Energy Savings and Field Experiences with Dual Integrated Appliances

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Dual integrated appliances (DIA)—water heaters used to provide both domestic hot water (DHW) and space heating—have a number of potential advantages over separate water heaters and furnaces. Compared to separate systems DIAs can be more energy efficient, easier to zone, easier to side vent and require less floor area. A two-year field study was conducted of DIAs installed in five multifamily and five small commercial locations to access the applicability of the systems in a cold weather climate. A PRInceton Scorekeeping Method (Fels 1986) (PRISM) analysis of alternating mode and pre/post data showed energy savings ranging from -14 to 28%, with an average of 11%. Approximate values of the combined annual efficiency (CAE) for the separate and DIA systems were computed using the PRISM estimated heating loads and manufacturer specified efficiencies. Energy savings estimated from the CAEs of the two types of systems ranged from 6 to 32%, with an average of 24 %. Systems with higher estimated savings generally had higher measured savings, but in only one case did the measured savings plus the uncertainty equal or exceed the estimated savings. The discrepancy between estimated and measured savings may be due in part to the DIA systems operation at lower than rated efficiency.

Field experiences from installing and operating DIA systems are also reported. During the design and specification process (1989) the authors found a limited availability of appropriate water heaters. In addition, code officials were sometimes reluctant to allow the installation of DIA systems. There were few complaints of inadequate space heat or reduced DHW temperatures. After 1 1/2 years of operation there were no reported failures of the four heaters with atmospheric burners, but the sealed combustion units had a number of combustion box, venting, and tank failures.

Introduction

Dual integrated appliances are simply water heaters that are used to provide both domestic hot water (DHW) and space heating. Although there are three different types of DIAs, this study only focuses on type II systems—often called combo heaters. A diagram of a typical type II DIA installation is displayed in Figure 1. For these systems the water heater hot water outlet is used not only for DHW, but also supplies water to a space heating coil. When space heat is required, a pump circulates hot water through the heating coil and returns it to the heater. The heating coil can be located near the heater or in a remote location and is available in vertical, horizontal, and wall-recessed units. The building thermostat typically activates both the blower and circulation pump simultaneously. The heater burner is controlled by the tank aquastat which is different from that used in a typical boiler system where the pump and burner are both activated by a thermostat. A DIA system controls these two components independently, since the heater water must always be kept warm for DHW use.

A DIA system has the advantage of having off-cycle losses for only one appliance and can potentially operate at a higher energy efficiency than similar separate systems. Apart from energy considerations, a DIA system has the following many advantages when compared to a separate system: (1) side venting or sealed combustion may be easier to accomplish with a single appliance, (2) the use of a horizontally mounted air handler will reduce the mechanical system floor area, (3) the heating system is easier to zone, (4) there is only one combustion appliance to maintain or replace.

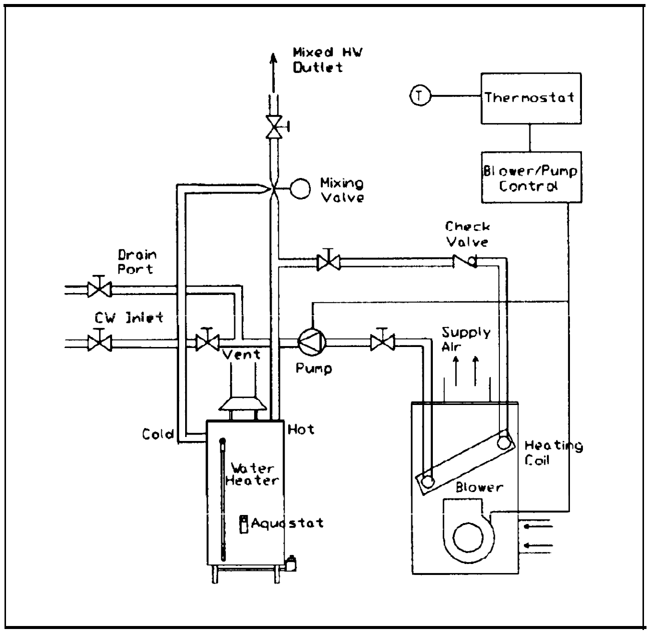

Figure 1. Diagram of Typical DIA

When this project began some code officials were reluctantto allow the installation of DIA systems. There were concerns of possible deleterious health effects from the stagnant water in the heating coil, lack of state codes, reduced heater life span, and that heaters were being used in a boiler application. Many of these concerns have been addressed and there is presently better acceptance of the systems. The State of Minnesota Plumbing Code (1990) has been amended to include guidelines for the installation of DIA systems. The guidelines specify that mixing valves are required to guard against injury from elevated DHW temperatures and that a method for purging the stagnant water in the heating coil be used to reduce the likelihood of Legionella growth. The water heaters must also be approved by the manufacturer for DIA use and all system components must be approved for potable water.

Resistance from code officials for using water heaters for space heating has occurred in other parts of the United States (ACHRN 1991; EDU 1989) and in Canada (Thrall 1989). The key point in this debate is the determination of the criteria used to define a appliance as either a water heater or a boiler. The courts have consistently found that adding a space heating load to water heaters does not transform water heaters into boilers (ACHRN 1991). The longevity of the DIA heaters has also been a concern. However, field studies have shown that using a water heater in a DIA system may actually increase the life span of the heater (Thrall 1989).

Dual integrated appliances are a relatively new type of system that do not have an extensive history to guide sizing of the heating coil output, storage tank volume, and heater input rate. While standard practices that are used to size other space heating systems are appropriate to size the heating coil output, sizing of the other system parameters requires consideration of DHW and space heating demands and their interaction. Pietsch and Talbert (1989) have used a simplified model of system operation to recommend guidelines for sizing DIA systems for multi-family (MF) and single family applications. The authors "rule of thumb," was that the heater output should typically be 1.2 times the rated coil output. In addition, the storage capacity should be between 3 to 5 times the peak hot water draw. For MF units without laundries this would require a storage volume of 40 to 50 gallons, but 50 to 75 gallons may be required for units with laundries.

Experimental Design

One of primary purposes of this study was to compare the energy use of a dual integrated appliance system to that of a separate furnace and water heater system. The first portion of this analysis used weekly or biweekly measured gas use to compute the energy savings of the installed DIA systems compared to the existing furnace and water heater. Simple computational methods were also used to estimate the energy savings of the DIA systems based on the rated efficiencies of the DIA, furnace, and water heaters. In addition, two of the systems were intensively monitored to determine seasonal efficiency. The results of those measurements are presented in the project final report (Bohac 1991).

Measured Gas Use Analysis

When possible, the DIA systems were installed in parallel with the existing systems to allow alternating mode tests to be performed on the two systems. The test was carried out by switching between the two systems every one or two weeks and recording the gas use by the active system. The inactive system was isolated so that it did not contribute to off-cycle losses. Due to space limitations, some of installations had to be complete change outs. The analysis at these sites was performed by comparing the gas use of the existing system from the previous year to that of one year following the installation. The normalized annual consumption (NAC) for each operating mode was computed using PRISM, the PRInceton Scorekeeping Method (Fels 1986).

Model Estimated Savings

A method of testing and rating DIAs, ASHRAE 124P, has been developed by ASHRAE (ASHRAE 1990). An appendix to this standard presents a method for computing the combined annual efficiency (CAE) of a separate water heater and space heating appliance:

$$CAE_{sep} = (ASHL + AWHL)/(ASHU + AWHU) \quad (1)$$

$$= (ASHU*AFUE + AWHU*EF)/(ASHU + AWHU) \quad (2)$$

$$= (ASHL + AWHL)/(ASHL/AFUE + AWHL/EF) \quad (3)$$

where ASHL = annual space heating load
AWHL = annual DHW load
ASHU = annual space heating use
AWHU = annual DHW use
AFUE = space heating appliance annual fuel utilization efficiency
EF = water heater energy factor

The PRISM analysis presented in the previous section can be used to compute the ASHU and AWHU. The ASHL, AWHL, and CAE_{sep} can then be computed from ASHU, AWHU and the manufacturers' efficiency ratings of AFUE and EF for the existing appliances.

At the time of this study (1989) no DIAs had been tested for use under the procedures specified in ASHRAE 124P. To provide an approximate comparison of estimated CAEs for DIAs and separate systems, a simplified method was developed to compute an approximate value of CAE for DIAs. When evaluating the CAE, it is typically considered that DHW is the primary load for the DIA heater and space heat is the secondary load. Thus, the heaters off-cycle losses are attributed to the DHW load and space heat is produced at the heaters steady state efficiency (E_{ss}). Using these assumptions, E_{ss} can be substituted for AFUE in equation (3) above to compute the CAE for a type II DIA:

$$CAE_{II} = (ASHL + AWHL)/(ASHL/E_{ss} + AWHL/EF)$$

This equation uses the DIA E_{ss} while only the recovery efficiency (E_r) of the DIA is typically available. However, the E_r is typically only from 1 to 4% below the E_{ss}, depending on the relative magnitude of the standby loss rate. Given the small difference between the two values, replacing E_{ss} in equation (4) with E_r plus will result in only a small loss in accuracy.

Site Selection and Description

This study targeted two markets: multifamily buildings with unit-level heating and DHW equipment and small commercial (SC) buildings. Ten sites were selected for the study based primarily on the potential to achieve DIA energy savings and also the capability of demonstrating those savings. One of the important factors for achieving savings is the size of the domestic hot water load. With a higher recovery efficiency, the absolute savings will be greater for buildings with higher DHW loads. A second source of savings is the reduced off-cycle losses of a single appliance compared to a heater and furnace. However, the heating load must typically be moderate so that the increase in the heater size required to satisfy the added space heating load does not significantly increase the absolute off-cycle loss rate.

Selection Criteria

The limited range of DIA heater output and efficiency restricted site selection. When this project began in the fall of 1989, fifty-six heaters from five manufacturers were manufacturer approved for use as DIAs. In order to be competitive with replacement furnaces, it was decided that the DIAs should have recovery efficiencies at least equal to the national minimum AFUE level of 78% (NAECA 1987). Of the fifteen heaters with E,s of 78% or greater only four had inputs greater than 40,000 Btu/h. Based on the sizing criteria mentioned previously, heaters with a recovery efficiency of 78% and 30,000 to 40,000 Btu/h inputs are appropriate for most newer multifamily units in Minnesota with floor areas of 1,000 ft^2 or less and many small businesses located in strip malls. In addition to sites with low heat loss, another target sample was SC locations with a heat loss of 50,000 Btu/h or greater which could take advantage of an expensive (list price of over $3,200), 100,000 Btu/h condensing heater.

The capability of accurately determining the savings from the DIA retrofit was also a consideration. This required that the building occupants and their activities would not change, the existing equipment was expected to last for another year, and no significant modifications would be made to the building thermal envelope. It was also necessary to select sites which had monthly gas use which was adequately modeled by outdoor temperature. Clean models were especially necessary for sites using a pre/post test method.

Site Description

The five multifamily test units are all located in a single, two story, eight-plex built in the early 1980s. They are built in a single row with four two-bedroom and four three-bedroom units. The three two-bedroom units used in the study have floor areas of 675 ft^2 and calculated design heat loss of 20,000 Btu/h. The two three-bedroom end units used in the study have floor areas of 930 ft^2 and heat losses of 27,000 Btu/h. The annual base (DHW and stove) use estimated from the PRISM gas use analysis ranged from 30 to 37% (211 to 371 ccf) of the total for all the units, except unit 72 which had a relatively higher base use of 52% (436 ccf). All of the units had the same furnace and water heaters. The furnaces had an input and output of 55,000 and 42,000 Btu/h respectively and a AFUE of 60.3%. The water heaters had an input of 36,000 Btu/h, storage capacity of 40 gallons, estimated EF of 0.4 and measured combustion efficiency of 77.2%.

A small commercial sandwich shop (4409) and dog grooming salon (4207) were selected due to relatively high DHW loads (496 and 382 ccf/yr respectively) and moderate space heating loads. The sandwich shop has a floor area of 3,350 ft^2 and a design heat loss of 54,200 Btu/h. The space heating is provided by two separate heating systems. The furnace that is being used for comparison in this study is only used to heat the rear of the shop and handles a smaller portion of the heating load. This furnace has an input of 50,000 Btu/h and a AFUE of 71.4%. The water heater has an input of 38,000 Btu/h, storage capacity of 40 gallons, and recovery efficiency of 73 %. The dog grooming salon has a floor area of 1,400 ft^2 and a design heat loss of 26,000 Btu/h. The existing equipment at the salon consisted of a furnace with an input of 80,000 Btu/h and AFUE of approximately 66%. The heater had an input of 40,000 Btu/h, storage capacity of 30 gallons, and recovery efficiency of 70%.

Two of the other SC sites are medical offices (3920 and 3925) with low annual base loads of 9 and 12% (120 and 164 ccf/yr) consisting almost entirely of DHW use and annual heating uses of 1208 and 1201 ccf. The buildings are designed and constructed similar to single family homes. They have floor areas of 2,900 and 3,600 ft^2 and design heat losses of 42,700 and 44,200 Btu/h respectively. They have similar type furnaces with AFUEs of 65. 8%. The furnace input for 3920 is 110,000 Btu/hr compared to 165,000 Btu/h for 3925. The heater at 3920 has an input of 33,000 Btu/h, storage capacity of 30 gallons, and recovery efficiency of approximately 70%. The heater at 3925 has an input of 75,000, storage capacity of 63 gallons, and recovery efficiency of approximately 76%.

The final SC site is a combination bagel shop and bakery. Since heat from the bagel cooker and oven was sufficient to heat the building on most days and the space heating and DHW equipment were connected to the same gas meter as the cooking equipment, a valid energy savings analysis was not possible.

Installed Systems

All of the installed systems met the new State of Minnesota code specifications for DIAs (SM 1990) with the exception that some did not have a method for purging the heating coil. The systems were all designed and operated as described in the Introduction section of this report. At sites where the furnaces were kept in place the furnaces were used as a air handler for the DIA. Otherwise a vertical air handler with heating coil replaced the furnace.

One of the difficulties of the study design was specifying the heating coil outputs of the DIA systems. All of the existing systems had capacities of over 150% of the estimated design load. It was expected that matching the existing capacities would allow a more even comparison to the existing systems, but would not provide a fair test of the savings achievable with the DIA systems. A compromise was selected in which the six systems at MF units 60 and 74; and SC sites 3920, 3925, 4409, and 4412 were designed to either match the existing furnace output or use the maximum output available which would come as close as possible to the furnace capacity. The systems installed at the other four locations used the design heat loss as a guide.

Due to space limitations in the furnace closets, all of the existing MF furnace and water heater systems had to be removed in order to install the DIA systems. The five DIA systems installed are described in Table 1. Each of the heaters has the same storage capacity of the old system, except the heater for 74 which is 10 gallons

Table 1. Description of DIA Systems Installed in Multifamily Units

Build ID	Heater Input (Btu/h)	Heater Output (Btu/h)	Coil Output (Btu/h)	Heater/ Coil Ratio	Storage Capacity (gal)	E_r (%)	EF	Comb. Eff. (%)	Burner Type	Vent Type	Installed Cost ($)
60	52,500	39,900	41,500	0.96	40	76	0.54	77.6	atmos.	vert.	2,212
64	40,000	34,000	30,000	1.13	40	85	0.61	81.2	atmos.	vert.	2,067
70	40,000	33,200	25,000	1.33	40	83	0.64	84.5	power	side	2,809
72	40,000	33,200	25,000	1.33	40	83	0.64	85.6	power	side	2,809
74	65,000	49,400	41,500	1.19	50	76	0.52	78.3	atmos.	vert.	2,212

larger. The coil outputs for the two larger, end units (60 and 74) closely match the output of the furnace. The heater for 74 has an output nearly a factor of 1.2 times the heating coil output and the heater for 60 has output which is only 96% of the rated coil output. The DIAs in both systems have E_rs of 76%, atmospheric burners, and vertical venting. In order to provide a higher output, larger heaters with lower E,s had to be used. The installation cost for each of the systems was $2,212. As a comparison, the heating contractor estimated that it would cost approximately $1,750 to install a furnace with an AFUE of 80% and water heater with an EF of approximately 0.5.

It was decided to test a system specifically designed for DIA applications in units 70 and 72. The air handler/heating coil of this system is factory wired and plumbed and is stacked on top of the heater to reduce the system footprint. The stacked design proved to be a significant advantage for these locations. Previously, a hole had to be cut in the hallway wall in order to replace the water heater. The heating coil output is well matched to the design load and heater output. The heaters have recovery efficiencies of 83%, power draft burners, and can be vented to the side or vertically. The installation cost for each system was $2,809.

A similar sized unit, with separate heater and air handler, was installed in unit 64. The heater input and storage capacity was the same as for the systems in 70 and 72, but the recovery efficiency, heater output, and coil output are all slightly higher. The DIA has a recovery efficiency of 85%, atmospheric burner, and uses the existing vertical vent. The installation cost of $2,067 was the least expensive of the five systems.

At three of SC sites (3920, 3925, and 4409) the DIA systems are installed in parallel with the existing separate systems. The other two sites (4207 and 4412) required the existing systems to be removed. The five systems installed at the small commercial sites are described in Table 2. Sites 3920 and 3925 use a high efficiency, condensing heater with the largest available heating coil (67,000 Btu/h). The coil outputs are below the furnace capacities, but are comfortably above the designs heat losses. The heaters have recovery efficiencies of 94%, power draft burners, and can be side vented through a coaxial termination unit. Due to the substantial reduction in the heating coil rated output from that of the furnaces and an extreme night setback at 3920, optional aquastats with a maximum set point of 160F were installed on the heaters. The installation cost for the system at site 3920 was $2,850 and $2,875 for site 3925.

The same system that is installed in MF unit 74 was also installed at site 4409. The coil output closely matched the furnace capacity. Since the recovery efficiency of the DIA heater is only 4.3% above the furnace AFUE, this was expected to serve as a good comparison of a DIA and separate system with similar efficiencies. The DIA system was installed in parallel with the existing system in the back portion of the shop at a cost of $2,809. Site 4207 was used as another test of the integrated DIA system. The coil output was only 104% of the estimated design load. The installation cost was $2,848. The fifth small commercial site (4412) was selected to demonstrate an innovative application of a DIA system. The heater was installed with two separate air handlers, heating, and cooling coils. A two-stage heating and cooling thermostat sequentially activated the two air handlers and heating coil pumps or cooling systems. Due to the multiple stages and added economizer and air conditioning equipment, the installation cost was far greater than that of the other systems—$5,680.

Table 2. Description of DIA Systems Installed at Small Commercial Sites

Build ID	Heater Input (Btu/h)	Heater Output (Btu/h)	Coil Output (Btu/h)	Heater/ Coil Ratio	Storage Capacity (gal)	E_r (%)	EF	Burner Type	Vent Type	Installed Cost ($)
3920	100,000	94,000	67,000	1.40	34	94	0.90	power, sealed	side	2,850
3925	100,000	94,000	67,000	1.40	34	94	0.90	power, sealed	vert.	2,875
4409	65,000	49,400	41,500	1.19	50	76	0.52	atmospheric	vert.	2,809
4207	40,000	33,200	29,000	1.14	40	83	0.64	power, sealed	side	2,848
4412	100,000	94,000	134,000	0.70	34	94	0.90	power, sealed	side	5,680

Results and Discussion

All of the systems were installed in the mid to later portion of the 1989/90 heating season. Gas use data was collected at the MF sites over two to three week periods during the heating season and at one month intervals over the summer. The data at the SC sites was collected on a weekly basis during the first heating season and biweekly thereafter.

Gas Use Analysis

The results of the pre/post analysis used to estimate the savings of the DIA systems in the five MF units are displayed in Table 3. Unfortunately, there was a change in occupancy in unit 74 two months after the installation which required that this site be removed from the final analysis. The model fits for the pre period were good with coefficients of variation (CV) for the NACs from 1.1 to 3.7% (8 to 30 ccf/yr)—well below the 5 or 10% limit commonly used for screening PRISM results (Dunsworth and Hewett 1985, Reynolds et al. 1990). The NACs of the pre-period range from 705 to 1003 ccf/yr with those for the three smaller units being lower than those for the larger ones. The NACs for the post-period range from 591 to 890 ccf/yr and have CVs ranging from 1.1 to 3.1% (10 to 19 ccf/yr). These results represent savings from 113 to 231 ccf/yr or from 11.3 to 27.5% and average 149 ccf/yr or 18.0%. The savings for all of these units are highly statistically significant with p-values less than or equal to 0.001.

The savings results generally follow the expected trend. Unit 60, which has the system with the lowest E_t and was sized to be similar to the furnace output, had the lowest savings. The savings were nearly the same for the integrated system in 70 and the DIA system in 64 that is of similar size and efficiency ratings but has a separate air handler/heating coil. Surprisingly, the greatest savings (27.5%) was achieved by the integrated system in 72. While the unexpectedly large savings can be partially attributed to the relatively high DHW load of 70, much of the difference between 72 and 70 is likely due to the instability in the PRISM NAC analysis. For example, the results obtained using data from February, 1990 to November, 1990 show only a 16.2% savings for 72 and a 19.4% savings for 70, while the savings for the entire post period were 27.5 and 17.1% respectively. Thus, the results for 72 are probably not as reliable as those for the other three units.

The PRISM results for the small commercial sites are displayed in Table 4. The NAC of the existing system at 3920 is 1216 ccf/yr and has a low standard error of 48 ccf/yr. In comparison, the DIA system has an NAC of 989 ccf/yr and shows a statistically significant savings of 227 ccf/yr (18.7%). The NAC of the existing system at 3925 is 1326 ccf/yr and the DIA savings are 223 ccf/yr (16.8%), which are statistically significant. Since both the existing and DIA systems at these two sites are similar, the similarity of their savings is expected.

The NAC for the existing system at 4409 is 1246 ccf/yr with a low standard error of 44 ccf/yr. In comparison, the

Table 3. Annual Energy Use and Savings Results for Multifamily Units

	NAC (ccf/yr)		NAC Savings	
ID	**Pre**	**Post**	**(%)**	**(ccf/yr)**
60	1003	890	11.3	113 (25)
	(23)	(10)	(2.5)	[0.001]
64	705	591	16.2	114 (16)
	(8)	(14)	(2.3)	[0.001]
70	808	670	17.1	138 (33)
	(30)	(13)	(4.0)	[0.001]
72	839	608	27.5	231 (21)
	(10)	(19)	(2.6)	[0.001]
		average:	18.0	149
				[0.001]

(#) - standard errors, [#] - p-values.

Table 4. Annual Energy Use and Savings Results for Small Commercial Sites

	NAC (ccf/yr)		NAC Savings	
ID	**Exist.**	**DIA**	**(%)**	**(ccf/yr)**
3920	1216	989	18.7	227 (64)
	(48)	(10)	(5.3)	[0.001]
3925	1326	1103	16.8	223 (66)
	(52)	(41)	(5.0)	[0.002]
4409	1246	1427	-14.5	-181 (80)
	(44)	(67)	(6.4)	[0.033]
4207	954	994	-4.2	-40 (118)
	(29)	(114)	(12.4)	[0.74]
		average:	4.2	57
				[0.001]

(#) - standard errors, [#] - p-values.

DIA system shows an increase in energy use of 181 ccf/yr (14.5%) which is statistically significant with a p-value of 0.033. Because of the similarity of the efficiencies of the two systems, the greater energy use of the DIA system is unexpected. It is possible that the DIA system interacted differently with the second heating system, causing the DIA to handle relatively more or less of the space heating load than that carried by the existing furnace. Another likely explanation is that the occupants operated the DIA system differently than the existing system. The occupants were not explicitly told, but were always aware, which system was being used.

The NACs for the two systems at 4207 are 954 ccf/yr for the existing and 994 ccf/yr for the DIA system. The energy use for the DIA system is 40 ccf/yr or 4.2% greater than that for the existing system. Due to the large uncertainty of the DIA NAC, the difference is not statistically significant.

It is important to note that none of the existing furnaces have AFUEs above the preferred level of 78%. After numerous site visits, it became obvious that it would not be possible to locate sites with furnaces having AFUEs over 78%. Consequently, the DIA energy use comparison is only valid for the systems that have been installed in the past (i.e., the expected savings from replacing an existing separate system) and not those that were required starting January, 1992.

Model Estimated Savings

Approximate values of the combined annual efficiency for the separate systems are computed using the PRISM estimated building loads and the manufacturer specified EFs and AFUEs. The results of these computations for the multifamily units are displayed in Table 5. The low AFUE of the existing furnaces (60.3%) caused the CAEs to average 56.1%. As shown in Table 6, the furnaces at the SC sites are somewhat more efficient. The CAEs ranged from 59.2 to 64.4% and are, on average, 6.9% higher than that for the MF units. The computed CAEs of the MF DIAs range from 68.2 to 78.4% and average 74.7%. The DIA system CAEs at the SC sites range from 68.2 to 94.6% and average 83.5%. The higher average CAE of the DIA systems is primarily a result of the DIAs having higher recovery efficiencies than the corresponding AFUEs of the existing furnaces.

Based on the CAEs of the two types of systems, the estimated savings of the MF DIA systems range from 17.7 to 27.4% and average 24.7%. The estimated savings for the SC DIA systems range from 6.1 to 32.0% and average 23.2% A comparison of the measured and estimated savings shows the expected trend of relatively higher measured savings for higher estimated savings. However, for only one MF unit does the addition of the uncertainty and measured savings equal or exceed the estimated savings. The average measured savings for the MF sites is 6.7% below the estimate and for the SC sites the measured is 19.0% below the estimate.

As has been stated earlier, the method for estimating the CAE is only approximate. However, for some of the locations, the rated efficiencies are similar enough to allow a straightforward comparison of the two systems. For example, at 4409 the DIA E_r is only 4.6% above the furnace AFUE and a small savings is expected. On the contrary, the pre/post analysis showed an increase of 14.5% in the DIA system energy use. It is possible that the pre/post

Table 5. Comparison of Energy Savings for Multifamily Units Based on Gas Use Analysis and Model Estimates

	DIA System					Existing System					Savings	
Buil d ID	Heater Output (Btu/h)*	Coil Output (Btu/h)	E_r (%)	EF	CAE (%)	Heater Output (Btu/h)*	Furn. Output (Btu/h)	AFU E (%)	EF	CAE (%)	Est. (%)	Meas. (%)
60	39,900	41,500	76.0	0.54	68.2	27,792	42,000	60.3	0.49	56.1	17.7	11.3
64	34,000	30,000	85.0	0.61	78.4	27,792	42,000	60.3	0.49	56.9	27.4	16.2
70	33,200	25,000	83.0	0.64	78.4	27,792	42,000	60.3	0.49	56.9	27.4	17.1
72	33,200	25,000	83.0	0.64	73.7	27,792	42,000	60.3	0.49	54.4	26.1	27.5
avg.-	35,075	30,375	81.8	0.61	74.7	27,792	42,000	60.3	0.49	56.1	24.7	18.0

* - computed from product of heater input and E_{ss}.

Table 6. Comparison of Energy Savings for Small Commercial Sites Based on Gas Use Analysis and Model Estimates

	DIA System					Existing System					Savings	
Build ID	Heater Output (Btu/h)*	Coil Output (Btu/h)	E_r (%)	EF	CAE (%)	Heater Output (Btu/h)*	Furn. Output (Btu/h)	AFUE (%)	EF	CAE (%)	Est. (%)	Meas. (%)
3920	94,000	67,000	94.0	0.90	94.6	23,100	84,000	65.8	0.50	64.4	32.0	18.7
3925	94,000	67,000	94.0	0.90	94.5	57,000	126,000	65.8	0.54	64.4	31.8	16.8
4409	49,400	41,500	76.0	0.52	68.2	27,740	39,000	71.4	0.51	64.1	6.1	-14.5
4207	33,200	29,000	83.0	0.64	76.7	28,000	62,000	66.0	0.49	59.2	22.8	-4.2
avg.-	67,650	51,125	86.8	0.74	83.5	33,960	77,750	67.3	0.51	63.0	23.2	4.2

* - computed from product of heater input and E_{SS}.

analysis method was somehow unfairly biased against the DIA systems. However, even the alternating mode tests at sites 3920, 3925, and 4409 resulted in an average measured savings of 7.0%; which is 16.3% below the CAE estimated savings for those three sites.

There are numerous possible explanations for the measured savings to be lower than estimated. The AFUE rating method may not properly apply to the older furnaces located in partially conditioned spaces, or to systems with space heating and DHW loads markedly different from that assumed in the methodology. Also, most often the space heating output of the DIAs were lower than those for the existing furnaces. This would have caused the air handlers to operate more frequently and may have exacerbated any increased air infiltration due to air handler operation or could have changed the air temperature distribution in the buildings. However, at the two locations with heating coil outputs closely matched to furnace outputs (60 and 4409) the savings were not substantially better than for the other sites. Also, the air handler was operated continuously during occupied hours at site 3920 and the savings were not much different from those for the similar system used at site 3925. Finally, the DIAs may not operate as efficiently as expected. The intensive monitoring at site 3920 indicated that the increased operating temperature of 160F probably resulted in a reduced combustion efficiency (Bohac 1991).

Field Experiences

Although some of the heating coils were oversized to match the existing furnace output, the ten systems installed for this project generally followed the sizing guidelines recommended by Pietsch and Talbert (1989). There were few occupant complaints of inadequate space heat or reduced DHW temperature during periods of high space heating loads. It is interesting that there were no reported complaints from unit 60, even though the rated coil output was slightly less than the heater output. The dog grooming shop (4207) felt that the DHW capacity was marginal in the heating season when they washed more than one dog an hour. The manager of the sandwich shop (4409) had some complaints of inadequate space heat during high DHW draws, but found that recovery time from DHW draws could be decreased by turning off the space heater. Overall, the building occupants were satisfied with the operation of the DIA systems.

There were no repairs performed on any of the four atmospheric burner, vertically vented DIAs. Five of the six power draft heaters had repairs which were related to the DIA system operation. During nearly two years of operation, two of the three high output, condensing heaters required multiple repairs. The repairs included replacing two igniter coils and one tank which had developed a leak. However, the manufacturer has modified the igniter design to make it more reliable. The original vent terminations of the three side-vented, integrated DIAs had to be modified. Large ice formations from the combustion gas restricted the inlet air flow and would not allow the burner to operate. The terminations were modified and have since worked without failure. The heaters in two of the three integrated DIAs have been replaced due to high concentrations of combustion gas carbon monoxide and a destroyed burner. These integrated DIAs are no longer being sold.

Conclusion

At the start of this project many code officials in Minnesota would not allow the installation of DIAs due to questions about Legionella in heating coils, reduced heater life span, accepted sizing methods, and the use of a water heater in a "boiler application." Many of these concerns have been addressed and there is presently much greater acceptance. Except for two small commercial locations with intermittently high DH W demands, there were no occupant complaints of low space or DHW temperatures and the occupants were generally satisfied with the systems. There were no equipment failures at the four sites which used atmospheric, vertically vented heaters. However, the higher efficiency heaters using sealed combustion burners had numerous problems which have been addressed by the manufacturer. The smaller of these two heaters, the integrated DIA, is no longer being sold.

The PRISM gas use analysis showed average energy savings of 18.0% for the DIA systems installed in four MF units and average savings of 4.2% for four SC sites. The systems with higher expected savings did generally result in comparatively higher savings. However, all the DIA systems were compared to furnaces with AFUEs below the presently minimum value of 78%. In addition, except on one case, the actual savings were less than that estimated by a simplified combined energy efficiency model. The average measured savings for the MF units was 6.7% below the estimated value and for the SC sites it was 19.0% below.

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