, CA.
10. Results of a few studies were summarized by M. Modera, Jacket and stack losses from multifamily boilers. *Proceedings of the American Council for an Energy-Efficient Economy Summer Study,* 1988, Vol. 2, p. 148-154. ACEEE, Washington, DC.

    Princeton University recently prepared a *Multifamily Building Energy Diagnostics Technical Reference Manual* for DOE that contains diagnostic tests for estimating the seasonal efficiency of multifamily boilers. These are probably too time-consuming to incorporate into a routine energy audit, but could be used to test a representative sample of your multifamily building stock.
11. Zawacki et al., 1982. Bonne and Patani (1982) got similar results from sophisticated computer modelling: 14% savings with perfect communication and 0.2% savings with no communication.
12. See Macriss et al., 1980.
13. See Bonne and Patani, 1982, for details.
14. See Macriss and Belles, 1976.
15. Installations included electronic ignitions in some cases. See Macriss et al., 1980.
16. See Bonne and Patani, 1982.
17. Ibid.