Designation: F2474 – 17

An American National Standard

Standard Test Method for Heat Gain to Space Performance of Commercial Kitchen Ventilation/Appliance Systems[1]

This standard is issued under the fixed designation F2474; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of appliance heat gain to space derived from the measurement and calculation of appliance energy consumption, energy exhausted, and energy to food, based on a system energy balance, parametric evaluation of operational or design variations in appliances, hoods, or replacement air configurations.

1.2 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

F1704 Test Method for Capture and Containment Performance of Commercial Kitchen Exhaust Ventilation Systems

2.2 *ASHRAE Standard:*[3]

ASHRAE Guideline 2-1986 (RA96) Engineering Analysis of Experimental Data

ASHRAE Terminology of Heating, Ventilation, Air-Conditioning, and Refrigeration

2.3 *ANSI Standards:*[4]

ANSI/ASHRAE 51 and ANSI/AMCA 210 Laboratory Method of Testing Fans for Rating

NOTE 1—The replacement air and exhaust system terms and their definitions are consistent with terminology used by the American Society of Heating, Refrigeration, and Air Conditioning Engineers.[5] Where there are references to cooking appliances, an attempt has been made to be consistent with terminology used in the test methods for commercial cooking appliances. For each energy rate defined as follows, there is a corresponding energy consumption that is equal to the average energy rate multiplied by elapsed time. Electric energy and rates are expressed in W, kW, and kWh. Gas energy consumption quantities and rates are expressed in Btu, kBtu, and kBtu/h. Energy rates for natural gas-fueled appliances are based on the higher heating value of natural gas.

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *energy rate, n*—average rate at which an appliance consumes energy during a specified condition (for example, idle or cooking).

3.1.2 *appliance/hood energy balance, n*—mathematical expression of appliance, exhaust system, and food energy relationship.

[actual appliance energy consumption]
= [heat gain to space from appliance(s)] + [energy exhausted] + [energy-to-food, if any]

3.1.3 *cold start, n*—condition in which appliances are energized with all components being at nominal room temperature.

3.1.4 *cooking energy consumption rate, n*—average rate of energy consumed by the appliance(s) during cooking specified in appliance test methods.

3.1.4.1 *Discussion*—In this test method, this rate is measured for heavy-load cooking in accordance with the applicable test method.

3.1.5 *exhaust energy rate, n*—average rate at which energy is removed from the test system.

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[1] This test method is under the jurisdiction of ASTM Committee F26 on Food Service Equipment and is the direct responsibility of Subcommittee F26.07 on Commercial Kitchen Ventilation.

Current edition approved June 1, 2017. Published July 2017. Originally approved in 2005. Last previous edition approved in 2014 as F2474 – 14. DOI: 10.1520/F2474-17.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE), 1791 Tullie Circle, NE, Atlanta, GA 30329

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

[5] The boldface numbers in parentheses refer to the list of references at the end of these test methods.

3.1.6 *exhaust flow rate, n*—volumetric flow of air (plus other gases and particulates) through the exhaust hood, measured in standard cubic feet per minute, scfm (standard litre per second, sL/s). This also shall be expressed as scfm per linear foot (sL/s per linear metre) of active exhaust hood length.

3.1.7 *energy-to-food rate, n*—average rate at which energy is transferred from the appliance to the food being cooked, using the cooking conditions specified in the applicable test methods.

3.1.8 *fan and control energy rate, n*—average rate of energy consumed by fans, controls, or other accessories associated with cooking appliance(s). This energy rate is measured during preheat, idle, and cooking tests.

3.1.9 *heat gain energy rate from appliance(s), n*—average rate at which energy is transferred from appliance(s) to the test space around the appliance(s), exclusive of the energy exhausted from the hood and the energy consumed by the food, if any.

3.1.9.1 *Discussion*—This gain includes conductive, convective, and radiant components. In conditions of complete capture, the predominant mechanism of heat gain consists of radiation from the appliance(s) and radiation from hood. In the condition of hood spillage, heat is gained additionally by convection.

3.1.10 *hood capture and containment, n*—ability of the hood to capture and contain grease-laden cooking vapors, convective heat, and other products of cooking processes. Hood capture refers to the products getting into the hood reservoir from the area under the hood while containment refers to the products staying in the hood reservoir.

3.1.11 *idle energy consumption rate, n*—average rate at which an appliance consumes energy while it is idling, holding, or ready-to-cook, at a temperature specified in the applicable test method.

3.1.12 *latent heat gain, n*—energy added to the test system by the vaporization of liquids that remain in the vapor phase prior to being exhausted, for example, by vapor emitted by products of combustion and cooking processes.

3.1.13 *makeup air handling hardware:*—

3.1.13.1 *diffuser, n*—outlet discharging supply air in various directions and planes.

3.1.13.2 *grille, n*—covering for any opening through which air passes.

3.1.13.3 *register, n*— grille equipped with a damper.

3.1.13.4 *throw, n*—horizontal or vertical axial distance an air stream travels after leaving an air outlet before maximum stream velocity is reduced to a specified terminal velocity, for example, 100, 150, or 200 ft/min (0.51, 0.76, or 1.02 m/s).

3.1.14 *measured energy input rate, n*—maximum or peak rate at which an appliance consumes energy measured during appliance preheat, that is, measured during the period of operation when all gas burners or electric heating elements are set to the highest setting.

3.1.15 *radiant heat gain, n*—fraction of the space energy gain provided by radiation.

3.1.15.1 *Discussion*—Radiant heat gain is not immediately converted into cooling load. Radiant energy must first be absorbed by surfaces that enclose the space and objects in the space. As soon as these surfaces and objects become warmer than the space air, some of their heat is transferred to the air in the space by convection. The composite heat storage capacity of these surfaces and objects determines the rate at which their respective surface temperatures increase for a given radiant input and thus governs the relationship between the radiant portion of heat gain and its corresponding part of the cooling load. The thermal storage effect is critically important in differentiating between instantaneous heat gain for a given space and its cooling load for that moment.

3.1.16 *rated energy input rate, n*—maximum or peak rate at which an appliance consumes energy as rated by the manufacturer and specified on the appliance nameplate.

3.1.17 *replacement air, n*—air deliberately supplied into the space (test room), and to the exhaust hood to compensate for the air, vapor, and contaminants being expelled (typically referred to as makeup air).

3.1.18 *supply flow rate, n*—volumetric flow of air supplied to the exhaust hood in an airtight room, measured in standard cubic feet per minute, scfm (standard litre per second, sL/s). This also shall be expressed as scfm per linear foot (sL/s per linear metre) of active exhaust hood length.

3.1.19 *threshold of capture and containment, n*—conditions of hood operation in which minimum flow rates are just sufficient to capture and contain the products generated by the appliance(s). In this context, two minimum capture and containment points are determined, one for appliance idle condition, and the other for heavy-load cooking condition.

3.1.20 *uncertainty, n*—measure of the precision errors in specified instrumentation or the measure of the repeatability of a reported result.

3.1.21 *ventilation, n*—that portion of supply air that is outdoor air plus any recirculated air that has been treated for the purpose of maintaining acceptable indoor air quality.

4. Summary of Test Method

4.1 This test method is used to characterize the performance of commercial kitchen ventilation systems. Such systems include one or more exhaust-only hoods, one or more cooking appliances under the hood(s), and a means of providing replacement (makeup) air. Ventilation system performance includes the evaluation of the rate at which heat is transferred to the space.

4.1.1 The heat gain from appliance(s) hood system is measured through energy balance measurements and calculations determined at specified hood exhaust flow rate(s). When heat gain is measured over a range of exhaust flow rates, the curve of energy gain to the test space versus exhaust rate reflects kitchen ventilation system performance, in terms of heat gain associated with the tested appliance(s).

4.1.2 In the simplest case, under idle mode, energy exhausted from the test system is measured and subtracted from the energy into the appliance(s) under the hood. The remainder is heat gain to the test space. In the cooking mode, energy to food also must be subtracted from appliance energy input to calculate heat gain to space.

4.1.3 Figs. 1-3 show sample curves for the theoretical view of heat gain due to hood spillage, an overall energy balance, and for heat gain versus exhaust flow rate for the general case.

5. Significance and Use

5.1 *Heat Gain to Space*—This test method determines the heat gain to the space from a hood/appliance system.

NOTE 2—To maintain a constant temperature in the conditioned space, this heat gain must be matched by space cooling. The space sensible cooling load, in tons, then equals the heat gain in Btu/h divided by the conversion factor of 12 000 Btu/h (3.412 W) per ton of cooling. Appliance heat gain data can be used for sizing air conditioning systems. Details of load calculation procedures can be found in ASHRAE, see Ref (**1**) and Ref (**2**)[5]. The calculation of associated cooling loads from heat gains to the test space at various flow rates can be used along with other information by heating, ventilation, air conditioning (HVAC), and exhaust system designers to achieve energy-conservative, integrated kitchen ventilation system designs.

5.2 *Parametric Studies:*

5.2.1 This test method also can be used to conduct parametric studies of alternative configurations of hoods, appliances, and replacement air systems. In general, these studies are conducted by holding constant all configuration and operational variables except the variable of interest. This test method, therefore, can be used to evaluate the following:

5.2.1.1 The overall system performance with various appliances, while holding the hood and replacement air system characteristics constant.

5.2.2 Entire hoods or characteristics of a single hood, such as end panels, can be varied with appliances and replacement air constant.

5.2.3 Replacement air characteristics, such as makeup air location, direction, and volume, can be varied with constant appliance and hood variables.

6. Apparatus

6.1 The general configuration and apparatus necessary to perform this test method is shown schematically in Fig. 4 and described in detail in Ref (**3**). Example test facilities are described in Refs (**4-6**). The exhaust hood under test is connected to an exhaust duct and fan and mounted in an airtight or non-airtight room. The exhaust fan is controlled by a variable speed drive to provide operation over a wide range of flow rates. A complementary makeup air fan is controlled to balance the exhaust rate, thereby maintaining a negligible static pressure difference between the inside and outside of the test room. The test facility includes the following:

6.1.1 *Airtight Room,* with sealable access door(s), to contain the exhaust hood to be tested, with specified cooking appliance(s) to be placed under the hood. The minimum volume of the room shall be 6000 ft^3. The room air leakage shall not exceed 20 scfm (9.4 sL/s) at 0.2 in. w.c. (49.8 Pa).

6.1.1.1 *Exhaust and Replacement Air Fans,* with variable-speed drives, to allow for operation over a wide range of exhaust airflow rates.

6.1.1.2 *Control System and Sensors,* to provide for automatic or manual adjustment of replacement air flow rate, relative to exhaust flow rate, to yield a differential static pressure between inside and outside of the airtight room not to exceed 0.05 in. w.c. (12.5 Pa).

6.1.1.3 *Air Flow Measurement System Laminar Flow Element,* AMCA 210 or equivalent nozzle chamber, mounted in the replacement or exhaust airstream, to measure airflow rate.

NOTE 3—Because of potential problems with measurement in the hot, possibly grease-laden exhaust air stream, exhaust airflow rate can be determined by measuring the replacement airflow rate on the supply side. This requires the design of an airtight test facility that ensures the supply rate equals the exhaust rate since air leakage outside the system boundary,

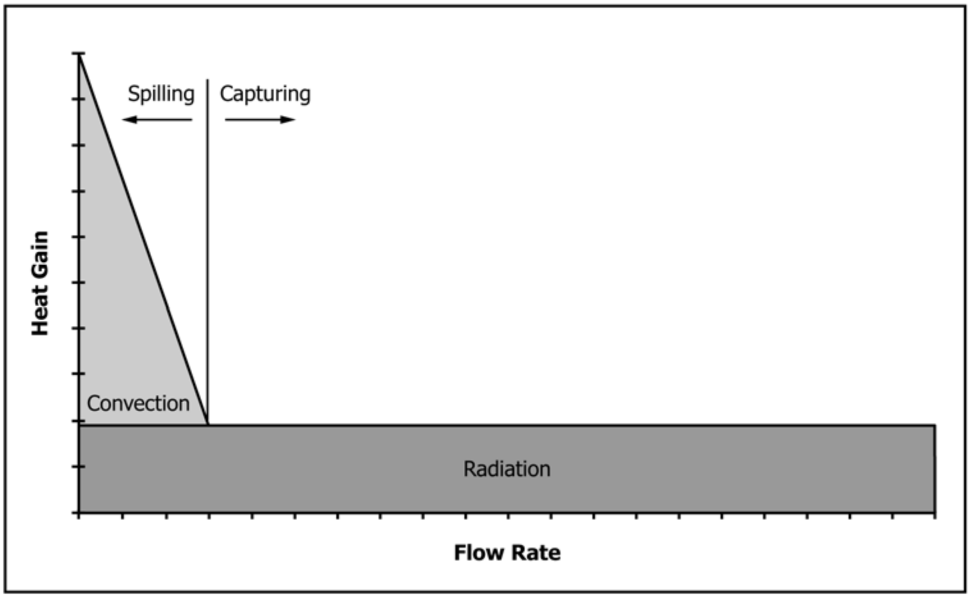

FIG. 1 Theoretical View of Heat Gain—Convective/Radiant Split

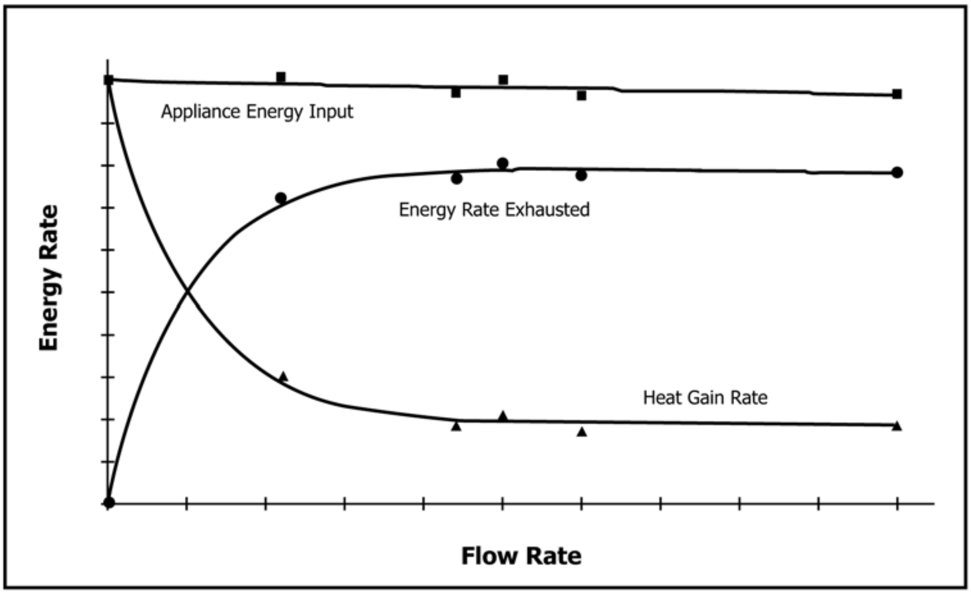

FIG. 2 Overall Energy Balance—Idle Condition

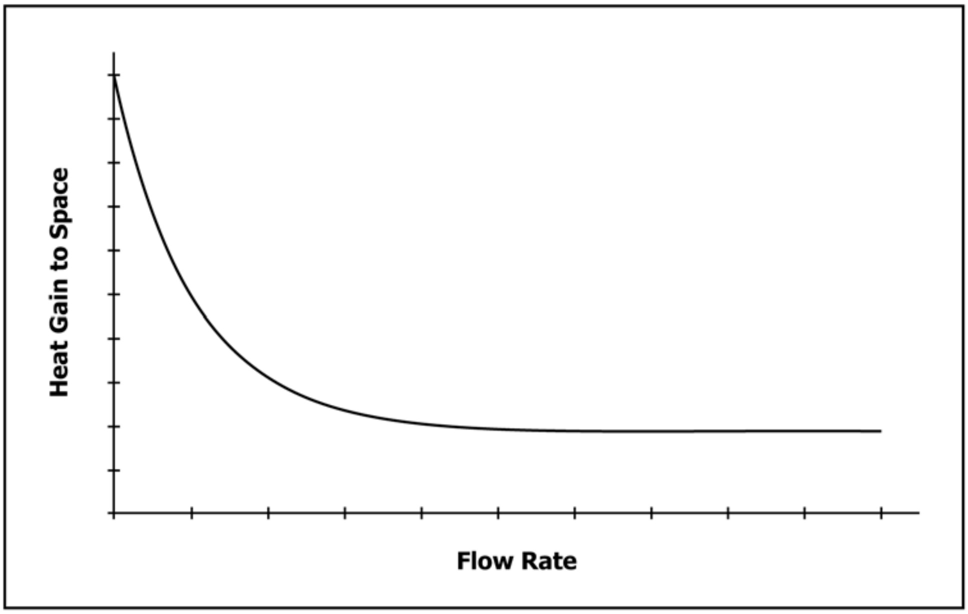

FIG. 3 Heat Gain Curve—Typical

that is, all components between supply and exhaust blowers making up the system, is negligible.

NOTE 4—Laminar flow elements have been used as an equivalent alternative to the flow nozzles in AMCA 210 (see 2.3).

6.1.2 *Non-Airtight Room,* to contain the exhaust hood and make-up air configuration to be tested, with specified cooking appliance(s) to be placed under the hood. The room is configured such that it allows replacement air to approach the entire front face of the exhaust hood slowly, as through a screened wall.

6.1.2.1 *Exhaust Fan,* with variable speed drive, to allow for operation over a wide range of exhaust airflow rates.

6.1.2.2 *Control System and Sensors,* to provide for automatic or manual adjustment of exhaust airflow rate.

6.1.2.3 *Air Flow Management System*—A Pitot tube traverse, nozzle chamber or equivalent in accordance with AMCA 210, mounted in the exhaust and make-up airstreams, to measure airflow rates.

NOTE 5—Laminar flow elements have been used as an equivalent alternative to the flow nozzles in AMCA 210 (see 2.3).

6.2 *Aspirated Temperature Tree(s),* for measurement of average temperature of makeup air from the test space crossing the plane of the tree(s) into the hood, see Fig. 5.

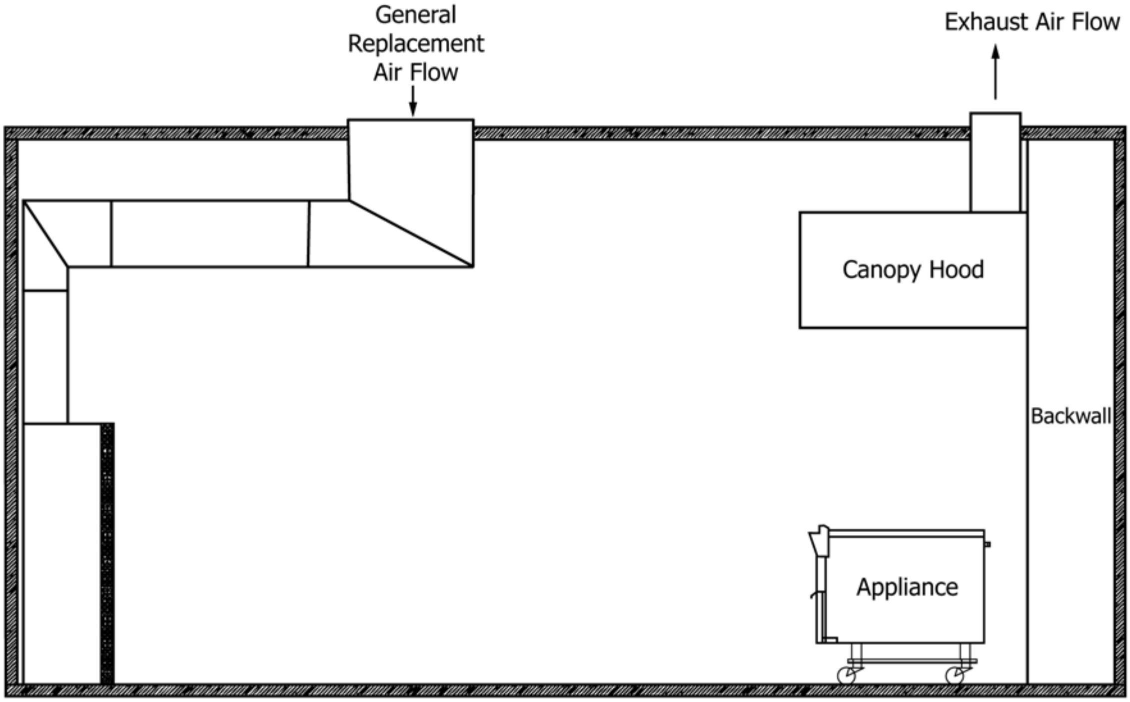

FIG. 4 Test Space Cross Section

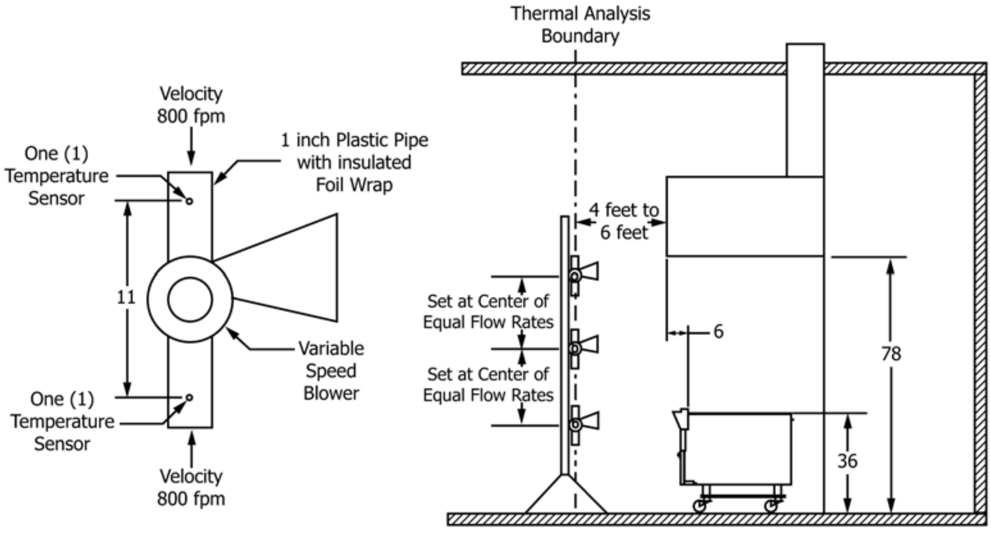

FIG. 5 Aspirated Temperature Tree Schematic and Setup

6.3 *Exhaust Duct Temperature Sensors,* a grid for measurement of the exhaust air temperature.

6.4 The applicable test methods include descriptions of the necessary apparatus and procedures for determining cooking appliance energy quantities.

6.5 *Data Acquisition System,* to provide for automatic logging of test parameters.

7. Reagents and Materials

7.1 *Water and Test Food Products*—Use water and test food products to determine energy-to-food as specified in the test methods listed in Section 2.

8. Sampling

8.1 *Hood and Appliance(s)*—Select representative production models for performance testing.

9. Preparation of Apparatus

9.1 Install the test hood in the airtight room in accordance with manufacturer's instructions or experimental design. When these instructions are not available, install wall canopy hoods flush against a wall or partition. Backshelf hoods shall be installed against a wall or partition. For wall canopy hoods, the lower front edge shall be a minimum of 78 in. (1.98 m) above the finished floor. Connect exhaust duct(s) to hood collar(s).

9.2 Install specified appliance(s) under the test hood in accordance with the applicable ASTM test method, if available. If not available, use a test method that is ANSI approved or approved by a standards development organization. If either of these is not available, use manufacturer's instructions. When such information is not available for griddles, fryers, and open top burners, allow a distance between the lowest edge of hood grease filters and the cooking surface between 1 and 2 ft (31 and 61 cm). For charbroilers, allow the range from 3.5 to 4 ft (107 to 122 cm). For wall canopy hoods, allow the minimum side and front overhangs to be 6 in. (15.3 cm). For backshelf hoods, allow the minimum side overhang to be 0 in. and the maximum front setback to be 12 in. (30.6 cm). If the hood is equipped with side panels, then the requirement of side overhang is ignored, provided that the cooking surface does not extend beyond the vertical plane of the hood sides. There shall be no obstructions or blockage of airflow for a minimum of 6 ft (183 cm) around the hood perimeter.

NOTE 6—Size the exhaust hood appropriately to match the above specified appliance(s).

9.3 Place the temperature trees 4 to 6 ft (1.2 to 1.8 m) in front of the hood or appliance(s) vertical, whichever is further into the test space, and maintain within the range from 75 to 78°F (24 to 26°C). At a minimum, place two trees in front of the hood, with optional trees placed around the hood/appliance system.

9.4 Replacement air may be supplied to diffusers in the test space. The specific arrangement shall be noted.

9.4.1 General replacement air provided to the test space shall be introduced from diffusers outside the thermal boundary. The general arrangement of replacement air diffusers and energy balance quantities are shown in Fig. 6.

NOTE 7—Document supply air configuration, louver, and damper positions.

9.5 Connect the appliance(s) to energy sources and test instruments in accordance with the applicable test methods. Included is the connection to calibrated energy test meters and for gas equipment and the connection to a pressure regulator downstream of the test meter. Electric and gas energy sources are adjusted to within 2.5 % of voltages and pressures, respectively, as specified by the manufacturer's instructions or in accordance with applicable test methods.

9.6 Once the equipment has been installed, draw a front and side view of the test setup.

10. Calibration

10.1 Calibrate the instrumentation and the data acquisition system in accordance with the device requirements to ensure accuracy of measurements.

10.2 *Temperature Sensors*—Calibrate all temperature sensors upon receipt to within ±0.9°F (0.5°C) against a NIST-traceable temperature reference over the range of expected measurements.

NOTE 8—The accuracy of the heat gain result is directly related to the difference between the exhaust and tree measurements. Experience indicates four-wire RTD sensors are the most practical.

10.3 *Gas Meter,* for measuring the gas consumption of an appliance, shall be a positive displacement type with a resolution of at least 0.01 ft^3 (0.0003 m^3) and a maximum error no greater than 1 % of the measured value for any demand greater than 2.2 ft^3/h (0.06 m^3/h).

10.4 *Watt-Hour Meter,* for measuring the electrical energy of an appliance, shall have a resolution of at least 1 Wh and a

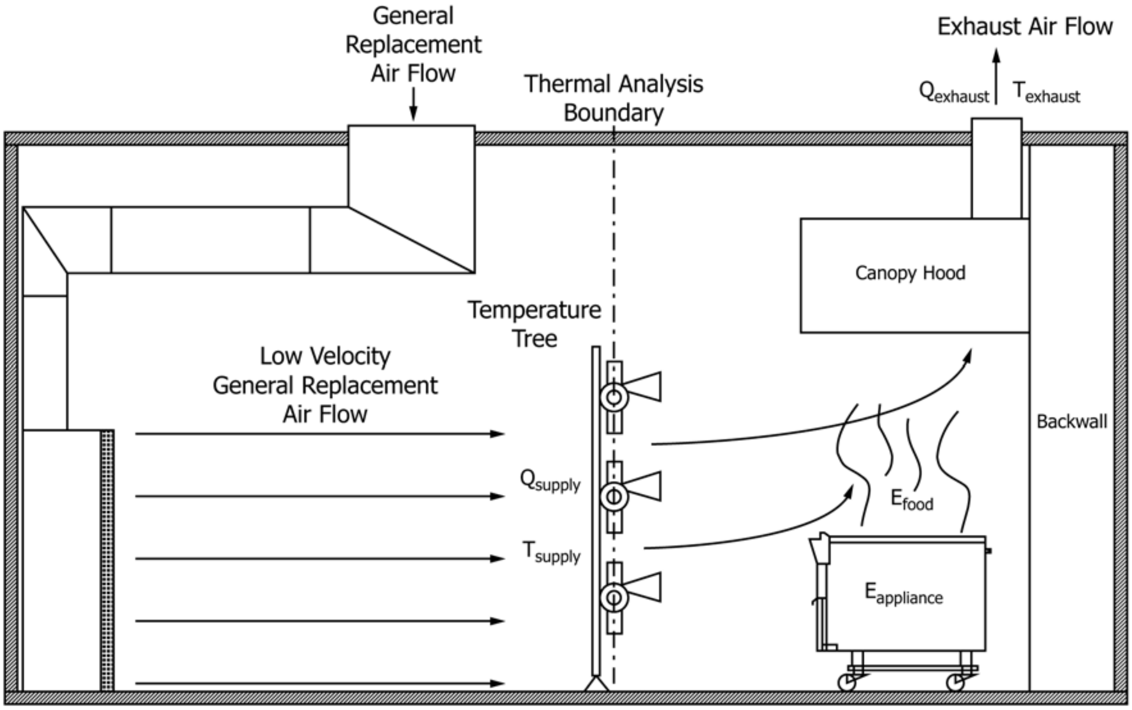

FIG. 6 Supply Air Diffusers and Energy Balance Quantities

maximum error no greater than 1.5 % of the measured value for any demand greater than 100 W.

11. Procedure

11.1 *Determination of Appliance Heat Gain to Space*—The general procedure for each test run includes determination of heat gain to the test space from operating hooded appliance(s) under specified flow rates or over a range of flow rates. Energy to food is determined using the applicable test methods. Maintain the tree(s) of aspirated temperature sensors within the range from 75 to 78°F (24 to 26°C) for all test points. For testing with appliance(s) under idle condition, energy to food is set equal to zero.

11.2 *Bulk Air Temperature Measurement Calibration:*

11.2.1 Turn off the appliance(s) under the hood and maintain them at room temperature. Turn off standing pilots of gas appliances.

11.2.2 Balance supply air and exhaust air volumes to obtain ambient pressure $|\Delta P_{neut}| \leq 0.05$ in. w.c. in the test space at exhaust rate cfm_1. Apply cooling/heating as necessary to maintain average laboratory temperature as measured with the temperature trees (T_{tree}) within the range from 75 to 78°F (24 to 26°C).

11.2.3 Allow the temperatures to stabilize for a minimum of 15 min.

11.2.4 The temperature difference between the aspirated temperature tree(s) T_{tree} and the exhaust temperature T_{exh} must be within ±0.2°F (0.1°C).

11.3 *Heat Gain Determination at Specified Flow Rates*—Conduct the heat gain test a minimum of three times. Additional test runs may be necessary to obtain the required precision for the reported test results (Annex A1).

11.4 *Heat Gain Determination for a Range of Flow Rates*—Conduct the heat gain test at a minimum of six different flow rates at the desired condition (cooking or idle). Additional points may be necessary to obtain the required precision for the reported test results (ASHRAE Guideline 2-1986).

NOTE 9—The most practical points to test at are idle capture and containment and cooking capture and containment as determined by Test Method F1704, and the U/L listed flow rate, and the IMC code flow rate.

11.5 Determine the condition for the heat gain test (cooking or idle). If idling, proceed to 11.6; if cooking, proceed to 11.7.

11.6 *Measurements with Appliance(s) Idling:*

11.6.1 Balance supply air and exhaust air volumes to obtain ambient pressure $|\Delta P_{neut}| \leq 0.05$ in. w.c. in the test space at predetermined flow rate, cfm_1

11.6.2 Operate all appliance(s) under the hood in idle conditions as specified in the ASTM procedure. Allow stabilization until the appliance develops a constant heating cycle (typically 2 h from a cold start condition). Apply cooling/heating as necessary to maintain average laboratory temperature as measured with the temperature trees T_{tree} within the range from 75 to 78°F (24 to 26°C) during the test.

11.6.3 Take a sample for 2 h for thermostatically controlled appliances and 1 h for non-thermostatically controlled appliances. Include in the sample the variables outlined in 12.3.

11.6.4 Adjust the flow rate down to the next predetermined flow rate. Allow a stabilization period until the appliance develops a constant heating cycle (typically 30 min) at each test point. Repeat 11.6.1 and 11.6.4 for predetermined flow rates

11.6.5 Calculate the required parameters, and report results for HG_{idle}.

NOTE 10—For thermostatically controlled appliances, an incremental increase in exhaust flow rate results in an incremental increase in the appliance's energy consumption. This is due to the higher cooling effects of the appliance cooking sections at higher exhaust rates yielding more energy demand by the thermostats to maintain the same appliance set operating conditions. For non-thermostatically controlled appliances, the appliance(s) energy consumption remains the same regardless of exhaust flow rate, but during the preheat period, the consumption rate may drop due to thermal expansion of fuel/energy transport components. If adjustment is required, it must be done during the first 10 min of the appliance preheat period.

11.6.6 At the user's request, the procedure in Appendix X2 can be used to determine the sensible convective and latent heat loads from a cooking process or recirculating system, but not the sensible radiant heat load.

11.7 *Measurement with Appliance(s) Cooking:*

11.7.1 Balance supply air and exhaust air volumes to obtain ambient pressure $|\Delta P_{neut}| \leq 0.05$ in. w.c. in the test space at the predetermined flow rate, cfm_1.

11.7.2 Allow an idle stabilization period until the appliance develops a constant heating cycle (typically 2 h from a cold start condition). Apply cooling/heating as necessary to maintain average laboratory temperature as measured with the temperature trees T_{tree} within the range from 75 to 78°F (24 to 26°C) during the test.

11.7.3 Operate all the appliance(s) under the hood at full-capacity conditions as specified in the applicable test procedure. Stabilize the system under heavy-load cooking conditions. Stabilization is done by cooking the number of stabilization loads specified in the test procedure and when during the cooking process, T_{exh} is $|T_{exh\ max\ (load\ n)} - T_{exh\ max\ (load\ (n-1))}|$ of successive loads ≤1°F.

11.7.4 Confirm full recovery of the appliance(s) cooking sections as specified in the ASTM procedure. Begin data collection before loading the first load of the actual cooking test. Continue sampling until unloading the last load and full recovery of the appliance(s) cooking sections.

NOTE 11—Place the cooked food either in a sealed and insulated container or removed outside the test system to minimize its energy from being released to the test space.

11.7.5 Calculate the required parameters from 12.3, and calculate results for HG_{cook}.

12. Calculation and Report

12.1 *Test Hood and Appliance(s)*—Summarize the physical and operating characteristics of the exhaust hood and installed appliances, reporting all manufacturer's specifications and deviations there from. Include in the summary hood and appliance(s) rated energy input rate, measured energy input rate, idle energy consumption rate, cooking energy consumption rate; hood overhangs(s), height(s), and size. Describe the specific appliance operating condition (for example, number of burners or elements on, and actual control settings).

12.2 *Apparatus*—Describe the physical characteristics of the airtight room, exhaust and makeup air systems, and installed instrumentation.

12.3 *Data Acquisition:*

12.3.1 The following parameters are determined or known prior to each test run:

12.3.1.1 α, an operator used to offset latent losses from combustion, defined as equal to 0.096 for hooded gas appliances, and zero for electric appliances.

12.3.1.2 *HV*, Btu/ft^3—Higher (gross) saturated heating value of natural gas.

12.3.1.3 $cfm_{1,2,n}$, predetermined test flow rates.

12.3.1.4 C_{pa}, specific heat of dry air, 0.24 Btu/[lb_a·°F].

12.3.1.5 C_{pv}, specific heat of water vapor, 0.44 Btu/[lb_a·°F]

12.3.1.6 R_a, gas constant for dry air, 53.352 ft·lb_f/[lb_m·°F].

12.3.2 The following parameters are monitored and recorded during each test run or at the end of each test run, or both:

12.3.2.1 V_{gas}, cubic feet, ft^3—Volume of gas consumed by the appliance(s) over the test period.

12.3.2.2 cfm_{gas}, cubic feet per minute, cfm—Average flow rate of combustion gas consumed over the test period.

12.3.2.3 E_{ctrl}, Btu/h—Average rate of energy consumed by controls, indicator lamps, fans, or other accessories associated with cooking appliance(s).

12.3.2.4 E_{app}, Btu/h—Average rate of energy consumed by burners of gas appliances, or heating elements of electric appliances, to maintain set operating temperature.

12.3.2.5 E_{input}, Btu/h—Average rate of total energy (that is, E_{app} + E_{ctrl}) consumed by the appliance(s).

12.3.2.6 ΔP_{neut}, in. H_2O—Static pressure differential between inside and outside the test space, measured at the neutral zone of the test space.

12.3.2.7 P_{gas}, in. Hg—Gas line gage pressure.

12.3.2.8 *Bp*, in. Hg—Ambient barometric pressure.

12.3.2.9 cfm_{tree}, cubic feet per minute, cfm—Actual flow rate of makeup air supplied from the test space.

12.3.2.10 T_{is}, °F—Average dry bulb temperature of supply air into the test space.

12.3.2.11 T_{exh}, °F—Average dry bulb temperature of exhaust air.

12.3.2.12 T_{tree}, °F—Average dry bulb temperature of makeup air supplied from the test space, that is crossing the plane of aspirated temperature tree(s).

12.3.2.13 T_{space}, °F—Average dry bulb temperature of test space.

12.3.2.14 T_{gas}, °F—Average dry bulb temperature of the gas consumed by the appliance(s).

12.3.2.15 $T_{w,tree}$, °F—Average wet bulb temperature of test space air, measured at the aspirated temperature tree(s) plane.

12.3.2.16 T_{test}, min—Elapsed time of the test run.

12.3.3 The following parameters are calculated at the end of each test run:

12.3.3.1 *Cp*, Btu/lb·°F—Specific heat of supply [makeup] air.

12.3.3.2 $Hg_{1,2,n}$, Btu/h—Average rate of heat gained by the test space at predetermined flow rates.

12.3.3.3 E_{exh}, Btu/h—Average rate of heat removed from the test space out of the hood energy exhaust rate.

12.3.3.4 E_{food}, Btu/h—Average rate of energy gained by the food product over the period T_{test}.

12.3.3.5 $E_{food,lat}$, Btu—Latent energy gained by the food product to vaporize some of its water content.

12.3.3.6 $E_{food,sens}$, Btu—Sensible energy gained by the food product to bring it from its initial temperature to its final temperature.

12.3.3.7 P_{cf}, dimensionless—Pressure correction factor.

12.3.3.8 T_{cf}, dimensionless—Temperature correction factor.

12.3.3.9 $scfm_{tree}$, scfm—Flow rate of makeup air supplied from the test space at standard density air.

12.3.3.10 M_{sup}, lb/h—Total mass flow rate of air supplied by the system.

12.3.3.11 W_{sup}, lb_v/lb_a—Equivalent humidity ratio of makeup air supplied from the hood and test space.

12.3.3.12 $W^*_{s,tree}$, lb_v/lb_a—Humidity ratio at saturation of makeup air supplied from the test space.

12.3.3.13 W_{tree}, lb_v/lb_a—Humidity ratio of makeup air supplied from the test space.

12.3.3.14 RH_{tree}, %—Relative humidity of air supplied from the test space.

12.3.3.15 v_{tree}, (ft^3/lb_a)—Specific volume of makeup air supplied from the test space.

12.3.4 The following are optional parameters and could be calculated at the end of each test run:

12.3.4.1 h_{tree}, Btu/lb_a—Specific enthalpy of makeup air supplied from the test space.

12.3.4.2 H_{tot}, Btu/h—Total enthalpy of makeup air supplied from the system.

12.3.4.3 E_{tree}, Btu/h—Energy of makeup air supplied from the test space.

12.3.4.4 E_{exh}, Btu/h—Energy of exhaust air leaving the test system.

12.3.4.5 M_{exh}, lb/min—Total exhaust mass flow rate.

12.4 *Calculation and Reporting of Test Results*—The preceding quantities are calculated for each tested exhaust rate, then reported for the specific hood/appliance(s) combination or exhaust flow rate, or plotted over the range of the tested exhaust rates. Average data over 2 h for thermostatically controlled appliances and 1 h for non-thermostatically controlled appliances. Whenever necessary, refer to 12.3 for the definition of symbols used throughout this test method. The complete description of relevant equations is provided in Appendix X1.

12.4.1 Energy rates can be reported for a particular hood/appliance(s) system at a specific exhaust flow rate with associated uncertainty.

12.4.2 The data can be used to generate energy rate curves over a range of flow rates. It is useful to make two graphs for each test run. The first graph is a plot of actual total appliance(s) energy consumption, energy exhausted, energy to food (if any), and heat gain versus flow rate. It is the global picture of energy consumed by the appliance(s) and all uses/dispositions of this energy. The second graph is just the heat gain curve with an expanded scale versus flow rate. The shape of this curve is a description of the overall performance of the hood, appliance(s), and supply air combination. Theoretically, there will be an inflection point corresponding to the flow rate for minimum capture and containment. This inflection point exists because at flow rates above minimum capture and containment, heat transfer to the space is mainly by radiation, however, it appears as a smooth curve due to the marginal effect of spillage. At flow rates lower than this point, heat transfer to the space is increased dramatically by convection, as well as radiation. The modes of heat gain is shown in Fig. 7.

12.4.3 For gas appliances, the energy consumption rate E_{app} (gas), corrected to standard atmospheric pressure of 29.921 in. Hg and standard temperature of 60°F is calculated using Eq 1 as follows:

$$E_{app}\,(\text{Btu/h}) = 60 \times cfm_{gas} \times HV \times T_{cf} \times P_{cf} \tag{1}$$

where:

HV = higher heating value of gas,
= total energy content of gas, Btu/ft^3, measured at
= standard conditions of 60°F and 29.921 in. Hg,
cfm_{gas} = ft^3 of gas consumed/min,
$= \dfrac{\text{volume of gas consumed }(ft^3)}{\text{test time}(min)}$

Tcf = temperature correction factor,
$= \dfrac{\text{absolute standard temperature }(°R)}{\text{absolute gas temperature }(°R)}$

= 520/[T$_{gas}$ + 460],
T_{gas} = gas temperature, °F,
Pcf = pressure correction factor to 29.921 in. Hg,
$= \dfrac{\text{absolute gas pressure }(in.\ Hg)}{\text{standard gas pressure }(in.\ Hg)}$

= $[Bp + P_{gas}]/[29.921]$,
Bp = ambient barometric pressure, in. Hg, and
P_{gas} = gas line gage pressure, in. Hg.

12.4.4 For electric appliances, the energy consumption rate E_{app} (elec), measured by a kWh meter or its equivalent and converted from kWh to Btu/h using Eq 2:

$$E_{app}\,(\text{Btu/h}) = \frac{\text{kWh }(measured) \times 3413\,(Btu/kWh) \times 60\,(min/h)}{\text{test time }(min)} \tag{2}$$

12.4.5 Controls energy, E$_{ctrl}$, is measured by meter measurement of electric energy consumed by controls, fans, or other accessories of cooking appliances. This energy is converted from kWh to Btu/h using the formula given in 12.4.4. For electric appliances, E$_{ctrl}$ is set to zero if it is measured as part of E$_{app}$.

12.4.6 The specific heat of makeup air, C$_p$, is determined using Eq 3:

$$Cp\,(\text{Btu/lb}_\text{a}\cdot°\text{F}) = C_{pa} + W_{sup}C_{pv} \tag{3}$$

where:

C_{pa} = specific heat of dry air, 0.24 Btu/(lb$_a$·°F),
C_{pv} = specific heat of water vapor, 0.44 Btu/(lb$_a$·°F), and
W_{sup} = humidity ratio of supply (makeup) air, lb$_v$/lb$_a$.

The humidity ratio W_{sup} is the equivalent ratio of the mixed airstream of makeup air supplied from the hood and test space and is dependent on temperature and pressure. For a typical HVAC calculation, a value of W_{sup} = 0.01 lb$_v$/lb$_a$ is often used and when substituted into the above equation, a value of C_p = 0.244 Btu/(lb$_a$·°F) is obtained. The use of this value results in a maximum error of ±2 % in enthalpy calculation. If desired, Appendix X1 outlines a comprehensive procedure for computing the actual humidity ratio.

12.4.7 Energy exhaust rate, E$_{exh}$, under idle and cooking conditions is computed using Eq 4:

$$E_{exh} = m_{sup} \times C_p[T_{exh} - T_{tree}] + \alpha E_{app} \tag{4}$$

where:

α = 0 for electric appliances, and 0.096 for hooded gas appliances,
m_{sup} = mass flow rate of total makeup air, lb$_a$/h,

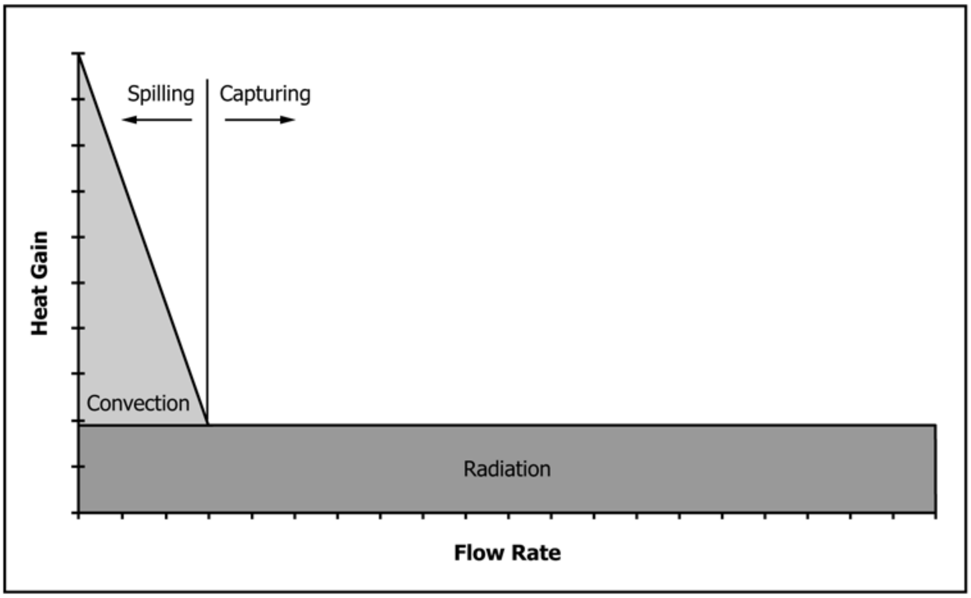

FIG. 7 Theoretical View of Heat Gain—Convective/Radiant Split

= $60 \times 0.075\ lb_a/ft^3 \times (scfm_{tree})$,
$scfm_{tree}$ = ft^3/min of makeup air from test space cfm_{tree} corrected to standard density air,
T_{exh} = average dry bulb temperature of exhaust air, °F,
T_{tree} = average dry bulb temperature of makeup air supplied from the test space, °F, and
C_p = specific heat of makeup air as determined from 12.4.6, Btu/lb_a°F.

Appendix X1 provides a comprehensive procedure for correcting the air flow rate cfm_{tree} to standard density air.

NOTE 12—Under cooking conditions, the energy used to vaporize water from food $E_{food,lat}$ is also part of the energy exhausted, but E_{food} is treated as a separate energy term to ease its representation graphically on the overall performance chart and because of its significance in calculating other performance variables in ASTM test methods.

12.4.8 Heat gain from appliance(s) under hood in idle mode, HG_{idle} is given in Eq 5:

$$HG_{idle} = [E_{app} + E_{ctrl}] - E_{exh} \tag{5}$$

12.4.9 Energy to food, E_{food}, for cooking tests, some of the appliance(s) energy is used to vaporize water in food, $E_{food,lat}$ (Btu), and some additional energy is used to add sensible heat to the food, $E_{food,sens}$ (Btu). These quantities and perhaps other components are measured and calculated in accordance with Appliance Performance Test Methods, and converted to energy rate using Eq 6 as follows:

$$E_{food}\,(\text{Btu/h}) = \frac{E_{food,lat} + E_{food,sens}}{\text{test time}\,(min) \times 60\,(min/h)} \tag{6}$$

12.4.10 Heat gain from appliances under hood in cooking mode, HG_{cook} is given by Eq 7:

$$HG_{cook} = [E_{app} + E_{ctrl}] - E_{exh} - E_{food} \tag{7}$$

12.4.11 Normalize the flow rate to the length of the hood used during testing, and enter it in Table 1.

$$\text{scfm/linear ft} = \text{scfm/length of hood}(ft) \tag{8}$$

12.4.12 As calculations of energy quantities are performed, values are entered in Table 1.

12.4.13 Repeat the preceding calculations for all tested flow rates. Table 1 will be used for the reporting of test results.

12.4.14 Report energy rates for a particular hood/appliance(s) system at a specific exhaust flow rate in accordance with Table 1, Note 1.

12.4.15 *Graphing the Energy Rate Results*—As indicated in 12.4.2, the energy quantities are plotted against the flow rate. Two curves are generated, one that shows the global energy balance curve, and the other shows the heat gain curve only on an expanded scale. The shape of the later curve indicates the overall energy performance of the hood/appliance/replacement air system. The magnitude of the energy gain curve can be used to estimate the cooling load. Typically, under stable laboratory conditions, there is smooth rise in the heat gain curve. This corresponds to the range of capture and containment. The threshold for capture and containment is found through flow visualization.

12.4.15.1 *Global Energy Balance Curves*—Using Table 1, for idle tests, plot the total energy consumed by the appliance(s) $E_{app} + E_{ctrl}$, and HG_{idle} all in units of kBtu/h against their corresponding flow rate in units of scfm/linear ft. Once all test points are plotted, the region bounded between the appliance energy curve and the heat gain curve is energy exhausted, E_{exh}. For cooking tests, however, graphing is done the same way as for idle tests except for one additional added energy quantity. This energy is the difference between appliance total energy consumption and energy-to-food. This also is plotted against the flow rate. The resultant region bounded between appliance total energy consumption and the stated difference is energy-to-food, and the resultant region bounded between the stated difference and heat gain curve is energy exhausted. A generic global (overall) energy balance chart for idle condition is shown in Fig. 8.

12.4.15.2 *Heat Gain Curve*—Using Table 1, for idle or cooking tests, plot the heat gain HG_{idle} in units of kBtu/h against their corresponding flow rate in scfm/linear ft. A generic heat gain curve for idle condition is shown in Fig. 9.

NOTE 13—A minimum of six data points are required to generate a curve. The curve must fit the functional: $E_{hg} = A + B \times e^{-(C \times cfm/linft)}$, where: A, B, and C are constants. Actual test results must be shown on the chart along with a 95 % confidence band. In accordance with ASTM requirements, test results that need to be fitted with a curve must be validated before they can be published. Validation is done by meeting uncertainty requirements stated in Section 13 for the results of each test point. The curves must comply with the requirements of 8.2 of ASHRAE Guideline 2-1986 (RA90). Only those curves that are validated can be published as complying with ASTM requirements.

13. Precision and Bias

13.1 *Precision:*

13.1.1 *Repeatability (Within Laboratory, Same Operator and Equipment):*

13.1.1.1 For exhaust energy rate E_{exh}, the percent uncertainty has been determined to be no greater than ±10 %.

TABLE 1 Sample Table of Results

NOTE 1—In accordance with ASTM requirements, test results must be validated before they can be published. Validation of results for each test point is done by meeting uncertainty requirements stated in Section 13 and detailed in Annex A1. To determine the uncertainty at each test point, results must be based on the average of at least three tests to obtain the required uncertainty. Only those test points that are validated can be published as complying with ASTM requirements. Results that are not validated in accordance with the preceding procedure must be identified as not meeting ASTM requirements if published in the same context as other points that do claim to meet the ASTM requirements.

Idle or Cooking Test	Q_{exh}, scfm/linear ft	$E_{app} + E_{ctrl}$, kBtu/h	E_{food}, kBtu/h	E_{exh}, kBtu/h	HG_{idle}, kBtu/h
cfm_1			if applicable		
cfm_2			if applicable		
cfm_3			if applicable		
cfm_4			if applicable		
cfm_n			if applicable		

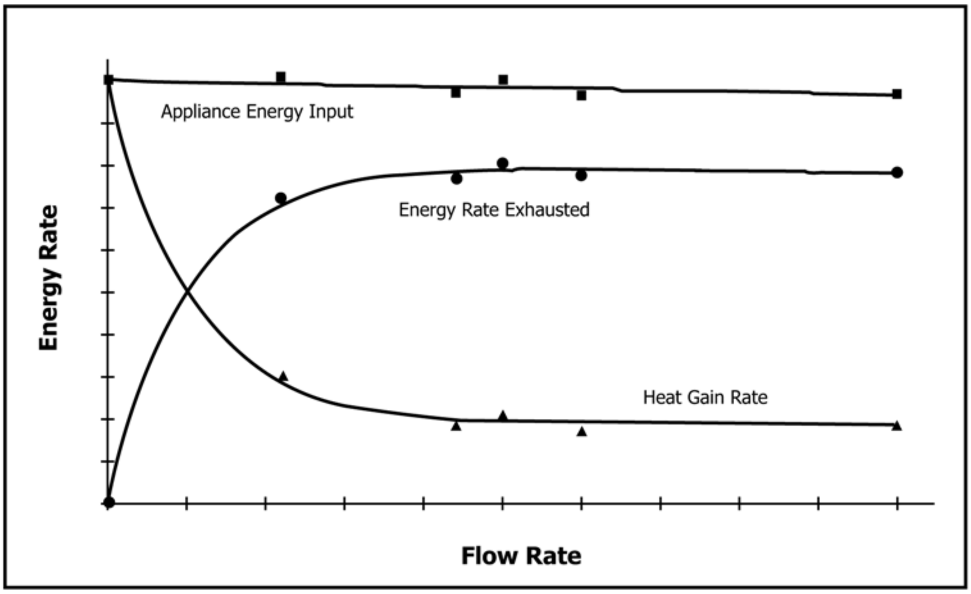

FIG. 8 Overall Energy Balance—Idle Condition

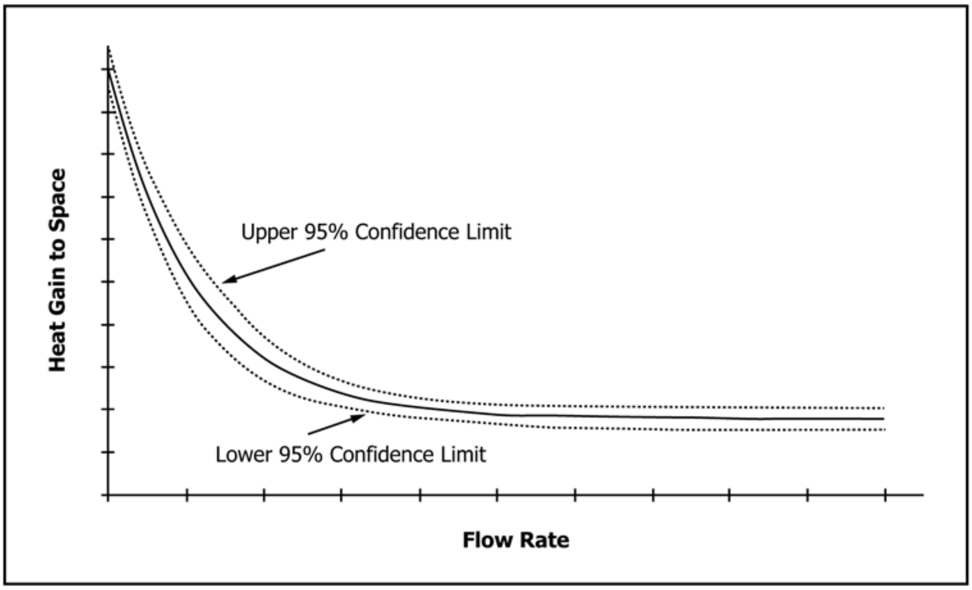

FIG. 9 Heat Gain Curve with Confidence Limits—Typical

13.1.1.2 For energy-to-food rate results E_{food}, based on ASTM test methods, the percent uncertainty in each result, based on at least three test runs, has been determined to be no greater than ±15 %.

13.1.1.3 For appliance(s) energy consumption rate E_{app}, the percent uncertainty has been determined to be no greater than ±10 %.

13.1.1.4 Accordingly, the percent uncertainty in heat gain is impacted by input uncertainties and shall be reported.

13.1.2 *Reproducibility (Multiple Laboratories)*—The interlaboratory precision of the procedures in this test method for measuring each reported parameter is being determined.

13.2 *Bias*—No statement can be made concerning the bias of the procedures in this test method because there are no accepted reference values for the parameters reported.

14. Keywords

14.1 appliances; commercial kitchen ventilation; cooling load; heat gain; test method

ANNEX

(Mandatory Information)

A1. UNCERTAINTY IN REPORTED TEST RESULTS

NOTE A1.1—The procedure described as follows is based on the method for determining the confidence interval for the average of several test results discussed in ASHRAE Guideline 2-1986 (RA96) (see 2.2). It only should be applied to test results that have been obtained within the tolerances specified in this test method.

A1.1 For the heat gain procedure, results are reported for the heat gain under idle condition HG_{idle}, or cooking condition HG_{cook}, or both. Each reported as an average of at least three test runs. The heat gain curve must include a minimum of six test flow rates, namely cfm_1 through cfm_n as defined in Table 1. In addition, the uncertainty in each of the following variables is calculated: appliance energy consumption rate E_{app}, energy exhausted E_{exh}, and heat gain HG_{idle} or HG_{cook}, or both. If the calculated uncertainty in one of the stated variables exceeds its maximum allowable uncertainty, additional test runs at the same condition are required until the uncertainty in each variable falls within its maximum allowable range.

A1.1.1 The uncertainty for each variable is calculated after the test run has been repeated three times. Then, it is checked against the maximum allowable uncertainty specified for the variable. If uncertainty in one variable exceeds its maximum allowable uncertainty, the test run is repeated and the uncertainty based on four runs is calculated and verified again. This process is continued until the uncertainty of each variable falls within its maximum allowable range.

NOTE A1.2—Verification tests that are spread over a long time span (several months) help evaluate environmental impacts like seasonal climatic changes.

A1.2 The uncertainty in a reported result helps to evaluate its precision. If, for example, the HG_{idle} is 20 kBtu/h, the uncertainty calculated for this variable in this test method was ±20 % or ±4 kBtu/h. This means that the true HG_{idle} is within the interval between 16 and 24 kBtu/h. This interval is determined at the 95 % confidence level, which means that there is only a 1 in 20 chance that the true HG_{idle} could be outside of this interval.

A1.3 Calculating the uncertainty not only guarantees the maximum uncertainty in the reported result but also is used to determine how many test runs are needed to satisfy this requirement. The uncertainty is calculated by multiplying the standard deviation of three or more test runs by a factor from Table A1.1, which depends on the number of test runs used to compute the average. The percent uncertainty is the ratio of the uncertainty to the average expressed as a percent.

A1.4 *Procedure:*

A1.4.1 The following procedure is provided for calculating uncertainty. It shall be carried out for the variables stated in A1.1. The uncertainty in the variables must be determined for at least two test flow rates.

TABLE A1.1 Uncertainty Factors

Number of Test Runs, n	Uncertainty Factor, C_n
3	2.48
4	1.59
5	1.24
6	1.05
7	0.92
8	0.84
9	0.77
10	0.72

A1.4.1.1 *Step 1*—Using the results of the first three test runs, calculate the average and standard deviation of each variable.

NOTE A1.3—The following formulas may be used to calculate the average and sample standard deviation. It is recommended, however, that a calculator with statistical function be used. If one is used, be sure to use the sample standard deviation function. Using the population standard deviation function will result in an error in the uncertainty.

The average of the variable based on three test runs is calculated as follows:

$$Xa_3 = \left(1/3\right) \times \left(X_1 + X_2 + X_3\right) \quad (A1.1)$$

where:

Xa_3 = average of results of the three test runs, and
X_1 , X_2, X_3 = results of the variable from Test Runs 1 through 3.

A1.4.1.2 The sample standard deviation of the variable based on the three test runs is given as follows:

$$S_3 \left(1/\sqrt{2}\right) \times \sqrt{\left(A_3 - B_3\right)} \quad (A1.2)$$

where:

S_3 = standard deviation of the variable based on three test runs,
A_3 = $(X_1)^2 + (X_2)^2 + (X_3)^2$, and
B_3 = $(1/3) \times (X_1 + X_2 + X_3)^2$.

A1.4.2 *Step 2*—Calculate the absolute uncertainty in each variable. From Table A1.1, look up the uncertainty factor for three test runs, then multiply the standard deviation computed in Step 1 by that factor:

$$U_3 = C_3 \times S_3 \quad (A1.3)$$

$$= 2.48 \times S_3$$

where:

U_3 = absolute uncertainty in the average value of the variable based on three test runs, and
C_3 = uncertainty factor for three test runs from Table A1.1.

A1.4.3 *Step 3*—Calculate the percent uncertainty in each variable using the average of the three test runs obtained from Step 1 and the absolute uncertainty from Step 2:

$$\%\ U_3 = \left(U_3/Xa_3\right) \times 100\ \% \quad (A1.4)$$

where:

$\% U_3$ = percent uncertainty in the average value of the variable based on three test runs.

A1.4.4 *Step 4*—If the percent uncertainty in each variable stated in Section 13 is within the maximum allowable uncertainty specified for the variable, then report the average of each variable obtained from Step 1 along with its uncertainty from Step 2 in the following format:

$$Xa_3 \pm U_3 \qquad (A1.5)$$

If the percent uncertainty in any one of the variables exceeds the maximum allowable uncertainty specified for that variable, then proceed to Step 5.

A1.4.5 *Step 5*—Run a fourth test for the test exhaust flow rate at which one of the variables calculated uncertainty exceeded its maximum allowable uncertainty.

A1.4.6 *Step 6*—Compute the average and the standard deviation of each variable based on the four test runs as follows:

$$Xa_4 = (1/4) \times (X_1 + X_2 + X_3 + X_4) \qquad (A1.6)$$

where:

Xa_4 = average of results of the four test runs, and

X_1, X_2, X_3, X_4 = results of the variable from Test Runs 1 through 4.

A1.4.6.1 The sample standard deviation of the variable based on four test runs is given as follows:

$$S_4 \left(1/\sqrt{3}\right) \times \sqrt{(A_4 - B_4)} \qquad (A1.7)$$

where:

S_4 = standard deviation of the variable based on four test runs,

A_4 = $(X_1)^2 + (X_2)^2 + (X_3)^2 + (X_4)^2$, and

B_4 = $(1/4) \times (X_1 + X_2 + X_3 + X_4)^2$.

A1.4.7 *Step 7*—Calculate the absolute uncertainty in each variable. From Table A1.1, look up the uncertainty factor for four test runs, then multiply the standard deviation computed in Step 1 by that factor:

$$U_4 = C_4 \times S_4 \qquad (A1.8)$$

$$= 1.59 \times S_4$$

where:

U_4 = absolute uncertainty in the average value of the variable based on four test runs, and

C_4 = uncertainty factor for four test runs from Table A1.1.

A1.4.8 *Step 8*—Calculate the percent uncertainty in each variable using the average of the four test runs obtained from Step 1 and the absolute uncertainty from Step 2:

$$\% U_4 = (U_4/Xa_4) \times 100\% \qquad (A1.9)$$

where:

$\% U_4$ = percent uncertainty in the average value of the variable based on four test runs.

A1.4.9 *Step 9*—If the percent uncertainty in each variable stated in Section 12 is within the maximum allowable uncertainty specified for the variable, then report the average of each variable obtained from Step 1 along with its uncertainty from Step 2 in the following format:

$$Xa_4 \pm U_4 \qquad (A1.10)$$

If the percent uncertainty in any one of the variables exceeds its maximum allowable uncertainty, then proceed to Step 10.

A1.4.10 *Step 10*—Run a fifth test for the test flow rate at which one of the variables calculated uncertainty exceeded its maximum allowable uncertainty. Then the calculation procedure is repeated over again for five test runs. The general formulas for calculating the average, standard deviation, absolute uncertainty, and percent uncertainty are listed as follows. These formulas shall be applied for each variable. The average of the variable based on "n" test runs is calculated as follows:

$$Xa_n = (1/n) \times \Sigma_i X_i \text{ for } i = 1 \text{ to } n \qquad (A1.11)$$

$$(1/n) \times (X_1 + X_2 + X_3 + X_4 + \ldots + X_n)$$

where:

Xa_n = average of results of n test runs, and

$X_1, X_2, X_3, X_4, \ldots, X_n$ = results of the variable from Test Runs 1 through n.

A1.4.10.1 The sample standard deviation of the variable based on n test runs is given as follows:

$$S_n\left(1/\sqrt{(n-1)}\right) \times \sqrt{(A_n - B_n)} \qquad (A1.12)$$

where:

S_n = standard deviation of the variable based on n test runs,

A_n = $(X_1)^2 + (X_2)^2 + (X_3)^2 + (X_4)^2 + \ldots + (X_n)^2$, and

B_n = $(1/n) \times (X_1 + X_2 + X_3 + X_4 + \ldots + X_n)^2$.

A1.4.10.2 The uncertainty in n test runs is given as follows:

$$U_n = C_n \times S_n \qquad (A1.13)$$

where:

U_n = absolute uncertainty in the average value of the variable based on n test runs, and

C_n = uncertainty factor for n test runs from Table A1.1.

A1.4.10.3 The percent uncertainty in each variable is calculated as follows:

$$\% U_n = (U_n/Xa_n) \times 100\% \qquad (A1.14)$$

where:

$\% U_n$ = percent uncertainty in the average value of the variable based on n test runs.

A1.4.10.4 Upon satisfying the uncertainty requirement for each variable based on n test runs, the average value of each variable is reported in the following format:

$$Xa_n \pm U_n \qquad (A1.15)$$

APPENDIXES

(Nonmandatory Information)

X1. ADDITIONAL EQUATIONS

X1.1 Throughout Appendix X1, equations are developed for exhaust-only systems (that is, hoods without integral supply). The schematic relationship of the test system energy quantities is shown in Fig. 6. Terms not defined in Appendix X1 are defined in Section 12.

X1.2 To describe the protocol mathematically, consider the energy balance of the test system shown in Fig. 4. Conservation of energy (first law of thermodynamics) states that the total amount of energy in a closed system remains constant. This can be written as follows:

$$\Sigma\, E_{in} - \Sigma\, E_{out} = \text{constant} \tag{X1.1}$$

where:

Σ = summation symbol.

X1.3 Referring to Fig. 4, neglecting losses, and considering idle condition, the sum of energy *in* includes energy from the appliances E_{app} and energy of air supplied from the test space at the tree E_{tree}. The sum of energy *out* is simply the energy exhausted E_{exh}. Thus, Eq X1.1 becomes:

$$(E_{app} + E_{tree}) - E_{exh} = HG_{idle} \tag{X1.2}$$

where the constant term is now replaced by heat gain, HG_{idle}.

X1.4 Introducing the specific enthalpy, h, and mass flow rate, m. Since $E = mh$, upon substitution, Eq X1.2 becomes:

$$E_{app} + m_{tree} h_{tree} - m_{exh} h_{exh} = HG_{idle} \tag{X1.3}$$

where:

m_{tree} = makeup air mass flow rate supplied from the test space, and
m_{exh} = total exhaust mass flow rate.

X1.5 Applying the law of conservation of mass,

$$m_{sup} = m_{tree} \tag{X1.4}$$

where:

m_{sup} = total makeup air mass flow rate supplied by the system.

X1.6 Upon substituting Eq X1.4, Eq X1.3 simplifies to the following:

$$HG_{idle} = E_{app} - m_{sup}\left[h_{exh} - h_{tree}\right] \tag{X1.5}$$

X1.7 The expression inside the brackets of Eq. X1.5 could be broken down into its sensible and latent heat components. Doing so, Eq X1.5 becomes the following:

$$HG_{idle} = E_{app} - m_{sup}\left[C_p(T_{exh} - T_{tree}) + \Delta h(W_{exh} - W_{tree})\right] \tag{X1.6}$$

where:

Δh = change of enthalpy required to vaporize or condense 1 lb of water, Btu/lb$_v$, and
C_p = specific heat of makeup air, Btu/lb°F.

X1.8 The humidity ratio of makeup air is the humidity ratio of the mixed airstream of makeup air supplied from the hood and test space. This is given by the following:

$$W_{sup} = W_{tree} \tag{X1.7}$$

X1.9 Substituting Eq X1.7 into Eq X1.6 to obtain the following:

$$HG_{idle} = E_{app} - m_{sup}\left[C_p(T_{exh} - T_{tree}) + \Delta h(W_{exh} - W_{sup})\right] \tag{X1.8}$$

X1.10 Generally, cooking appliances utilize electric energy (other than the energy used for heating elements on electric appliances) to power controls or other accessories associated with them. Using E_{ctrl} to represent this energy, Eq X1.8 becomes the following:

$$HG_{idle} = \left[E_{app} + E_{ctrl}\right] - m_{sup}\left[C_p(T_{exh} - T_{tree}) + \Delta h(W_{exh} - W_{sup})\right] \tag{X1.9}$$

X1.11 For electric appliances, E_{ctrl} is set to zero if it is measured as part of E_{app}. Eq X1.9 is the general equation that governs heat gain by the test space from the appliance(s). In practice, the energy consumed by gas appliances E_{app} is calculated based on the higher (gross) heating value of natural gas that includes latent energy loss, due to water evaporation during combustion. These latent losses amount to an average of 9.6 % of the gross energy. Under full-capture mode, these losses are part of energy exhausted. Thus, under idle condition, $m_{sup}\Delta h\ (W_{exh} - W_{sup})$ is equal to 0.096 E_{app} for gas appliances, and is equal to zero for electric appliances.

X1.12 Introducing the operator, α, define:

$$\alpha = 0 \text{ for electric appliance}(s),\ \textit{and} \tag{X1.10}$$

$$0.096 \text{ for hooded gas appliances.}$$

X1.12.1 Considering the preceding discussion and applying Eq X1.10 to Eq X1.9 to obtain the following:

$$HG_{idle} = \left[E_{app} + E_{ctrl}\right] - m_{sup} C_p \left[T_{exh} - T_{tree}\right] - \alpha E_{app} \tag{X1.11}$$

$$= E_{input} - E_{exh}$$

where:

E_{input} = E_{app} + E_{ctrl}, and
E_{exh} = $m_{sup}\ C_p\ [T_{exh} - T_{tree}] + \alpha E_{app}$

X1.13 If cooking tests are performed, some of the energy consumed by the appliance(s) is gained by the food. The primary components of heat gained by the food are sensible gain $E_{food,sens}$, and latent gain $E_{food,lat}$ which is part of the energy exhausted. These and other components of food energy are calculated in accordance with the test methods listed in Section 2, and must be subtracted from the right side of Eq X1.11. To minimize food energy from being released to the test space and be counted as part of the heat gain from the appliance, the cooked food is unloaded from the appliance and immediately placed either in a sealed and insulated container or removed outside the test space. Using E_{food} to represent total energy to food, Eq X1.11 becomes the following:

$$HG_{cook} = [E_{app}+E_{ctrl}] - m_{sup}C_p[T_{exh} - T_{tree}] \quad (X1.12)$$

$$-\alpha E_{app} - E_{food}$$

$$= E_{input} - E_{exh} - E_{food}$$

where:

E_{food} = $E_{food,lat} + E_{food,sens}$

X1.14 The humidity ratio of the total makeup air, W_{sup}, is dependent upon the humidity ratios of air supplied from test space, W_{tree}. The humidity ratio of the mixed airstream is calculated using the following equation:

$$W_{sup}(lb_v/lb_a) = W_{tree} \quad (X1.13)$$

The following procedures are used to compute humidity ratio of makeup air for use in Eq X1.13.

X1.15 *Computing the Humidity Ratio of Makeup Air From the Test Space W_{tree}:*

X1.15.1 From the steam table, look up the saturation pressure, P_{sat} (in. Hg), at the measured wet-bulb temperature $T_{w,tree}$, °F.

X1.15.2 Compute the humidity ratio at saturation, $W^*_{s,tree}$ as follows:

$$W^*_{s,tree} = 0.62198\,(P_{sat}/(Bp - P_{sat})) \quad (X1.14)$$

X1.15.3 Compute the humidity ratio W_{tree} as follows:

$$W_{tree}(lb_v/lb_a) = \frac{(1093 - 0.566\,T_{w,tree})\,W^*_{s,ih} - 0.240\,(T_{tree} - T_{w,tree})}{1093+0.444T_{tree} - T_{w,tree}} \quad (X1.15)$$

The following procedures are used to correct makeup air volumes to standard density air for use in Eq X1.13.

X1.16 *Correcting Makeup Air Volumes to Standard Density Air, $scfm_{tree}$:*

X1.16.1 Compute the specific volume of air supplied from the test space v_{tree} (ft^3/lb$_a$) as follows:

$$v_{tree} = (R_a\,(T_{tree}+459.67)/Bp)\,(1+1.6078\,W_{tree}) \quad (X1.16)$$

where:

R_a = gas constant for dry air, 53.352 ft·lb$_f$/(lb$_m$·°F).

X1.16.2 Correct air volumes to standard density air as follows:

$$scfm_{tree} = cfm_{tree}\,(13.33/v_{tree}) \quad (X1.17)$$

where:

cfm_{tree} = actual ft^3/min of air supplied from the test space.

X1.17 Using Eq X1.13, compute the equivalent humidity ratio W_{sup}. The following procedures are used to compute the specific and total enthalpy of makeup air.

X1.18 *Specific Enthalpy of Makeup Air, h_{tree}:*

X1.18.1 The specific enthalpy of makeup air supplied from the test space is computed as follows:

$$h_{tree} = 0.24T_{tree} + W_{tree}(1061+0.444T_{tree}) \quad (X1.18)$$

X1.18.2 The total enthalpy of makeup air supplied by the system is given as follows:

$$H_{tot} = m_{tree}h_{tree} \quad (X1.19)$$

where:

$$m_{tree} = 0.075 \times 60 \times scfm_{tree} \quad (X1.20)$$

X2. PROCEDURE FOR DETERMINING THE CONVECTIVE HEAT AND MOISTURE LOADS FROM COOKING PROCESSES

X2.1 Scope

X2.1.1 The test procedure in this appendix is used to determine the sensible convective and latent heat loads from an appliance or hood/appliance system.

X2.1.2 The test procedure in this appendix is not used to determine the sensible radiant heat load from a cooking process or recirculating system.

X2.2 Terminology

X2.2.1 *Definitions of Terms Specific to This Appendix:*

X2.2.1.1 *sensible heat, n*—heat added to a space corresponding to the change in dry bulb temperature transferred by conduction, convection, or radiation, or a combination thereof.

X2.2.1.2 *latent heat, n*—heat added to a space corresponding to the change in humidity ratio.

X2.2.1.3 *moisture gain, n*—moisture added to a space.

X2.2.1.4 *recirculating system, n*—system designed to capture and contain grease-laden effluent from a cooking process and does not exhaust to outside.

X2.3 Summary of Test Method

X2.3.1 This test method measures and calculates the sensible and convective heat, and moisture gain from cooking processes and recirculating systems.

X2.4 Significance and Use

X2.4.1 The heat and moisture loads can be used to determine the general ventilation requirements for the space.

X2.5 Apparatus

X2.5.1 *Capture Hood*—Install the capture hood in the room with 12-in. overhangs beyond the test appliance.

X2.5.2 *Appliances*—Locate appliance centered under capture hood.

X2.6 Preparation of Apparatus

X2.6.1 *Hood Capture and Containment*—Verify the hood capture and containment of the appliance thermal plume according to Test Method F1704.

X2.6.2 *Set Up*—Set up according to Fig. X2.1.

X2.6.2.1 *Energy Balance:*

$$E_{mua} - E_{exh} - E_{sensible\ radiant} + E_{appliance} = 0 \quad (X2.1)$$

Or:

$$E_{exh} - E_{mua} + E_{sensible\ radiant} = E_{appliance} \quad (X2.2)$$

where:

E_{mua} = the energy in the makeup air stream
$E_{sensible\ radiant}$ = the radiative energy from the appliance
$E_{exhaust}$ = the energy in the exhaust air stream (including sensible convective and latent)
$E_{appliance}$ = the energy input to the appliance

X2.6.2.2 Solving for heat loads gives:

$$q_{sensible\ convective\ load} = 1.08\,Q_{std}\left(T_{db-exh} - T_{db-mua}\right) \quad (X2.3)$$

$$q_{latent\ load} = 4840\,Q_{std}\left(W_{exh} - W_{mua}\right) \quad (X2.4)$$

X2.6.2.3 And for moisture load:

$$m_w = \frac{Q_{exh}\left(W_{exh} - W_{mua}\right)}{V_{exh}} \times 60 min/h \quad (X2.5)$$

where:

$q_{sensible\ convective\ load}$ = the convective sensible heat load to the space in Btu/h
$q_{latent\ load}$ = the convective latent heat load to the space in Btu/h
m_w = the moisture load to the space in lb_w/h
$Q_{exhaust}$ = the volumetric flow rate of the exhaust air stream in cfm
Q_{std} = the volumetric flow rate of the air stream at standard conditions in cfm
V_{exh} = specific volume of exhaust air stream ft^3/lb dry air
T_{db-mua} = the dry bulb temperature of the makeup air stream in °F

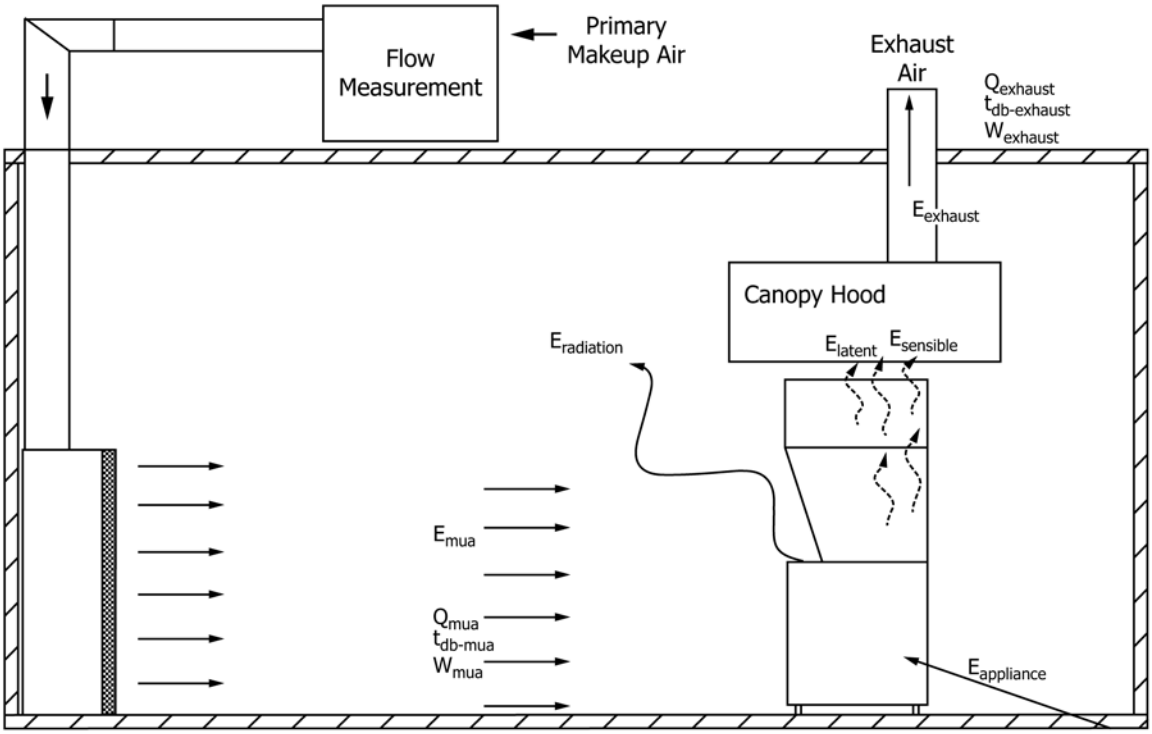

FIG. X2.1 Laboratory Energy Balance Diagram

$T_{db\text{-}exh}$ = the dry bulb temperature of the exhaust air stream in °F

W_{mua} = the humidity ratio of the makeup air stream in pound of water per pound of dry air

$W_{exhausted}$ = the humidity ratio of the exhaust air stream in pound of water per pound of dry air

X2.7 Procedure

X2.7.1 The appliance/hood system is operated for a sufficient period of time to ensure stabilization of the laboratory, hood, ductwork, and equipment temperatures, as specified in Section 11.

X2.8 Calculation and Report

X2.8.1 Measure dry bulb temperatures, dew point temperatures and calculate humidity ratios, airflow rates, specific volume of airstreams.

X2.8.2 Calculate convective sensible heat load to the space in Btu/h, convective latent heat load to the space in Btu/h and the moisture load to the space in lb_w/h according to Eq X2.3, Eq X2.4, and Eq X2.5, respectively.

X2.8.3 In addition to reporting the parameters in Section 12, report sensible convective load, latent load, moisture load, humidity ratios of makeup and exhaust airstreams, dew point temperature, and specific volume of exhaust air.

X2.9 Precision and Bias

X2.9.1 Determine according to Section 13.

REFERENCES

(1) Chapter 29, Non-Residential Cooling and Heating Load Calculations, 2001 *Fundamentals Handbook*, American Society of Heating, Refrigeration, and Air Conditioning Engineers, Atlanta, GA.

(2) *Cooling and Heating Load Calculation Manual*, American Society of Heating, Ventilation, and Air-Conditioning Engineers, Inc., Atlanta, GA, 1992 .

(3) Gordon, E.B., Horton, D.J., and Parvin, F.A., "Description of a Commercial Kitchen Ventilation (CKV) Laboratory Facility," *ASHRAE Transactions*, 101, 1995, (1).

(4) Soling, S.P., and Knapp, J., "Laboratory Design of Energy Efficient Exhaust Hoods," *ASHRAE Transactions* 91, 1985, (1).

(5) Gordon, E.B., Horton, D.J., and Parvin, F.A., "Development and Application of a Standard Test Method for the Performance of Exhaust Hoods with Commercial Cooking Appliances, *ASHRAE Transactions* 100, 1994, (2).

(6) Smith, V.A., Swierczyna, R.T., and Claar, C.N., "Application and Enhancement of the Standard Test Method for the Performance of Commercial Kitchen Ventilation Systems," *ASHRAE Transactions* 101, 1995, (2).