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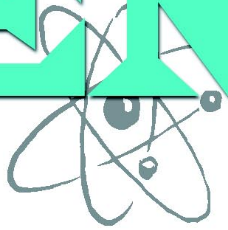
Predicting ENERGY Consumption



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Decisions to purchase a commercial kitchen ventilation (CKV) system often are based on rule-of-thumb estimates using a $/cfm index (i.e., annual energy cost to operate the CKV system divided by the average exhaust ventilation rate), typically ranging between $1 and $3 per cfm ($2.12 and $6.36 per L/s) per year. Unfortunately, the $/cfm index may not reflect actual energy consumption and cost.

If the $/cfm indicator has been derived from detailed engineering calculations or a computer simulation of a similar project in a similar location, its application may be appropriate and relatively accurate. However, if the index has been selected casually, the resulting estimate of the system operating cost may be wrong.

An inherent bias exists on the part of an equipment supplier or designer to select a higher $/cfm index when promoting an energy-efficient product. This cost estimating practice is easy to inflate and can generate energy costs out of proportion with the whole-facility energy bill.

As an example, assume a casual dining facility with a design exhaust rate of 6,000 cfm (2830 L/s) operating 16 hours per day. At $2/cfm ($4.24 per L/s) per year, the CKV system energy cost would be $12,000. If the annual gas and electric bills for the facility total $50,000, the CKV system would represent 24% of this total. Not impossible, but less plausible than if the estimate had been based on $1/cfm ($2.12 per L/s) and the CKV energy cost estimated at $6,000.

In many situations, such as in the design of a CKV system for a multi-unit restaurant operation or a large institutional food service facility, the magnitude of the potential energy savings and/or capital cost of the proposed kitchen ventilation system deserves a more rigorous energy cost analysis. Guidelines for estimating the energy consumption and cost of kitchen ventilation systems are not well established. Engineers often rely on their own "in-house" energy calculation protocol to generate this estimate. This article provides insight into the complexity of the energy model, and introduces a no-cost, publicly available calculation tool for engineers who do not work in the food service field regularly.

Factors Affecting Energy Consumption and Cost

Beyond the design exhaust ventilation rate itself, the energy consumption and cost of a CKV system are affected by key factors such as geographic location, operating hours of the system, static pressure and fan efficiencies, makeup air heating setpoint, makeup air cooling setpoint and level of dehumidification, efficiency of heating and cooling systems, level of interaction with kitchen HVAC system, appliances under the hood and associated heat gain to space, and applied utility rates.

Hours of Operation. The energy consumption of a CKV system is proportional to its hours of operation, where a 12-hour per day operation consumes significantly less energy than a 24-hour operation. But when the system cost estimate is based on a $/cfm index, the accounting for differences in operating time may not be obvious (e.g., $2/cfm [$4.24 per L/s] for a 24-hour operation becomes approximately $1/cfm [$2.12 per L/s] for a 12-hour operation and $0.50/cfm [$1.06 per L/s] for a six-hour operation — all of which are real-world scenarios in commercial food service). Although the energy consumption is proportional to operating time, it is not a straight-line relationship. In the winter, the heating load will increase during the evening hours over daytime hours. In the summer, cooling loads will increase during daytime hours over the evening hours.

Makeup Air Heating and Cooling. Stating the obvious, makeup air (MUA) heating and cooling loads vary dramatically across the continent. The MUA heating load in Minneapolis and Chicago can be a significant component, while in San Diego and Miami it may not exist at all. The reciprocal is true for cooling. And the latent energy component in Miami quickly differentiates itself from the desert climates.

Kitchen Appliance Heat Gain to Space. It is difficult to uncouple the impact of appliance heat gain[1] on the heating and cooling load, as the primary purpose of the exhaust hood is to ventilate cooking equipment that is at operating temperature. Radiant heat gain from cooking equipment, such as underfired broilers, can be a significant factor in the energy equation. In general, the internal load from both hooded and unhooded equipment in the kitchen results in a "balance point" temperature that is much lower (e.g., 50°F [10°C]) than it is in other types of commercial spaces. This factor is significant in estimating makeup air heating loads, as it is often possible to introduce makeup air at a much lower temperature than the ambient kitchen temperature. If the makeup air is heated to a higher than needed temperature, the "balance point" heating credit may be shifted to the kitchen rooftop unit. But, this increased return air temperature also can result in simultaneous heating by the MUA unit and cooling by the kitchen rooftop HVAC unit.

Fan Energy. Depending on system static pressure, fan energy may be a significant component. The author has measured combined exhaust fan and makeup air fan power ranging from a low of 200 W per 1,000 cfm (200 W per 472 L/s) to a high of 1,000 W per 1,000 cfm (1,000 W per 472 L/s) —a five-to-one ratio! The higher-pressure drop systems tend to be associated with larger, engineered systems in hospitals and hotels. Quick service restaurants with backshelf hoods tend toward the middle of this range, while casual dining facilities and supermarkets with canopy hoods and short duct runs are generally near the lower end of the scale.

Energy Rates. The cost of energy (particularly electricity) varies significantly across North America. The electricity rate applied to a commercial food service operation can range from $0.04/kWh to $0.18/kWh, depending on location, season, the size of operation (and associated rate established with the utility), and the hours of operation per day. System operating time affects the applied utility rate as the contribution of an electric demand charge (or time-of-use rate) is diminished for a 24-hour, seven-day-per-week operation compared to an eight-hour, five-day-per-week operation. Although gas rates tend to be more uniform, they vary depending on the geographic location, season and the local utility. Accurate energy-cost estimates can only be generated with realistic utility rates for the project location.

'Unfortunately, the $/cfm index may not reflect actual energy consumption and cost.'

Energy Consumption & Cost Components

Analogous to developing a cost estimate for any project, the more one can dissect and estimate individual cost components, the better the chance that the overall cost estimate will be more accurate. Typically, the engineer defaults to the makeup air heating and cooling load as a primary estimate for the CKV energy cost. Although this may be the dominant component in many cases, all parameters in the cost equation should be considered, including:

- Makeup air heating,
- HVAC transfer air heating (if applicable),
- Makeup air cooling,
- HVAC transfer air cooling (if applicable),
- Exhaust fan energy,
- Makeup fan energy, and
- HVAC supply fan energy (if applicable).

Outdoor Air Load Calculations

Although the equations for calculating the heating and cooling load of an outdoor air load are used by engineers to calculate the design heating or cooling requirements for a given outdoor airflow rate,[2] it is more difficult to integrate (particularly using hand calculations) the hourly energy requirements over a complete heating or cooling season. Average outdoor air temperatures must be determined (or assumed) over a specified period of time (e.g., heating or cooling month), the operating time of the system must be considered, and the effective setpoint of the outdoor air heating or cooling system must be established. On one level, an engineer can simply estimate average outdoor temperatures from published degree-day data for different locations. On a more complex level, the engineer may apply hour-by-hour energy simulations to calculate the outdoor air loads. However, the level of effort associated with this second option may exceed the engineer's budget for the analysis of an outdoor air load reduction strategy.

Outdoor Air Load Calculator (OALC). The need for an easy-to-use tool to accurately determine the heating and cooling load for a given amount of outdoor (makeup) air led to the development of a no-cost, publicly available software referred to generically as the outdoor air load calculator (OALC). Since this tool does not model a complete building in detail, the minimal required input parameters are geographic location, outdoor airflow, operating hours, and the heating and cooling setpoints. With these basic inputs, the OALC is able to calculate monthly and annual heating and cooling loads, as well as design loads (the maximum heating and cooling load that occurred during the year).

Through a "Details" menu, it is possible to customize the calculation setup for dehumidification, equipment lockout during parts of the year, and fan characteristics for estimating exhaust and makeup air fan energy consumption. The versatility of the OALC allows simulation of a variety of scenarios. It also places responsibility on the user. Casual selection of user inputs may result in unrealistic results.

The OALC uses weather data in four-hour bins for the calculation of heating and cooling loads. Weather data is available for 239 U.S. and 47 Canadian locations. The individual

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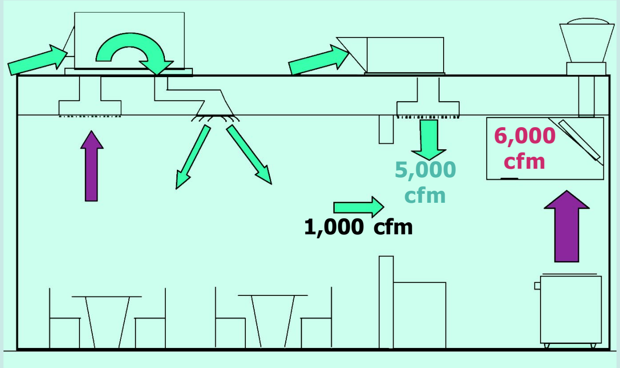

Figure 1: Simplified schematic of restaurant kitchen ventilation system used as a basis for estimating CKV costs for three U.S. cities. This kitchen uses a 6,000 cfm (2830 L/s) exhaust hood that operates from 6 a.m. to 10 p.m., seven days per week. A dedicated MUA supplies 5,000 cfm (2360 L/s) of the replacement air and 1,000 cfm (472 L/s) is air transferred from the restaurant HVAC.

Example: CKV Energy And Cost Estimates

The simplified restaurant schematic shown in *Figure 1* has been used as a basis for estimating CKV costs for three U.S. cities (Chicago, Los Angeles and Miami) with representative utility rates. Two scenarios have been developed for each city, representing an upper and lower estimate in energy consumption and cost charged against the CKV system.

The parameters for this commercial food service facility include a 6,000 cfm (2830 L/s) kitchen exhaust hood operating from 6 a.m. to 10 p.m., seven days per week. Five-thousand cfm (2360 L/s) of the replacement air requirement is supplied locally through a dedicated MUA unit (conditioned to the level indicated in the example scenario). One-thousand cfm (472 L/s) of the replacement air is transferred from the restaurant HVAC system.

The energy cost associated with conditioning this transfer air may or may not be assigned to the CKV system. If this amount of outdoor air is being brought into the dining room to satisfy ANSI/ASHRAE Standard 62, *Ventilation for Acceptable Indoor Air Quality,* ventilation requirements, then charging its energy cost against the CKV system may not be defensible.

Operating Hours	6 a.m. to 10 p.m. (16 Hours/Day)	
Exhaust Airflow	6,000 cfm	
Makeup Airflow	5,000 cfm	
Thermostat Setpoints	Heating = 55°F; Cooling = 85°F	
Dehumidification was set to limit RH to 70%. (Based on a space temperature of 85°F, without reheating option. No dehumidification will occur when heating is required.)		
Heating Design Load	387.1 kBtu/h	
Cooling Design Load	108.2 kBtu/h	
Fan Energy	Supply (5,000 cfm) Exhaust (6,000 cfm)	
Total Static Pressure	0.5 in. w.c.	1.5 in. w.c.
Motor Rated Input	0.529 kW	1.665 kW
Motor Energy Consumption	3087 kWh	9725 kWh

Calculated Monthly Loads		
Month	**Heating Load**	**Cooling Load**
January	87,213 kBtu	0 kBtu
February	66,221 kBtu	0 kBtu
March	53,657 kBtu	0 kBtu
April	18,964 kBtu	0 kBtu
May	3,090 kBtu	6 kBtu
June	84 kBtu	435 kBtu
July	0 kBtu	1,832 kBtu
August	5 kBtu	1,252 kBtu
September	588 kBtu	56 kBtu
October	11,118 kBtu	0 kBtu
November	39,762 kBtu	0 kBtu
December	76,989 kBtu	0 kBtu
Total/Year	**357,691 kBtu**	**3,581 kBtu**

Table 1: Input and output screen for the OALC.

Applied Energy Rate 6 a.m. – 10 p.m.	$0.09/kWh	$0.60/therm
	Reference	**Annual Cost ($)**
Exhaust Fan Energy	6,000 cfm @1.5	875.25
Makeup Air Fan Energy	5,000 cfm @ 0.5	277.83
Supply Fan Energy	NA	0.00
Makeup Air Heating	5,000 cfm to 55°F	2,384.61
Makeup Air Cooling	5,000 cfm to 85°F	41.97
Dehumidify to 70% Without Reheat		
Total		**$ 3,579.66**
	Design cfm	
$/cfm Index	6,000	$0.60

Table 2: Lower limit of estimated CKV system energy cost for Chicago.

Chicago: Scenario 1a

Assumptions: Dedicated MUA air heated with a direct-fired MUA unit and ductstat set to 55°F (12°C) (offsetting appliance heat gain). Although there is no air conditioning on the makeup air, kitchen temperature does not exceed 85°F (29°C) due to kitchen HVAC unit offsetting impact of unconditioned outdoor air. It is assumed that a large portion of the dedicated makeup air diffuses throughout the kitchen space and enters the return air of the HVAC system (which has the same energy impact as conditioning the makeup air to 85°F [29°C]). Heating and cooling energy, as well as fan energy, for the 1,000 cfm (472 L/s) transfer air are not charged against the CKV system. Other parameters are reflected in the OACL input and output (*Table 1*). A COP of 2.25 was applied to the air-cooling calculation. Direct-fired MUA heater efficiency was assumed to be 90%. Representative energy rates of $0.60 per therm and $0.09 per kWh were applied to generate the costs shown in *Table 2*.

Chicago: Scenario 1b

Assumptions: Same as Scenario 1a with fully conditioned makeup air. Ductstat set at 68°F (20°C) for heating and 76°F (24°C) for cooling (with dehumidification to 70% RH). Cost of conditioning transfer air (i.e., 68°F [20°C] and 76°F [24°C]) is charged to the CKV system. This may overstate the heating load, as these setpoints do not account for internal loads within space. A heating efficiency of 70% is assumed for the transfer air supplied by the rooftop units. A portion of the supply fan energy also is charged against the CKV system. Utility costs remain the same as Scenario 1a. Calculated energy costs are shown in *Table 3.*

Applied Energy Rate 6 a.m. – 10 p.m.	$0.09/kWh	$0.60/therm
	Reference	**Annual Cost ($)**
Exhaust Fan Energy	6,000 cfm @1.5	875.25
Makeup Air Fan Energy	5,000 cfm @ 0.5	277.83
Supply Fan Energy	1,000 cfm @ 0.25	38.40
Makeup Air Heating	5,000 cfm to 68°F	5,221.99
Makeup Air Cooling	5,000 cfm to 76°F	679.00
Transfer Air Heating	1,000 cfm to 68°F	1,068.14
Transfer Air Cooling	1,000 cfm to 76°F	135.80
Dehumidify to 70% Without Reheat		
Total		**$ 8,296.41**
	Design cfm	
$/cfm Index	6,000	$1.38

Table 3: Upper limit of estimated CKV system energy cost for Chicago.

Miami: Scenario 2a

Assumptions: Dedicated MUA air heated with a direct-fired MUA unit and ductstat set to 55°F (13°C). (In reality, makeup air heating would not be specified for a Miami restaurant.) There is no air-conditioning on makeup air, but kitchen temperature does not exceed 85°F (29°C) due to the kitchen HVAC unit offsetting impact of unconditioned outdoor air (same energy impact as conditioning the makeup air to 85°F [29°C]). Heating and cooling energy, as well as fan energy, for the 1,000 cfm (472 L/s) transfer air are not charged against the CKV system. Other input parameters are similar to the Chicago scenario. A COP of 2.25 was applied to the air-conditioning calculation. Representative energy rates of $0.80 per therm and $0.07 per kWh were applied to generate the costs shown in *Table 4*.

Applied Energy Rate 6 a.m. – 10 p.m.	$0.07/kWh	$0.80/therm
	Reference	**Annual Cost ($)**
Exhaust Fan Energy	6,000 cfm @1.5	696.15
Makeup Air Fan Energy	5,000 cfm @ 0.5	214.90
Supply Fan Energy	NA	0.00
Makeup Air Heating	5,000 cfm to 55°F	10.63
Makeup Air Cooling	5,000 cfm to 85°F	348.48
Transfer Air Heating	NA	0.00
Transfer Air Cooling	NA	0.00
Dehumidify to 70% Without Reheat		
Total		**$ 1,270.16**
	Design cfm	
$/cfm Index	6,000	$0.21

Table 4: Lower limit of estimated CKV system energy cost for Miami.

Miami: Scenario 2b

Assumptions: Same as Scenario 2a but with fully conditioned makeup air. Ductstat set at 68°F (20°C) for heating and 76°F (24°C) for cooling (with dehumidification to 70% RH). Cost of conditioning transfer air to the same temperatures is charged to the CKV system (i.e., 68°F [20°C] and 76°F [24°C]). A heating efficiency of 70% is applied to the transfer air with a COP of 2.25 for cooling. A portion of the supply fan energy also is charged against the CKV system. Utility costs remain the same as Scenario 2a. Calculated energy costs are shown in *Table 5*.

Applied Energy Rate 6 a.m. – 10 p.m.	$0.07/kWh	$0.80/therm
	Reference	**Annual Cost ($)**
Exhaust Fan Energy	6,000 cfm @1.5	875.25
Makeup Air Fan Energy	5,000 cfm @ 0.5	277.83
Supply Fan Energy	1,000 cfm @ 0.25	38.40
Makeup Air Heating	5,000 cfm to 68°F	167.37
Makeup Air Cooling	5,000 cfm to 76°F	6,560.26
Transfer Air Heating	1,000 cfm to 68°F	34.23
Transfer Air Cooling	1,000 cfm to 76°F	1,312.05
Dehumidify to 70%Without Reheat		
Total		**$ 9,265.40**
	Design cfm	
$/cfm Index	6,000	$1.54

Table 5: Upper limit of estimated CKV system energy cost for Miami.

Los Angeles: Scenario 3a

Assumptions: Dedicated MUA air heated with a direct-fired MUA unit and ductstat set to 55°F (13°C) (offsetting appliance heat gain). No air conditioning on makeup air, but kitchen temperature is assumed to not exceed 85°F (29°C) due to the kitchen HVAC unit offsetting impact of unconditioned outdoor air diffusing throughout the kitchen space. Heating and cooling energy as well as fan energy for the 1,000 cfm (472 L/s) transfer air are not charged against the CKV system. Representative energy rates of $0.70 per therm and $0.16 per kWh were applied to the energy components to generate the costs shown in *Table 6*.

Applied Energy Rate 6 a.m. – 10 p.m.	$0.16/kWh	$0.70/therm
	Reference	**Annual Cost ($)**
Exhaust Fan Energy	6,000 cfm @1.5	1,585.60
Makeup Air Fan Energy	5,000 cfm @ 0.5	489.44
Supply Fan Energy	NA	0.00
Makeup Air Heating	5,000 cfm to 55°F	66.90
Makeup Air Cooling	5,000 cfm to 85°F	3.10
Transfer Air Heating	NA	0.00
Transfer Air Cooling	NA	0.00
Dehumidify to 70% Without Reheat		
Total		**$ 2,145.05**
	Design cfm	
$/cfm Index	6,000	$0.36

Table 6: Lower limit of estimated CKV system energy cost for Los Angeles.

Los Angeles: Scenario 3b

Assumptions: Same as Scenario 3a with fully conditioned makeup air. Ductstat set at 68°F (20°C) for heating and 76°F (24°C) for cooling (with dehumidification to 70% RH). Cost of conditioning transfer air to the same temperatures is charged to the CKV system (i.e., 68°F [20°C] and 76°F [24°C]). A heating efficiency of 70% is assumed for the transfer air, while a COP of 2.25 is applied to the cooling calculation. A portion of the supply fan energy also is charged against the CKV system. Utility costs remain the same as Scenario 3a. Calculated energy costs are shown in *Table 7*.

Applied Energy Rate 6 a.m. – 10 p.m.	$0.16/kWh	$0.70/therm
	Reference	**Annual Cost ($)**
Exhaust Fan Energy	6,000 cfm @1.5	1,556.00
Makeup Air Fan Energy	5,000 cfm @ 0.5	493.92
Supply Fan Energy	1,000 cfm @ 0.25	70.56
Makeup Air Heating	5,000 cfm to 68°F	1,700.84
Makeup Air Cooling	5,000 cfm to 76°F	98.84
Transfer Air Heating	1,000 cfm to 68°F	347.90
Transfer Air Cooling	1,000 cfm to 76°F	19.77
Dehumidify to 70% Without Reheat		
Total		**$ 4,287.83**
	Design cfm	
$/cfm Index	6,000	$0.71

Table 7: Upper limit of estimated CKV system energy cost for Los Angeles.

weather data files contain dry-bulb temperature and relative humidity with a time and date stamp. The algorithms incorporated in the software tool were described in an ASHRAE symposium paper.[3]

The OALC is available as freeware at www.archenergy.com/ckv/oac/default.htm. The only system requirement is a Web browser that supports Java 1.1.

Other Tools. A national gas industry research organization developed an appliance energy cost estimating software program[4] that includes the kitchen ventilation component. Although this software factors in the dynamics of the kitchen environment (e.g., appliance heat gain, interaction with HVAC system, etc.), the architecture and energy algorithms are not transparent and output does not report units of energy. It does, however, provide the industry with another option for estimating kitchen ventilation energy costs.

Conclusions

The kitchen ventilation energy consumption and operating cost examples clearly illustrate the impact of climate, setpoint, energy rates, and whether the cost of conditioning transfer air is charged to the CKV system. The two scenarios for each location were developed using assumptions that establish an upper and a lower limit for the system energy cost. It is anticipated that actual energy consumption and cost for operating facilities would fall within this range.

The energy costs calculated for Chicago, Miami and Los Angeles suggest that the $/cfm index often used by the CKV industry is overstated for many parts of the U.S. Cooling loads may not be as significant as one might expect, particularly when MUA is unconditioned and kitchen temperature and humidity rise accordingly, despite the obvious compromise in indoor environment. The actual number of hours (as a percentage of the total hours in the year) when the outdoor air temperature is above the cooling setpoint is less than one might assume for many U.S. locations. Even in Miami, if kitchen temperatures are allowed to approach 85°F (29°C), the cooling load is minimal. But for a fully conditioned kitchen in Miami, the makeup air-cooling load dominates and the latent load becomes a significant component.

For low-static systems (and associated fan horsepower), the energy consumption of CKV systems in desert-type climates can be very low, particularly if combined with evaporative cooling. If the CKV system is in a larger building with long duct runs, fan energy consumption can increase significantly. It is common that CKV systems in institutional and large commercial facilities tend to have higher system static pressures and fully conditioned makeup air, making these systems good candidates for variable speed strategies.

Estimating the energy consumption and cost of a CKV system using a systematic approach provides insights into how a CKV system will interact with the overall building HVAC system, as well as providing an economic foundation for energy-efficient design.

References

1. *2001 ASHRAE Handbook—Fundamentals,* Chapter 29.

2. *2001 ASHRAE Handbook—Fundamentals,* Chapter 31.

3. Fisher, 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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