Implementing the Results of Ventilation Research
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Experimental Validation of ASHRAE SPC-129 Standard Method of Measuring Air Change Effectiveness

Francis (Bud) Offermann III, Martin T O'Flaherty, Marc A Waz, Nathan B Erlin

Indoor Environmental Engineering, 1448 Pine St, Suite 103, San Francisco, CA 94109, USA

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Francis (Bud) J. Offermann III PE CIH
Martin T. O'Flaherty, Marc A. Waz, and Nathan B. Erlin

Indoor Environmental Engineering
1448 Pine street, Suite 103
San Francisco, CA 94109
(415)-567-7700

SYNOPSIS. ASHRAE has developed a draft of a measurement standard, Standard 129, entitled "Standard Method of Measuring Air Change Effectiveness." This standard defines a method of measurement for measuring air change effectiveness in mechanically ventilated spaces, and provides a discussion of how the values of air change effectiveness may be used to demonstrate compliance with ASHRAE 62-1989.

Since Standard 129 defines relatively complicated tracer gas procedures for measuring air change effectiveness, the Standard Project Committee 129P and the cognizant technical committee (TC 5.3) have recommended an experimental evaluation of the measurement procedure. The objectives of the proposed work are to obtain information on the practicality of the measurement procedures and to quantify the precision of measured values of air change effectiveness.

The experimental test plan involves measuring the air change effectiveness at ten workstations in an 800 ft^2 office space mock up. Tests will be repeated under fixed temperature and airflow rate conditions ten times for the step up and ten times for the step down (decay) measurement methods. Sulfur hexafluoride will be used as the tracer gas and three different sample collection techniques will be used simultaneously; line sampling, grab sampling, and integrated bag sampling.

This paper presents our experimental protocol to evaluate this proposed new standard. Preliminary results will be presented at the meeting and the complete set of data will be published as an ASHRAE technical paper at an upcoming ASHRAE meeting.

1.0 INTRODUCTION. Today there is an increased interest in ventilation effectiveness being stimulated by the tremendous increase in the interest of indoor air quality and the general lack of information regarding the impact of ventilation effectiveness upon indoor air quality.

An early ventilation effectiveness parameter called "the mixing factor" was used to describe the mixing of outside air in a space as early as 1958 in the United States (ACGIH). This mixing factor was defined as the ratio of the effective air changes to the theoretical or nominal air changes. A 1960 article by Richard Brief suggested that the mixing factor "may vary from 1/3 to 1/10." He further cautioned that a mixing factor of 1/10 be used by individuals "not particularly familiar with the efficiency of air mixing within enclosed spaces." An early tracer gas study by Peter Drivas, reported mixing factors of 0.3 to 0.7. Following these early recommendations and experimental studies many researchers have cited values in this range when discussing outside air mixing factors.

However, it should be noted that the rather low mixing factor values reported in the Drivas study were obtained in laboratory test spaces with very high air exchange rates (e.g. 13-15 air changes per hour) where we would expect there to be difficulties in achieving good mixing conditions. Yoshiaki Ishizu noted in a 1980 paper that when the outside air flow rate "divided by the volume of the room increases, the mixing factor becomes smaller."

While we now have considerably much more experimental data regarding mixing of outside air in buildings, it is still just a drop in the bucket with perhaps less than a dozen building studies under very specific operating conditions and done using different measurement protocols. The little data available today suggests that for office systems operating at minimum outside percentages the mixing of outside air <u>in rooms</u> gives rise to ventilation rates not substantially different from that if there was perfect mixing (e.g. within 10-30%). Rather less data are available regarding mixing of outside air at the air handler although there have been reports of differences of as much as 30% as compared to perfect mixing. Some measurements of European non-recirculating displacement ventilation systems have reported air exchange rates in the occupied zone up to 30% higher than those predicted by perfect mixing.

Thus, while the impact of mixing upon the distribution of outside air may not be as significant as previously held (e.g. mixing factors of just 1/10 to 1/3), the possibilities of actual air exchange rates being even 20-30% less than that calculated assuming perfect mixing is sufficient to inspire the development of models to predict performance. The development of these models should be an exciting dance between the empirical researchers who provide the test data upon which the theoretical researchers may validate and improve their models. A standard measurement protocol for collecting field or laboratory data is desirable since it will provide a larger and more reliable data set for model validation and thus expedite the progress of the model development process.

Further driving the increased interest in ventilation effectiveness is the fact that this concept is connected to minimum outside air requirements set forth in the current ASHRAE Standard 62-1989, "Ventilation for Acceptable Indoor Air Quality." The minimum ventilation rates contained within Table 2 of Standard 62-1989, are based upon an assumption that the outdoor air being delivered to the space is perfectly mixed with the indoor air.

To this end, ASHRAE has developed a draft of a measurement standard, Standard 129, entitled "Standard Method of Measuring Air Change Effectiveness." This proposed standard defines a standard method of measurement for measuring air change effectiveness in mechanically ventilated spaces, and in Appendix B provides a discussion of how the values of air change effectiveness may be used to demonstrate compliance with ASHRAE 62-1989.

Since Standard 129 defines relatively complicated tracer gas procedures for measuring air change effectiveness, and is based upon the experience of a small number of researchers, the

Standard Project Committee 129P and the cognizant technical committee (TC 5.3) have recommended an experimental evaluation of the measurement procedure as defined in the RFP "Validation of Standard 129 - Standard Method of Measuring Air Change Effectiveness." The project being described here is in response to this RFP.

2.0 STUDY OBJECTIVES. The objectives of the proposed work are:

1.) to obtain information on the practicality of the measurement procedures in the draft of Standard 129 and to obtain recommendations that can be used to improve future versions of the standard; and

2.) to quantify the precision of measured values of air change effectiveness, when the measurement procedures specified in the draft of Standard 129 P are utilized.

3.0 TEST PROTOCOL. The following is our technical plan to conduct the work requested in 891-TRP. The following is a description of each of the tasks together with a description of our test facilities and instrumentation we propose to dedicate to this research project.

3.1 Task 1. Test Space Preparation. We will use a specially prepared test room that meets the criteria stipulated in Section 4 of the draft Standard 129. In addition the test space will be prepared to meet the following additional requirements:

a.) furnished with typical office furniture including desks, tables, chairs, and partitions.
b.) contain functional lighting and office equipment.
c.) contain 10 workstations and a floor area of at least 800 ft^2.
d.) have at least one adjoining indoor space.
e.) equipped with a typical air distribution system with multiple supply outlets and return grilles at or near ceiling height.

3.1.1 Test Space Description. The test space is located on the second floor of a three story office building. Indoor Environmental Engineering's offices and laboratory are located on the first floor. The floor area of the test space is 800 ft^2 and has a slab-to-slab ceiling height of 10.9 feet. A suspended ceiling is positioned 29 inches below the ceiling slab and holds the fluorescent lighting fixtures and supply air diffusers and return air grilles. The test space is adjoined on three sides by other indoor spaces and an exterior wall on one side. The test space has been pressurized to identify any leaks between the space and adjacent spaces and these leaks have been sealed. An instrument room for the tracer gas equipment and data acquisition system are located in the adjoining space immediately to the north of the test space.

3.1.2 Test Space Furnishings. The test space is furnished with 10 workstations as depicted in Figure 1. Each work station is equipped with a desk, chair, and partitions. In addition to these requested furnishings we propose to add simulated heat loads in place of real occupants and computer equipment. We propose to add two 100 watt heat loads, each contained within separate cubicle enclosures at each work station. This controlled approach will add a heat load similar to that of occupants and computers, but in a more repeatable and controlled manner. The test space is furnished with six fluorescent fixtures four bulb (four 34 watt bulbs per fixture) which are mounted in the suspended ceiling.

3.1.3 HVAC Equipment. The test space is equipped with a dedicated constant volume air handler which serves only the test space. The air handling unit is a basic fan coil unit suspended from the ceiling. Outside air is delivered to the mixing box where it mixes with return air which is drawn up through the return air grilles in the suspended ceiling. Outdoor air is delivered in a controlled manner by a separate forced air supply. Exhaust air is removed from the space also in a controlled manner by a separate forced air exhaust. Both exhaust and outside air flow rates are adjustable and the flow rates are monitored by orifice plate flow measuring stations.

Space temperature and supply/return air temperature difference is controlled by a proportional controller which controls an electric re-heat coil in the air handling unit. The supply and return air temperature difference is maintained within 1 °C. This temperature control is important since buoyancy effects are an important factor influencing the mixing of the supply air in the space.

3.1.4 Ventilation System Configuration for Tests. The repeat measurements of air change effectiveness requires that all airstrip flow rates be constant for the entire series of tests. This requirement is important, since one of the objectives of the series of repeat test is to determine the precision of the measurement method, and the flow rates of the air streams is an important variable in determining the air change effectiveness.

For these tests we propose to set the outside air delivery rate to the test space to 200 cfm. This corresponds to the minimum rate of 20 cfm/occupant (i.e. 10 workstations x 20 cfm/occupant) proposed by ASHRAE Standard 62-1989. We have selected this rate since it is under the minimum prescribed rates proposed by Standard 62-1989 that air change effectiveness becomes critical to meeting the minimum ventilation requirements.

We also plan to set the total supply air flow rate to the test space to 600 cfm. This corresponds to a moderate supply air circulation rate of 0.75 cfm/ft^2 and a relatively high outside air percentage in the supply air stream of 33%. A high air circulation rate with a low outside air percentage is not desirable for these tests since it will tend to create a well mixed space. Under well mixed conditions the repeated tests of air change effectiveness will predominantly be just a measure of the precision of the tracer gas sampling and analysis. In order for some of the more stochastic variables related to air mixing to come in to play, it is desirable to create a ventilation scenario where there is less than perfect mixing.

Thus, the relatively high nominal outside air exchange rate in combination with the relatively high outside air percentage proposed for these tests will insure a ventilation scenario that is not atypical of office spaces and is likely to create an air change effectiveness of less than unity.

3.2 Task 2. Instrumentation and Equipment Preparation. We propose to use sulfur hexafluoride (SF_6) gas as a tracer gas for all tests conducted in this study. SF_6 meets all of the criteria stipulated in Section 5.1 of the draft Standard 129. The following is a description of the analytical, sampling and injection equipment proposed for this study.

3.2.1 Tracer Gas Analysis Equipment. We propose to use a pair of gas chromatographs equipped with electron capture detectors. These instruments are highly sensitive and reliable gas analyzers which are microprocessor controlled. The linear measurement range of the instrument is 0.02 ppb to 20 ppb with a precision of ± 3 % of the measured value. We propose to calibrate the analyzer using specially prepared calibration gasses together with a precision gas divider. These calibrations span the range of concentrations (i.e. 0.05 ppb to 20 ppb) we are planning for the tests. All calibration gasses will be prepared to a tolerance of ± 2%.

3.2.2 Tracer Gas Sampling Equipment. As required in Parts 4 and 5 of the RFP Scope of Work, three different air sampling methods are required:

- direct sampling into the analyzer
- grab sampling followed by subsequent analyses and
- time integrated sampling with sample bags followed by subsequent analyses

The following describes the equipment we propose to use for each of these three sampling techniques.

• Direct sampling into the analyzer. We propose to use the microprocessor controlled multi-port sampling manifold built into each of the two chromatographs. Each chromatograph is capable of sequentially sampling from up to 9 different locations. We are proposing a total of twelve sample locations (i.e. breathing level at 10 workstations, in the single exhaust air stream at one location, and in the outside air stream). The simultaneous use of two gas chromatographs will allow for a sample analysis frequency of one sample every 45 seconds. We propose to use special 4mm OD, 3mm ID nylon tubing for transport of tracer gas samples to the chromatograph. This type of tubing, unlike Teflon tubing, is not prone to adsorbing or desorbing tracer gas from the sample.

• Grab sampling followed by subsequent analyses. We propose to collect grab samples using a 60 cc polypropylene slip-tip syringes. As with the direct sampling method, we propose to use special 4mm OD, 3mm ID nylon tubing for pump assisted transport of tracer gas samples to the syringe samplers. Samples will be withdrawn from the sample lines through a gas tight needle septa using a custom built 12 syringe sampling unit. The syringe samples will then be analyzed by installing the sample bags directly onto the inlet ports of chromatograph, which will sequentially transfer the samples for analysis.

• Time integrated sampling with sample bags followed by subsequent analyses. We propose to use 1 Liter Tedlar (2 mil) bags to collect time integrated samples. Air samples will be transported into the bags at a constant rate using 33 RPM peristaltic pumps fitted with Norprene tubing. The sample flow rates of the peristaltic pumps will be set for a constant sampling rate in the range of 3 to 5 cc/min.

3.2.3 Tracer Gas Sampling Locations. We are proposing to measure the tracer gas concentration at seated breathing height (i.e. 4 feet above the floor) at each of the ten workstations. The 4 mm OD nylon sampling lines and integrated bag samplers will be attached to a guide wire strung between the floor and sealing at each workstation seat. We will also measure the tracer gas concentration in the exhaust air stream at a position downstream of the orifice plate (i.e. to insure good mixing) and upstream of the exhaust fan (i.e. to avoid effects from any air leakage). The 4 mm OD nylon sampling lines and integrated bag samplers will be attached to a multipoint air sampling manifold installed in the exhaust duct in a manner to insure a representative sample of the tracer gas concentration as required in Section 5.4.4 of the draft Standard 129. The use of sealed PVC pipe will insure that the exhaust air concentration is not effected by air leakage.

3.2.4 Tracer Gas Injection Equipment. We propose to use a mass flow meter to provide a constant injection rate of tracer gas. The mass flow controller has a measurement precision of 0.2% full scale which exceeds the requirements set forth in Section 5.3.1 of the draft Standard 129. The inlet to the mass flow controller will be connected directly via 1/4 OD copper tubing to a pressure regulated supply of tracer gas from a compressed tank of tracer gas (i.e. 0.1% pure SF_6 balance air). The outlet of the mass flow controller will be connected directly via 1/4 OD copper tubing to a multipoint tracer gas injection manifold installed in the outside air upstream of both the outside air fan and orifice plate flow monitoring station in a manner to insure a uniform concentration of the tracer gas in the outside air stream. The data acquisition system will read the analog output of the mass flow controller once per minute in order to provide a detailed record of the tracer gas injection rate into the test space. We will validate the calibration of the mass flow controller using a bubble meter once before and once after the series of tests.

3.2.5 Air Flow Rate Measurement Equipment. We will measure the outside, exhaust, supply, and return air flow rates using methods described in ASHRAE 111-1988, ASHRAE 41.7-

1984, and ASHRAE 41.2-1987. We will monitor the exhaust and outside air flow rates with orifice plate flow measuring stations. The outside air and exhaust air ducts are six inch PVC pipe which has been specially sealed to be air tight. Orifice plate differential pressures will be monitored with electronic pressure transducers with analog outputs connected to the data acquisition system. We will measure the supply and return air flow rates as required in Section 6.3 of the draft Standard 129 using velocity traverses of the ducts. We will measure the supply air flow rate from each of the supply air diffusers and return air grilles using an electronic airflow capture hood. The airflow capture hood will be calibrated once before and once after the series of tests using an orifice plate flow measuring station.

3.2.6 Air Temperature Measurement Equipment. We will monitor the temperature in the supply and return air streams using resistance temperature detectors (RTD's) positioned in the air streams to provide a representative measurement of the air temperature.

3.2.7 Data Acquisition System. We will use an 12-bit 8-channel A/D converter (Strawberry Tree) connected to a Macintosh personal computer. As described in the above sections this data acquisition system will be used to collect once per minute the tracer gas injection rate, the outside air, exhaust air, and supply air flow rates, and the supply and return air temperatures. The accuracy of the data logger is ± 0.2 % of reading. Data will be backed up on hard disc as well as displayed in real time on the computer screen to facilitate monitoring of the test data during the tests. Tracer gas data will be collected by a separate personal computer connected to the chromatographs.

3.3 Task 3. QA/QC Measurements.

The QA/QC checks of the measurement system performance described in Sections 5.2.2 through 5.4.4.2 of the draft Standard 129. These QA/QC tests include the following tests:

- 5.2.2 Tracer Gas Analyzer Precision and Stability
- 5.2.3 Tracer Gas Analyzer Calibration
- 5.3.1 Tracer Gas Injection Rate Stability
- 5.3.2 Tracer Gas Injection System Leak Check
- 5.4.1 Sample Tubing Check
- 5.4.2 Grab Sampling Check
- 5.4.3 Time Integrated Sampling with Sample Bags Check
- 5.4.4 Representative Sampling from Airstreams Check

These QA/QC tests will be conducted once prior to any of the test space air change effectiveness measurements and once following the test space air change effectiveness measurements.

3.4 Task 4. Well Mixed Chamber Tests.

We propose to conduct the well mixed chamber tests as described in Section 5.7 of the draft Standard 129 four times as required in the RFP (Scope Item #3). We propose for these tests to use a small cubicle chamber with an air volume of 2 m^3. The size of this chamber will insure that the air samples withdrawn from the test chamber must not exceed 0.01 chamber volumes per hour as required in Section 5.7 of the draft Standard 129. The chamber is fabricated from plywood and is lined on this inside with 6 mil polyethylene which is sealed with an adhesive to the plywood to form an air tight enclosure.

We propose to supply the chamber with 1.0 air changes per hour of tracer free air at a constant rate. The outside air and exhaust air ducts are three inch PVC pipe which has been specially sealed to be air tight. Orifice plate differential pressures will be monitored with electronic pressure transducers with analog outputs connected to the data acquisition system. The data acquisition system will read the orifice plate pressure drops once per minute in order to provide a detailed record of the air flow rates into and out of the test chamber. A pair of mixing fans in the chamber will be used to insure complete mixing of the tracer gas in the chamber. As required in Section 5.7 of the draft Standard 129 the concentration of tracer gas will be monitored at eight locations in the chamber selected to be in the centroids of eight equal volumes of air. The tracer gas concentration will also be monitored in the exhaust air stream using a multipoint air sampling manifold installed in the exhaust duct in a manner to insure a representative sample of the tracer gas concentration as required in Section 5.4.4 of the draft Standard 129.

All three sampling methods (i.e. direct, grab, and integrated bag samples) will be performed simultaneously during the four repeated measurements of a tracer step up test and the four repeated measurements of a tracer decay test. These tests will be completed prior to any of the test space air change effectiveness measurements.

3.5 Task 5. Ten Repeated Step Up and Decay Tests.

We propose to conduct ten repeated step up and step down tests as described in Scope Items #4 and #5 of the RFP. The test space and instrumentation/equipment will be configured as proposed in Tasks 1 and 2. All three sampling methods (i.e. direct, grab, and integrated bag samples) will be performed simultaneously during these repeated tests. Internal heat loads, all air stream flow rates, and supply and return air temperatures will be kept constant for the entire series of tests within the limits specified in the draft standard.

4.0 REFERENCES

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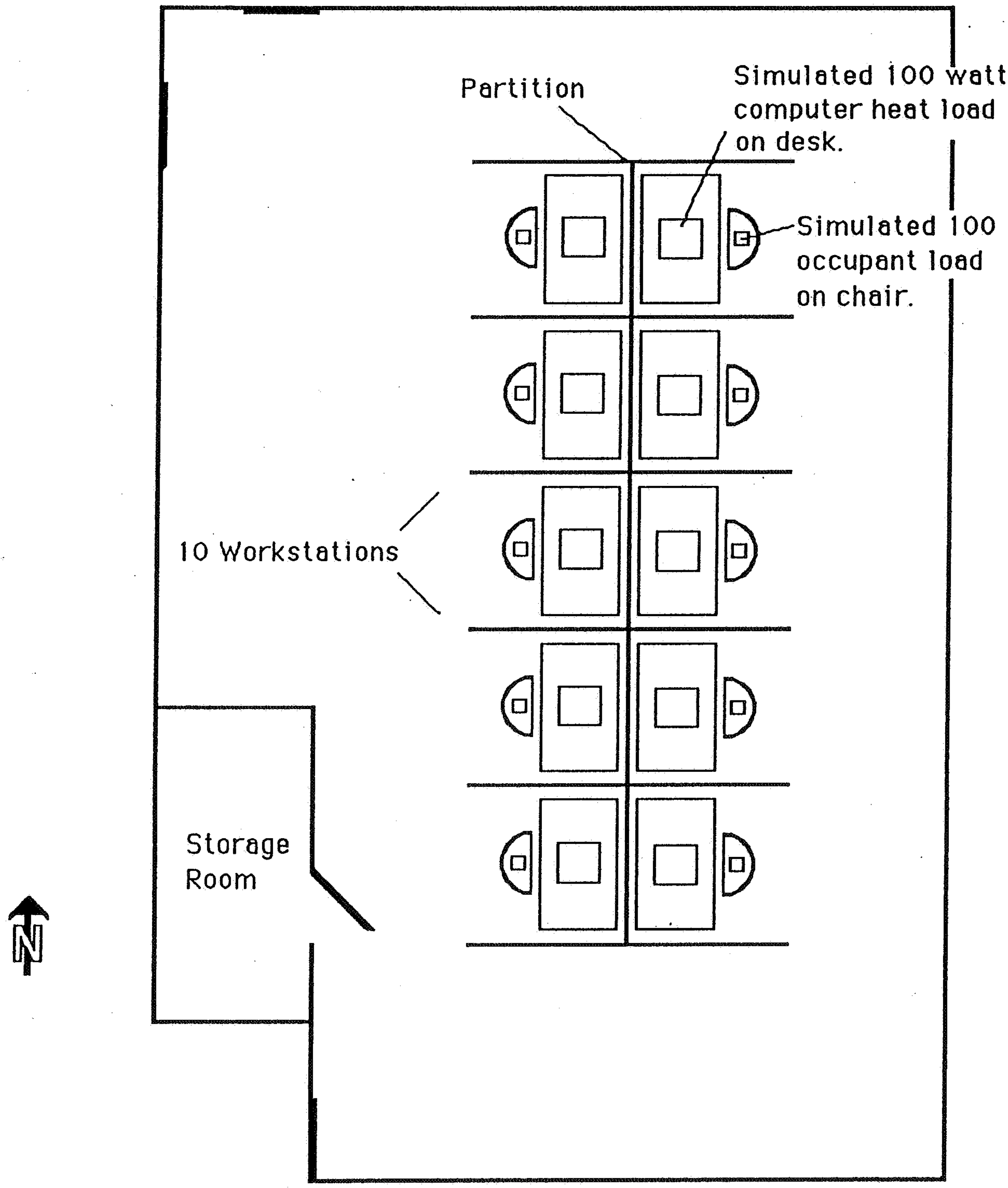

Figure 1. Floor plan of test space depicting the location of ten workstations with simulated people and computer heat loads.