Energy-Efficient Makeup Air Units

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Unless you live in paradise, delivering makeup air to most buildings is expensive. *Table 1* shows the amount of work it takes to heat and cool air (based on Chicago conditions) for a standard rooftop unit (a unit that recirculates air with typical air conditioning loads) and a makeup air (MUA) unit. Note the standard unit conditions represent 400 cfm/ton (53.68 L/[s·kW]) with 80°F dry bulb/67°F wet bulb (26.7°C dry bulb/19.4°C wet bulb) return air conditions. It can be seen that a MUA unit requires more than twice the cooling and five times the heating work as a standard unit.

For many HVAC solutions a dedicated outdoor air system (DOAS) is required such as variable refrigerant flow systems (VRF), ground source heat pumps (GSHP), and chilled beams (*Figure 1*). Many process applications (labs, industrial processes, garages, etc.) also require makeup air (MUA) systems. All these applications require some form of make up air unit that can move and filter outdoor air as well as heat and cool (depending on location and application). Since these units consume significant energy in most applications, a discussion on how to improve their efficiency is warranted.

A basic MUA unit has to meet certain minimum performance requirements:

- 80% efficient (indirect fired) gas heat[1] (assuming a gas heat unit);
- 10 EER (Energy Efficiency Ratio)[2] if DX cooling is required;
- Fan performance is generally marginalized but is accounted in the unit EER requirement (assuming there is cooling); and
- Basic wall construction called out in the product specification. A basic unit is typically single wall, 0.5 to 1 in. (13 to 25 mm) fiberglass insulation.

To move beyond a basic unit, four areas of improvement will be considered: gas heat, DX cooling, fan performance, and casing performance (*Figure 2*). The energy usage calculations are based on a 10,000 cfm (4700 L/s) MUA unit in Chicago. The cost[3] of gas is $0.79/therm and electricity is $0.10 kWh. The carbon dioxide (CO_2) equivalent conversion[4] for natural gas is 0.510 CO_2e lb/kWh (0.232 kg/kWh) and for electricity is 1.670 CO_2e

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TABLE 1 MUA energy requirements.

	DESIGN CONDITIONS DRY BULB/WET BULB °F	Δ ENTHALPY (BTU/H · CFM)	COOLING WORK (W/CFM)	HEATING WORK (BTU/H · CFM)
STANDARD UNIT	80/67 to 57.6/57	30	3.0	
	54.1 to 70 (20% OA)	16		19
MUA UNIT	90/75 to 55/54.5	70	7.0	
	−1.5 to 70	78		97

lb/kWh (0.758 kg/kWh). Calculations are based on 24/7 operation.

Improving Gas Heating

To improve gas heating the efficiency needs to be increased. Gas heat efficiency is heat added to the airstream/heat released in the combustion of the fuel. By code, MUA units need to have 80% minimum efficiency.

Technology is now available to raise the heating efficiency of MUA units to 90% or greater (*Photo 1*). However, this results in acidic condensation of water vapor in the combustion gas. As well, the increased heat exchanger surface area increases the air pressure drop by approximately 0.10 in. w.c. (25 Pa), which will increase fan work.

Condensing boilers have been gaining acceptance for some time now but they are located in a boiler room with a floor drain. A condensing gas furnace in a roof mounted MUA unit requires careful planning both by the design engineer and the installing contractor, particularly if the ambient falls below freezing. It is recommended that the condensate be routed down through the roof curb to a drain within the building. If the condensate must be exposed to freezing conditions, heating tracing should be applied. Local codes may also require pH neutralizing kits.

Table 2 compares the natural gas savings between an 80% efficient and 90% efficient furnace. The savings in natural gas and operating cost are around 11%. In this application it is about a two-year payback.

Improving DX Cooling

Minimum efficiencies for package rooftop units in a recirculation application are provided in ASHRAE Standard 90.1. The efficiencies are based on AHRI Standard 340/360 that assumes 80°F/67°F (26.7°C/19.4°C) dry bulb/wet bulb entering air conditions. Since a MUA unit sees more demanding loads, the efficiencies listed are not generally obtained. Since the airflow rate per unit of cooling is typically half in

FIGURE 1 Typical make-up air system.

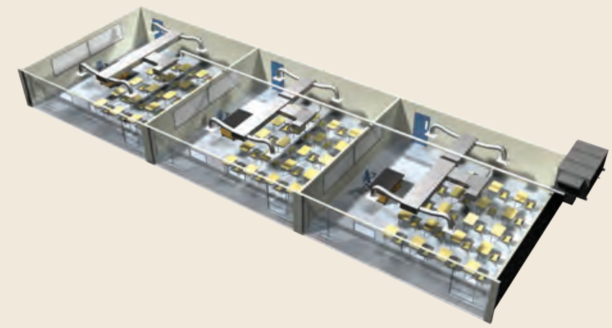


FIGURE 2 High performance MUA unit.

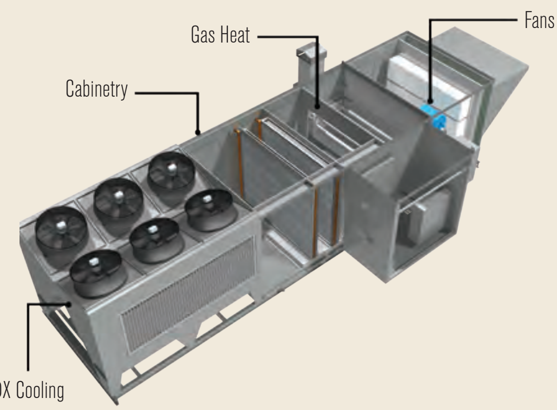
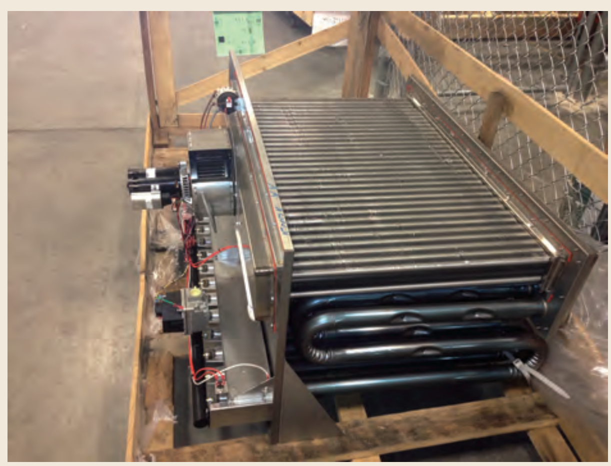


PHOTO 1 Ninety percent gas furnace.



a MUA unit (i.e., 200 cfm/ton [26.84 L/s·kW]) versus a recirculating unit (i.e., 400 cfm/ton [53.68 L/s·kW]), it is often not possible to operate a MUA unit at the conditions stated in AHRI Standard 340/360. The end result is that cooling efficiency targets for MUA units are not well established and are left up to the designer.

TABLE 2 Gas heat savings.

TEMPERATURE RANGE (°F)	NUMBER OF OCCURRENCES (HR)	HEAT LOAD (BTU/H)	80% EFFICIENCY		90% EFFICIENCY	
			GAS USAGE (CFH)	COST ($)	GAS USAGE (CFH)	COST ($)
65 to 75	1,252	108,500	132	638	117	567
55 to 65	1,472	325,500	397	2,230	353	1,982
45 to 55	1,204	542,500	662	3,147	588	2,797
35 to 45	1,380	759,500	926	5,172	823	4,597
25 to 35	1,396	976,500	1,191	6,506	1059	5,783
15 to 25	648	1,193,500	1,456	3,731	1293	3,316
5 to 15	202	1,410,500	1,720	1,359	1529	1,208
–5 to 5	88	1,627,500	1,984	683	1765	607
–15 to (–5)	28	895,125	1,092	241	970	215
Totals	7,642			23,706		21,072

TABLE 3 DX cooling savings.

TEMPERATURE RANGE (°F)	NUMBER OF OCCURRENCES (HR)	COOLING LOAD (BTU/H)	10 EER		11 EER	
			ELECTRICITY USAGE (W)	COST ($)	ELECTRICITY USAGE (W)	COST ($)
90 to 100	48	1,288,800	128,880	330	117,164	299
80 to 90	466	996,300	99,630	2,207	90,572	2,007
70 to 80	1,234	661,050	66,105	4,050	60,095	3,682
60 to 70	1,480	248,400	24,840	1,659	22,582	1,508
Totals	3,228			8,247		7,497

TABLE 4 Fan savings.

FAN TYPE	AIRFLOW (CFM)	FAN WORK (W)	ANNUAL WORK (KWH)	ANNUAL COST ($)
Twin FC Scrolled Fans	10,000	6,833	59,860	5,986
Twin AF Scrolled Fans	10,000	5,655	49,535	4,953
Belt Drive Plenum Fan	10,000	5,252	46,006	4,601
Direct Drive Plenum Fan	10,000	4,939	43,261	4,326

Energy efficiency ratio (EER) is the total cooling capacity (Btu/h)/electrical power for supply air fans, condenser fans, and compressors (W). Since supply fan work will be discussed separately, let's assume an EER of 10 for just the compressors and condenser fans at MUA conditions for a basic unit and an EER of 11 for a high efficiency unit. As well, it is assumed that dehumidification is required and thus the air will be cooled to 55°F (12.8°C). (where neutral air temperatures are required, DX cooled makeup air units often include hot gas reheat, which uses waste heat to warm the air).

Table 3 shows the savings are around 9% with a four-year payback. Location has a lot to do with the payback. Moving the location from Chicago to Miami would greatly improve the payback for the improved cooling efficiency.

Supply Fan Savings

Indirect fired MUA units must have the fans in a blow-through position relative to the furnaces. This is a safety issue. The most cost-effective fans are forward-curved scrolled fans, but they discharge into an open plenum, which is not an ideal application. There is little static pressure regain without discharge ductwork. For scrolled fans, this loss is usually accounted for by adjusting the total static pressure (TSP) for the system loss or by using fan curves that are based on actual testing with a scrolled fan in a blow-through arrangement. In this case, the TSP was increased by 0.2 in. w.c. (50 Pa) to account for the system effect and will impact the fan efficiency.

Optional fan arrangements include airfoil scrolled fans, and belt and direct drive plenum fans. Belt drive units have a drive loss around 2% while direct drive fans will require a VFD that will introduce a drive loss around 2%. From an energy point of view for constant volume applications, direct (VFD) and belt drive losses are about equal.

Table 4 summarizes the impact of different fan choices using 3 in. w.c. (750 Pa) total static pressure for a 10,000 cfm (4700 L/s) unit operating 24/7.

The energy savings from worst to best is 28% and has a less than two-year payback. The direct drive plenum fans also offer reduced maintenance (no belts) and the ability to vary the supply airflow for further energy savings (depending on the building application).

Casing Savings

Casing energy losses take two forms; thermal losses through the cabinet wall and exfiltration (air leakage on the positive pressure side of the fan). Exfiltration adds a secondary loss in that the supply fan airflow rate will likely be increased (through the testing and balancing process) to deliver the correct airflow to the point of use thus increasing the fan work and likely the heating and cooling work.

A basic unit casing in a MUA unit is typically single-wall steel with 0.5 in. to 1 in. (12 to 25 mm) fiberglass insulation glued to it. The R value will be around 2. A high performance casing will be 2 in. (51 mm) injected foam construction with an R value around R-13. The supply air pressure will cause deflection in the cabinet walls. Deflection creates openings that lead to air infiltration or exfiltration. Single-wall construction units can have significant deflection and thus leakage.* Injected foam cabinets are very rigid and can have a deflection of less than L/240. For a basic cabinet the leakage rate is assumed to be 4% while for the high performance cabinet the leakage rate is assumed to be 1%.[5]

TABLE 5 Casing savings.

		BASIC CABINET				HIGH PERFORMANCE CABINET			
		CABINET HEAT LOSS		INFILTRATION		CABINET HEAT LOSS		INFILTRATION	
TEMPERATURE RANGE DB (°F)	NUMBER OF OCCURANCES (HR)	LOAD (BTU/H)	COST ($)	HEAT LOAD (BTU/H)	COST ($)	HEAT LOAD (BTU/H)	COST ($)	HEAT LOAD (BTU/H)	COST ($)
90 to 100	48	6192	1	32,832	9	953	0	8,208	2
80 to 90	466	3,096	6	21,132	45	477	1	5,283	11
70 to 80	1234	629	4	7,722	47	97	1	1,931	12
60 to 70	1480	1,935	14	8,680	65	298	2	2,170	16
50 to 60	1187	3,870	22	17,360	99	595	3	4,340	25
40 to 50	1058	5,805	29	26,040	131	893	5	6,510	33
30 to 40	1739	7,740	65	34,720	290	1,191	10	8,680	72
20 to 30	896	9,675	41	43,400	185	1,488	6	10,850	46
10 to 20	461	11,610	25	52,080	113	1,786	4	13,020	28
0 to 10	132	13,545	9	60,760	38	2,084	1	15,190	10
–10 to 0	59	15,480	4	69,440	20	2,382	1	17,360	5
Totals	8760		221		1,041		34		260

Table 5 shows that a high performance cabinet can offer a 77% savings and that cabinet leakage is three to five times more important than thermal loss. The savings are comparable to DX cooling improvement for this climate.

TABLE 6 Savings summary.

SAVINGS ITEM	BASIC (KWH)	HIGH PERFORMANCE (KWH)	DIFFERENCE (KWH)	PERCENT	$/YR	CO_2
GAS	901,508	801,341	100,167	11	2,634	51,085
DX COOLING	82,470	74,973	7,497	9	750	12,520
FANS	59,860	43,261	16,599	28	1,660	27,720
CASING	45,370	10,562	34,808	77	968	18,420
TOTAL	1,089,208	930,137	159,071		6,012	109,745

Summary and Conclusions

Table 6 summarizes the savings that are possible by using equipment that performs beyond the minimum requirements. The energy savings for all improvements are 14%, and the cost savings are around $6,000/yr. This works out to around $0.60/supply air cfm per year ($0.29/supply air L/s per year). Assuming a 20% premium for the high-performance unit, the payback is around two years. Smaller units will have a higher premium and hence a longer payback. Since a MUA unit is a high energy consuming device, investing in greater than minimum efficiency performance is generally a good design goal and offers a better return on investment than upgrading other components in the HVAC system.

Table 6 also shows the CO_2 equivalent savings based on factors from ASHRAE Standard 189.1. The CO_2 reduction is almost 110,000 lbs/yr.

Not all the reviewed improvements are equal in savings and some are location dependent. Fan improvement savings are universal in terms of location. Any improvement to the fan system will deliver good results as long as the unit is running. Cabinet performance is also fairly universal. The bulk of the energy penalty comes from leakage so the weather conditions at point of use are less of an influence. Cold weather climates benefit more from better thermal performance than hot climates (the temperature differences are larger).

Cooling and heating savings are heavily dependent on location. Miami will enjoy a fast payback on improved cooling efficiency while Winnipeg will see the same for the high-performance furnace. In this example, the improved cooling in Chicago has the longest payback due to the low BIN hours of operation. In Miami, cooling would be one of the most important improvements. The designer should take this into account when specifying equipment. A quick review of the BIN hours for the

* It is possible to build a single-wall casing with fiberglass insulation that has a deflection of L/240 or less. Many high-end custom AHU manufacturers do this. It is less common in packaged rooftop units.

project location should point out where to recommend increased product performance.

Operating hours will also impact savings. For this analysis, the assumption was 24/7 operation. In many applications, the MUA unit may only see 30% to 50% operating hours, which will cut the annual savings and prolong the payback period.

There are other things that can be done to reduce energy usage including:

- Reducing operating time (don't run it unless you have to).
- Considering demand control ventilation or some other means of reducing the supply airflow when possible. This improves the value of the direct drive plenum fans with VFDs.
- Use low leakage outdoor air dampers to reduce infiltration when the unit is off. In very cold climates consider insulated low leak dampers.
- Consider face and bypass DX coil arrangements to reduce the condensing unit size (this requires expanding the RH comfort criteria). This will cut the cooling load in half reducing the first cost and operating cost. It will also avoid the need for any reheat; however, dehumidification will be reduced. In many applications this may be acceptable.
- Evaporative cooling (depending on location).
- Single air path (reheat) or dual air path energy recovery. A dual air path energy recovery unit can offer substantial savings however at a higher first cost for both the unit and the return air ducting work. ASHRAE Standard 90.1 has requirements for exhaust air energy recovery depending on location and application. The proposed energy savings outlined in this article would also apply to an energy recovery MUA unit.

References

1. ANSI Z83.8/CSA 2.6 -2013, *Standard for Gas Unit Heaters, Gas Packaged Heaters, Gas Utility Heaters and Gas-Fired Duct Furnaces.*

2. ANSI/ASHRAE/IES Standard 90.1 -2013, *Energy Standard For Buildings Except Low-Rise Residential Buildings.*

3. Natural Gas and Electricity rates are based 2013 U.S. Energy Information Administration.

4. ANSI/ASHRAE/USGBC/IES Standard 189.1 -2009, *Standard for the Design of High Performance Green Buildings*. Table 7.5.3.

5. Crowther, H. 2014. "Air Leakage in Air Handling Units." Price Industries White Paper. ■