Keeping Cooks in the Kitchen

Solving the Makeup Air Dilemma

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Cooks at a 24-hour family restaurant chain were so uncomfortable in their assigned work areas that they sought relief in remote parts of the kitchen. The owner's construction architect took calibrated temperature readings in the kitchen and found temperature variations of up to 10°F (5.5°C). Our firm was asked to provide an energy and cost-conscious design to alleviate this condition.

The initial review found a fairly traditional HVAC system. The system included separate rooftop HVAC units for the dining areas and kitchen, along with two direct gas-fired makeup air units for the kitchen hoods. The hood systems shown in *Figure 1* were a compensating design with backwall makeup air plenums. The hood system was supplied by the owner as part of the kitchen package and was installed by the stainless steel fabricator. To provide better comfort for the space, the cause of the temperature variations and discomfort needed to be determined. The radiant heat gain from cooking appliances is documented in *ASHRAE Handbook—Fundamentals*, Chapter 29.[1] These gains, along with normal considerations, such as lighting and people loads, had been previously calculated. Neither the cooking appliances nor other loads had changed. The uncomfortable conditions caused us to ask if all of the heat gains to the space been included in the client's current design?

A recent commercial kitchen ventilation (CKV) study[2] tested the impact of various compensating makeup air (MUA) designs on hood capture and containment (C&C). According to the study, over-specified exhaust can increase the chance local MUA will have a negative impact on hood C&C. In addition, smoke testing showed that some of the makeup air introduced through the backwall plenums was flowing into the kitchen before it entered the hood. Was the hood exhaust over-specified? Was the operation of the hood makeup air system adding to the discomfort? Was the makeup air creating a "false," or previously uncalculated, kitchen load? Observations, based on the temperature profiles and ancillary data, indicated this was potentially true.

A new "replacement air" kitchen ventilation concept was investigated as a possible solution. ASHRAE Technical Committee 5.10, Kitchen Ventilation,[3] recently defined replacement air as "all outdoor air required, by the hood, for proper C&C." The definition is important, as it reminds the mechanical engineer to consider all available sources of outdoor air. The defined sources include *makeup*, *kitchen supply* and *transfer*. By definition, outdoor air introduced through a compensating hood (any hood design that includes an integral method for introducing outdoor air) is the *makeup* component of replacement air. Outdoor air that is introduced into the kitchen, remote from the hood, is defined as the *kitchen supply* component. The third potential source of outdoor air is *transfer,* which is outdoor air that is initially introduced into an adjacent space, and then moved to the kitchen by pressurization or ducted fan power. In most applications, kitchen supply and transfer air are the outdoor component of airflow used to condition the affected space. Makeup air typically is not cooled and, if heated, it is heated to a temperature lower than supply or transfer air.

A clearer understanding of kitchen replacement air helped us to next address the "false" load. Was the makeup air and/or hood style playing a major role in the kitchen discomfort? Data from the manufacturer of the HVAC units used by this customer, and from a variable volume controls manufacturer helped us answer this question.

A recent survey by the controls manufacturer for a national restaurant chain found that it was common for the MUA unit to be heating at the same time that the HVAC unit was attempting to cool the kitchen. The HVAC manufacturer provided additional data demonstrating this energy waste. The manufacturers' field surveys reported routine kitchen HVAC compressor operation even when outdoor air temperatures were as low as 38°F (3°C). Could the client's system be heating and cooling simultaneously?

In this kitchen, the HVAC unit and the MUA units were controlled separately. An outdoor air thermostat controlled the call for MUA heat while a separate room thermostat controlled the kitchen HVAC unit. This was the control scheme that allowed simultaneous HVAC cooling and MUA heating. It was determined that this was not a case of a "false" load. The competition between these systems created a real load not considered in the original design calculations, which was adding to the discomfort in the kitchen.

A list was prepared that included three steps for all new designs. First, the hood selection needed to be an integral component of the total building HVAC design. Second, the exhaust rate needed to be confirmed as adequate yet not over-specified. Third, the negative impact of the makeup airflow on kitchen comfort had to be eliminated. Gaining control of the hood design was the first step. After discussing the issues with the client, it was agreed that if our firm was to accept responsibility for kitchen comfort and building HVAC performance, we needed the authority to control design and selection of the hood system.

The second step dealt with the hood exhaust rate, which is both a code and a performance issue. Code requires minimum exhaust rates for standard hoods. However, the use of typically lower exhaust rates associated with listed hoods is permitted. This client already was using a listed canopy style hood. Our firm had successfully lowered exhaust air volumes by changing from canopy hoods to listed backshelf style hoods shown in *Figure 2* for other national restaurant accounts. Site visits to some of these restaurants found hood C&C was excellent at the reduced backshelf airflow rates. Other backshelf benefits included a brighter and more visually open kitchen. The cooks commented on being more comfortable working with cooking appliances ventilated by the backshelf hood rather than with the canopy hood. Finally, the CKV study[2] supports the application of listed backshelf hoods to reduce hood exhaust.

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Was this client a backshelf candidate? The type of cooking appliances drives the backshelf hood selection. The types, used for the heat gain calculations, included upright appliances, such as ovens, which obviously do not fit under a backshelf hood. Most of the appliances were fryers, griddles, broilers and a range, which would fit under the backshelf hood.

The second step confirmed the new hood design exhaust rate was adequate and not over-specified. As shown in *Table 1*, CKV total hood exhaust was reduced 31%, by using listed Type I backshelf hoods for the appropriate appliances. The ovens, which could not be ventilated by backshelf hoods, were placed under separate Type II canopy hoods. Identical cooking appliances and appliance quantities were used in both designs. Some appliances were relocated to consolidate them under appropriate backshelf or canopy hoods. Total lineal feet of hood changed from 30 ft to 28 ft, 9 in. (9 to 8.75 m). Primary reduction in overall hood length was the decreased end overhang required when designing backshelf hoods. As some hoods and appliances were rearranged, the individual fan breakdown (*Table 1*) does not, therefore, accurately reflect the breakdown of changes in individual hood airflow.

The third step was to quantify the impact of all of the outdoor air introduced into the restaurant. It was determined that the dining room ventilation rate, from the previous design, was correct. After subtracting for restroom exhaust and dining room pressurization, it was determined 24% of total hood replacement air could be transferred from the dining room. Ducts were designed to transfer air between the dining room and kitchen. Ducted transfer should be used when the size of openings between spaces would create air velocities greater than 50 fpm (0.25 m/s). Higher velocities can cause poor air distribution and cool cooked food.

In a traditional design, the mechanical engineer is typically required to furnish the difference between hood exhaust and MUA through the building system. Often the engineers' response is, "the difference is too much—can you increase the makeup air?" The CKV study[2] reports, "In fact, the 80% rule-of-thumb for

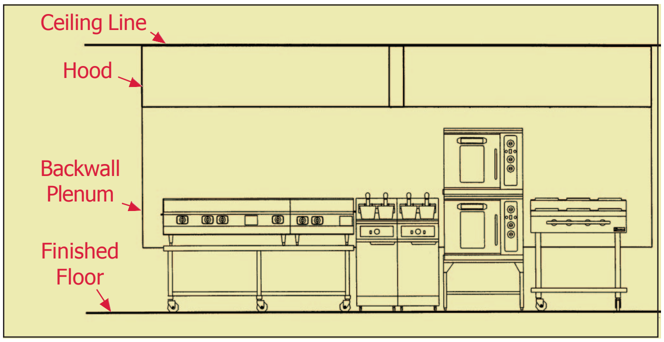

Figure 1: Kitchen with canopy hood.

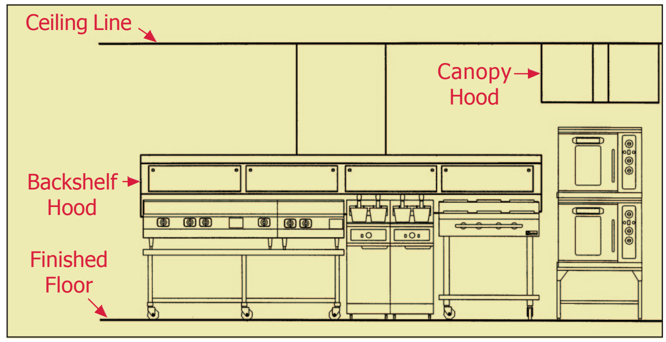

Figure 2: Kitchen with backshelf and canopy hood.

sizing airflow through a kitchen hood MUA system can be a recipe for trouble, particularly if the exhaust airflow rate has been over-specified to start with." The exhaust airflow rate had been addressed, but with 76% of the replacement air still needed, it became obvious the solution was not simply to increase the MUA. The actual kitchen ventilation and heating/cooling needs would be determined next and makeup air would be considered last.

Only the portion of kitchen supply that originates as outdoor air can be calculated as the kitchen supply component of replacement air. In the previous system only 600 cfm (283 L/s) (of the 6,000 cfm [2830 L/s] handled by the kitchen HVAC unit) originated as outdoor air. The balance of 5,400 cfm (2550 L/s) was recirculated. In the proposed design, a single replacement air unit (RAU) would replace the existing kitchen HVAC unit and the two MUA units. The kitchen supply would be reduced to 4,730 cfm (2230 L/s), with 100% originating as outdoor air. It was determined, with proper exhaust rates, and the elimination of any "false" MUA loads, this volume was sufficient to provide comfort and properly ventilate the kitchen.

The question remained: would the energy costs to heat and cool 100% outdoor air for kitchen supply meet the client's energy and cost conscious requirements? The specified backshelf hood vendor also manufactures RAUs. The manufacturer assisted in a comparison of equipment size, original equipment cost and energy costs. The client began working on a comparison of installation costs. If one or two makeup air units and makeup air duct system(s) were to be eliminated, what impact would that have on overall costs?

Load calculations were performed comparing tonnage required to provide 4,760 cfm through a single RAU, to the tonnage required by the previous kitchen HVAC unit. The comparison indicated a 16% increase in tonnage required with the RAU design. The full 16% could not, however, be attributed solely to the change to 100% outdoor air. In previous installations, outdoor design conditions often had been exceeded. This led to a decision to increase the outdoor design conditions for this project. Based on the manufacturers' recommendations, the sensible leaving condition for the RAU was raised into the lower 60s (16°C to 20°C) as opposed to the mid-50s (13°C) for the HVAC unit. This change helped to lower the tonnage, and its reasoning will be explained later.

With all air volumes set and the RAU sized, it was now possible to make energy comparisons. An important energy saving factor in the RAU design is the ability to use outdoor air without heating or cooling. All competition between conventional HVAC and MUA units was eliminated. Therefore, any time conditions warrant, outdoor air can be supplied without heating or cooling. Unlike conventional economizer systems, the RAU design can accomplish this without upsetting building pressure or altering the performance of the air-distribution system.

For this comparison, RAU setpoints of 55°F (13°C) for heating and 65°F (18°C) for cooling were selected. The RAU selected also includes an enthalpy controller to monitor compressor operation. The unit selected is listed with direct gas fired heat and a modulating DX cooling control. The modulating refrigeration control provides dehumidification in part-load conditions. Heat controls provide a 35:1 burner turndown ratio. These features eliminate humidity and temperature swings, help reduce energy consumption, and are critical for kitchen comfort.

The previous design allowed simultaneous MUA heating and kitchen cooling. No attempt was made to calculate the cost of this simultaneous operation. Field survey data suggested kitchen cooling when outdoor air temperatures were as low as 38°F (3°C). Because this number had not been verified for this clients' operation, a much more conservative 50°F (10°C) cooling setpoint was used. No attempt was made to calculate the "false" load placed on the system by makeup air or to estimate the heating and/or cooling cost of the air recirculated through the original kitchen HVAC unit. As transfer air remained constant, only kitchen outdoor air was calculated for this energy comparison.

A useful tool for making the energy comparisons is the outdoor air load calculator, available at www.archenergy.com or www.fishernickelinc.com. The creation of this public-domain software was detailed in a previous ASHRAE paper[3] and is discussed in detail in the "Predicting Energy Consumption" article in this issue. The following calculations were generated using this tool.

Using the conservative parameters stated previously, the owner's previous conventional design resulted in calculated annual energy loads of 710,235 MBtu/h for heating and 121,884 Mbtu/h for cooling. The RAU design, furnishing 100% of the heated and cooled kitchen supply, resulted in calculated annual energy loads of 479,508 MBtu/h for heating and 99,213 MBtu/h for cooling. These totals represent a 30% reduction in annual energy consumption. These results prompted the client to proceed with the replacement air design. Makeup air units were eliminated.

The next step was to design the kitchen supply distribution system. Desired diffusers were selected to get a one- or two-way adjustable throw that would give a good lineal flow pattern into the hood area. Diffusers were selected carefully to achieve maximum terminal velocities of 50 fpm (0.25 m/s) at the hood. Standard aspirating diffusers should not be used in the immediate area of the hood. The chosen diffusers were perforated with adjustable patterns that would allow a relatively even air distribution with low cfm/diffuser. The air is distributed primarily in the area around the hood. The intent was to get a good distribution of air throughout the cooking area. This distribution allows conditioning of the space (and associated cooking personnel) by sweeping above the cooking surfaces, then down into the backshelf hoods. This movement allowed maximum capture of heat generated by the cooking equipment before it could enter the space. Areas away from the cooking equipment used standard adjustable two-, three- and four-way throw diffusers, again avoiding directing air at the hoods.

Exhaust Fan	Hood	Original cfm	RAU cfm
EF-1	Hood 1	1,708	2,439
EF-2	Hood 1	1,709	612
EF-3	Hood 2	2,375	675
EF-4	Hood 3	1,688	1,422
Total		7,480	5,148

Table 1: Exhaust airflow comparison.

During normal operation of the HVAC equipment and hoods, no air will be returned to the RAU. The heat gain is exhausted through the kitchen hood. This design allows a more even temperature gradient in the space. Kitchen personnel are exposed more directly to the RAU kitchen supply condition, as it exits the diffusers, than with a normal aspirating design that first mixes air at the ceiling. For this reason, the supply air temperature was raised to the lower 60°F (15.5°C) range. A return system is provided as part of the design only to allow for a condition when all the hoods might be off and the space requires conditioning. The increase in diffuser quantity, required by the RAU design, was a cost concern that would be answered by the installation bids.

A final concern is air balance. Because of the close relationship between the dining room and kitchen airflow conditions, all HVAC and RAU systems must be balanced *together* by a qualified air balance contractor. The old method of separately balancing the building HVAC and kitchen MUA cannot be allowed.

With the air-distribution layout complete, the client was able to finalize construction bids. The HVAC installation cost, using the replacement air design, proved to be considerably lower than the conventional design. The final result of hood cost savings, installation cost savings and increased RAU costs netted a small cost increase. However, the increase was low enough to be offset by energy savings within the first year of operation. The replacement air design proved to be an affordable, energy saving, alternative to the clients' previous conventional HVAC/MUA design. Gaining control of the hood design provided the ability to incorporate the hood into a complete building HVAC system. The change also made possible a system designed to deliver dining room and kitchen comfort, with substantial energy reductions, at a cost that was easy for the client to authorize.

Summary

1. Poor CKVS performance can easily overwhelm the performance of the best building HVAC design. Responsibility for the performance of the HVAC design rests with the mechanical engineer. The potential liabilities this responsibility places on the engineer should make evident the need to include CKVS design as an integral part of the total building HVAC design.

2. Listed backshelf hoods provide effective C&C with reduced hood exhaust rates when appropriate cooking appliances are used. The backshelf hood provides a more open kitchen, which can be lit effectively using conventional ceiling fixtures. Operator comfort is increased both physically and psychologically.

3. Replacement air designs eliminate the conflict between conventional HVAC and MUA units. Elimination of these conflicts can lead to greater comfort and reduced energy consumption. This concept can work with both listed backshelf, as well as listed canopy hood designs.

4. When comparing original equipment costs and energy costs, the replacement air design proved to be beneficial to the client.

5. The hood and RAU manufacturer can be very helpful in the proper application of these designs.

6. Specification Sections 15733 "Replacement Air Units" and 15870 "Kitchen Hoods" have been approved by the AIA. These documents aid the engineer in the process of specifying replacement air systems.

References

1. *2001 ASHRAE Handbook—Fundamentals*, "Non-Residential Cooling and Heating Load Calculation Procedures."

2. California Energy Commission. 2002. *Design Guide - Improving Commercial Kitchen Ventilation System Performance.* Architectural Energy Corporation and Fisher Nickel, Inc.

3. Fisher, D., et al. 1999. "Estimating the energy-saving benefit of reduced-flow and/or multi-speed commercial kitchen ventilation systems." *ASHRAE Transactions*.

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