A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

National Renewable Energy Laboratory
Innovation for Our Energy Future

Experimental Evaluation of Indoor Air Distribution in High-Performance Residential Buildings

Part I. General Descriptions and Qualification Tests

A.A. Jalalzadeh-Azar

With Contributions by Ed Hancock and Doug Powell

Technical Report
NREL/TP-550-40392
December 2007

NREL is operated by Midwest Research Institute • Battelle   Contract No. DE-AC36-99-GO10337

Experimental Evaluation of Indoor Air Distribution in High-Performance Residential Buildings

Part I. General Descriptions and Qualification Tests

A.A. Jalalzadeh-Azar

With Contributions by Ed Hancock and Doug Powell

Technical Report

NREL/TP-550-40392

December 2007

Prepared under Task No. BET78004

National Renewable Energy Laboratory

1617 Cole Boulevard, Golden, Colorado 80401-3393

303-275-3000 • www.nrel.gov

Operated for the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
by Midwest Research Institute • Battelle

Contract No. DE-AC36-99-GO10337

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

Nomenclature

$\overline{C}_{SF6,Room}$	Average tracer gas concentration in the test room, ppm
t	Time, minute
$T_{S.A.}$	Supply air temperature, R
$T_{R.A.}$	Return air temperature, R
$\dot{Q}$	Volumetric flow rate, cfm
V_{Room}	Volume of the test room, ft^3

Contents

Executive Summary

This report describes the experimental setup, procedure, and qualification tests implemented in the initial phase of a research project aimed at characterizing the air mixing performance of a prevalent air distribution system in heating season. The system of interest incorporates a high sidewall supply air (SA) diffuser and a low return air (RA) grille directly below. Potential poor air mixing performance is inherent with this type of air distribution in heating mode, particularly during the period of recovery from a setback in which the difference between the SA and the bulk room temperatures is more pronounced. The stratification formed under such conditions can be exacerbated in efficient homes that are conditioned by downsized HVAC systems with a reduced design flow rate. The objectives of the research project is to characterize the performance of this type of air distribution system under various operating conditions and to provide recommendations for improving the air mixing performance in efficient homes with respect to comfort and ventilation effectiveness.

The experimental facility consists of an instrumented test room, an apparatus for generating SA stream under various operating conditions, and data acquisition systems. A cooling system is available to precool the test room before each test, as necessary. The test room is an empty insulated enclosure and incorporates a high sidewall SA diffuser with no flow deflection and a wall-mounted, near-floor grille located directly below the diffuser. As described in this report, the initial phase of the project (1) addressed and minimized the uncertainties of the measuring devices and variables, (2) estimated the infiltration in the test room, and (3) discussed the results of the qualification tests. A number of these tests incorporated a tracer gas analysis in parallel with the evaluation of the temperature profiles in the test room. The purpose of these tests was to debug the experimental facility and to provide data and develop qualitative understanding of the system performance that could be used to define the scope of the subsequent phase of the project.

Introduction

As the Building America Program[1] (BAP) promotes higher levels of energy savings for high-performance residential buildings, a trend of HVAC system downsizing is emerging. This downsizing has resulted in a significant reduction in the design air flow rates of the central HVAC systems, raising issues regarding air distribution/diffusion effectiveness in energy-efficient homes. Most important are concerns about comfort, ventilation effectiveness, and HVAC system energy efficiency, which can be adversely affected by poor air distribution and diffusion caused by a reduction in design air flow rates and velocities of the supply air.

The main objective of this project is to experimentally characterize an air distribution system in heating mode during a period of recovery from setback. The specific air distribution system under evaluation incorporates a high sidewall supply-air (SA) register/diffuser and a near-floor wall return air (RA) grille directly below. With this arrangement, the highest temperature difference between the supply air and the room can occur during the recovery period and create a favorable condition for stratification. The experimental approach will provide realistic input data and results for verification of computational fluid dynamics modeling that will follow to encompass a wide range of scenarios encountered in real-world applications, addressing issues of comfort and ventilation effectiveness.

Figure 1 presents the major activities of this experimental project, along with the schedule. As seen in this figure, the experiments fall into two categories: "qualification tests" and "actual tests." The qualification tests are designed to primarily validate the experimental approach. This report describes the activities of a transitional period in which the qualification tests are concluded in preparation for the actual tests in the next phase. In this report, the experimental facility is described, and the results of preliminary tests are analyzed.

[1] Building America Program, www.eere.energy.gov/buildings/building_america/

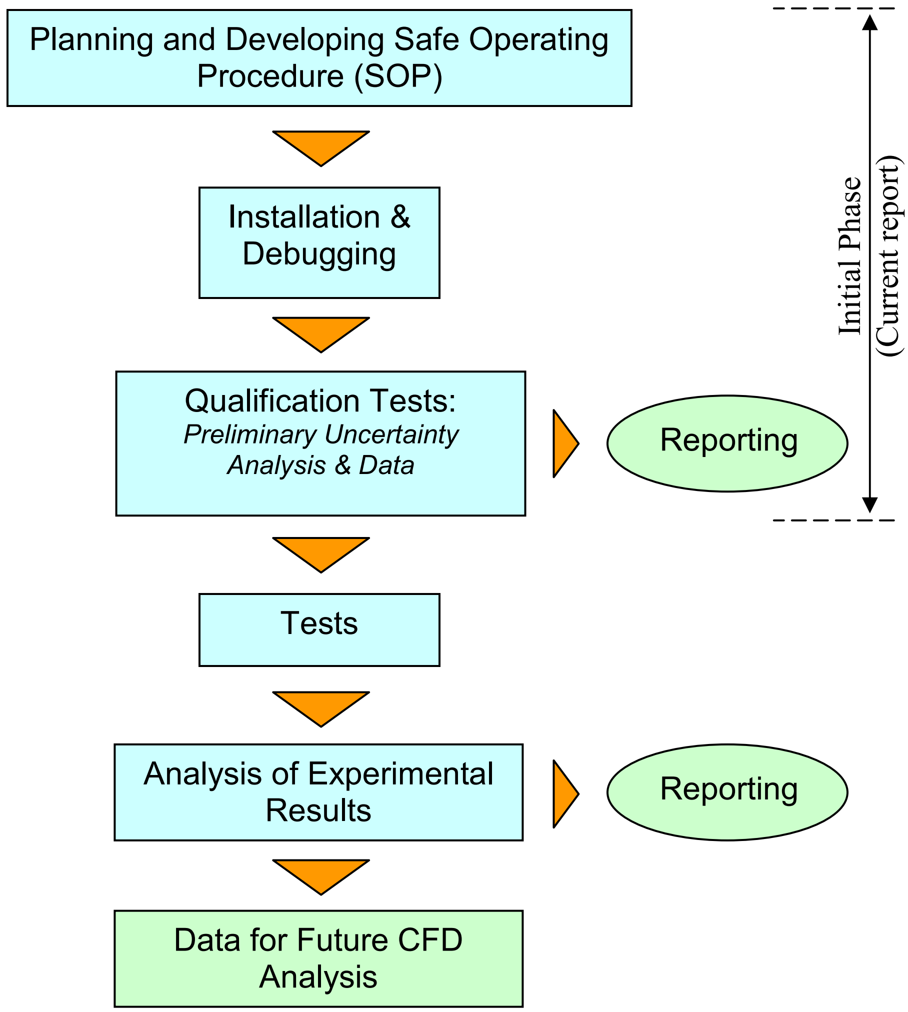

Figure 1. Project activities

Experimental Facility

An experimental facility was installed in compliance with the NREL Safe Operating Procedure[2] (Appendix A). Figures 2 and 3 provide the facility layout and the schematic of the experimental system, respectively. The apparatus consists of a SA fan with a variable frequency drive, a 6-kW electric heater, an SA plenum with a flow straightener (a 2-in. thick honeycomb plate) upstream of the register, a RA plenum downstream of the RA grille, an exhaust system, a tracer-gas (i.e., SF_6) injection system, and instruments for measuring the experimental variables at the principal points. A bypass line is installed to ensure stable SA conditions before commencing each test. The mode of operation (i.e., bypass versus normal) is set by an assembly of gate dampers. Figures 4, 5, and 6 further illustrate the components of the experimental system.

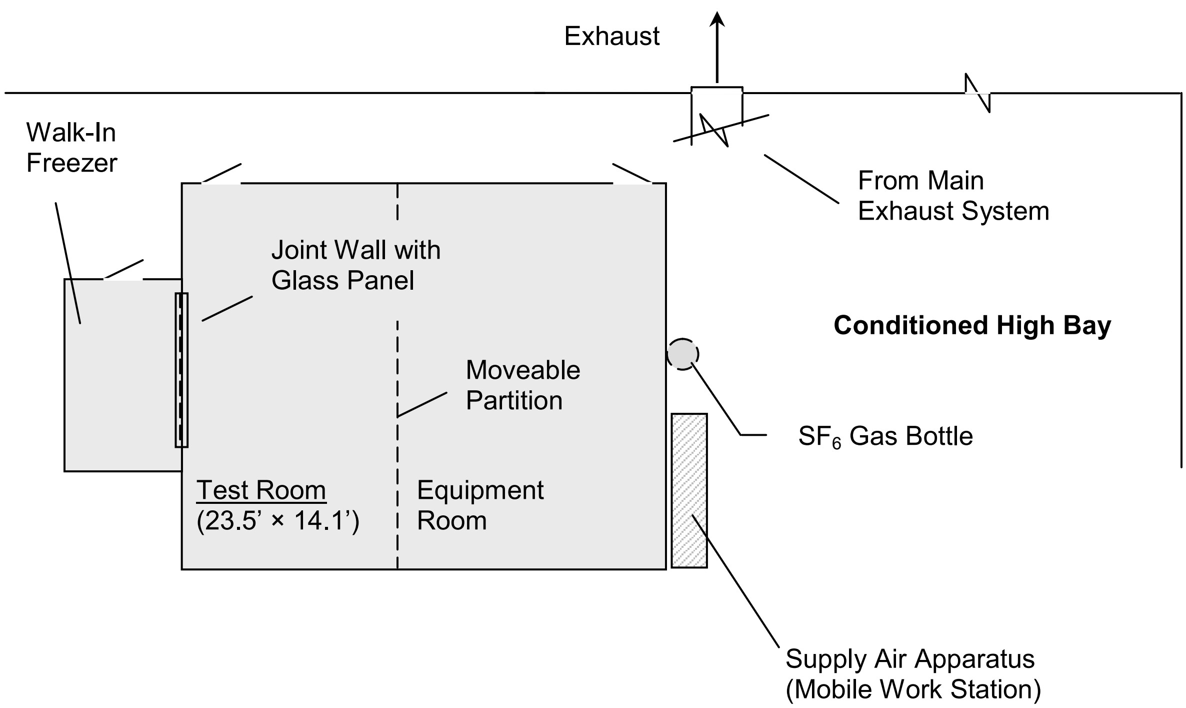

Figure 2. Test facility layout

[2] National Renewable Energy Laboratory. March 23, 2006. Safe Operating Procedure for Air Diffusion/Distribution Test Loop, SOP No. 748. Golden, Colorado: NREL.

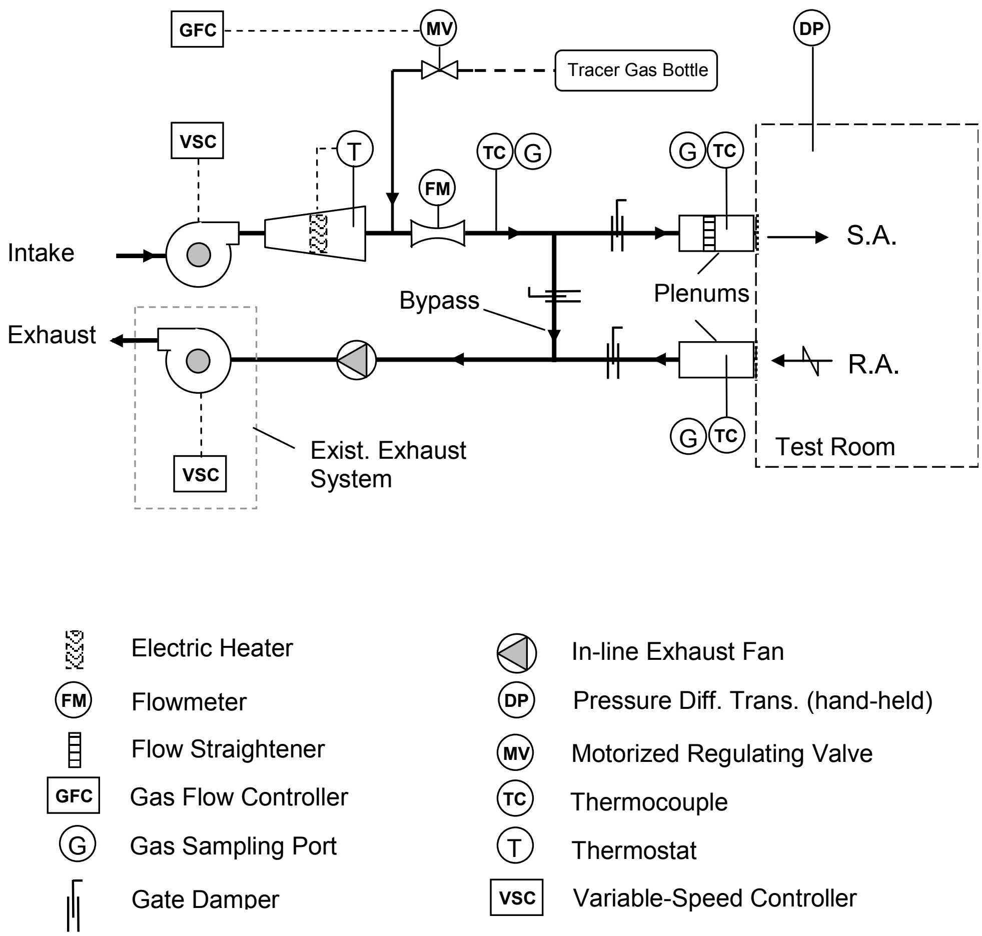

Figure 3. Schematic of experimental facility

Figure 4. Supply-air apparatus

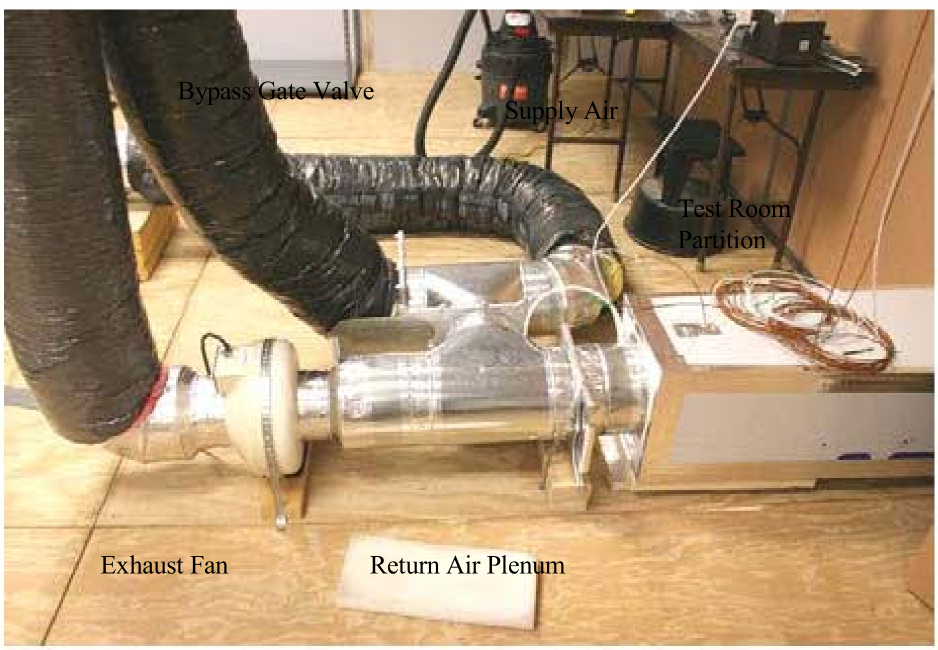

Figure 5. Flow bypass assembly

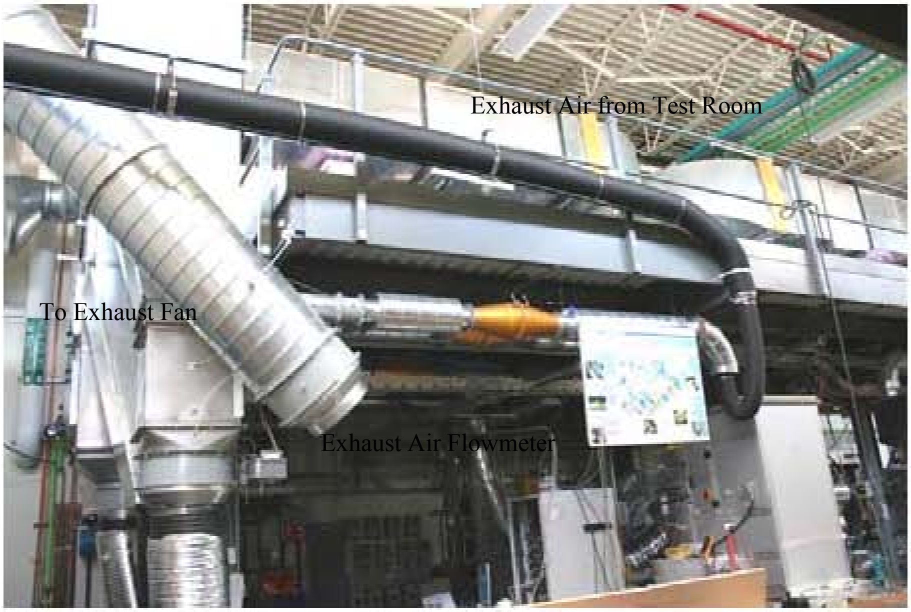

Figure 6. Exhaust system

The air from the test room is exhausted through an inline fan and a previously installed exhaust system, which is equipped with a variable-speed exhaust fan. The inline exhaust fan (Figures 3 and 5) with a flow capacity of 200 cfm is normally activated, whereas the secondary fan is normally turned off, unless it is needed to achieve higher flow rates through the test room and/or to accurately maintain the room pressure at a specific level.

The test room, measuring 23.5 ft × 14.1 ft × 9 ft, can be pre-cooled by circulating air between the room and the adjacent walk-in cooler, as illustrated in Figure 7 . A movable partition made of insulating foam boards (Gatorfoam Laminated Panel) separates the test room from the adjacent equipment room, as seen in Figures 2 and 7. The other walls of the test room are also well insulated, except for the glass portion of the joint wall between the test room and the walk-in cooler, which is intended to simulate heat loss through windows. However, the glass panel can be covered with insulating panels, as it is the case for the tests discussed in this report. To achieve spatial uniformity of the thermal properties within the test room at the beginning of each experiment, a portable mixing fan is utilized (not shown).

To evaluate the air distribution and diffusion within the test room, the following variables were measured:

- SA properties – flow rate, temperature, tracer gas concentration, and velocity profile (at the register).
- RA properties – flow rate (when necessary), temperature, and tracer gas concentration.
- Room air properties – a matrix of temperature measurements and limited tracer gas concentration measurements. (The pressure differential between the room and its surroundings is also measured in some experiments to address and control the infiltration/exfiltration.)

Figure 7. Test room

The measuring devices are described as follows:

- All the temperature variables are measured with T-type thermocouples, which are appropriate for the temperature range of interest (60^o to 140^oF). The temperature data are collected at 1-min intervals.
- The gas concentration measurements are taken by an INNOVA AirTech Instruments 1303 Multipoint Sampler and Doser. However, because (1) the ports are activated sequentially and (2) sampling and measuring the gas concentration takes about 2 minutes for each sample, only two of the ports are used in this project in order to minimize the time intervals at which the transient behavior of the gas concentration in the RA stream is captured. With this arrangement, each variable is measured at 4-min intervals. As for the SA stream, the gas concentration remains fairly constant because the SA flow rate and the amount of injected SF_6 are usually kept constant throughout each experiment. (The flow rate of the tracer gas is determined based on the SA flow rate setpoint and is maintained by an automatic valve and a flow-controlling device: PORTER Instrument CM-2 Module.) Therefore, a few measurements of the SA gas concentration throughout a given test (particularly at the beginning and the end) should be sufficient for tests involving a constant SA flow rate.
- The SA flow rate is measured through a flow nozzle with a TSI mass flowmeter.

A Campbell Scientific CR10 is used for data acquisition, except the tracer gas data. Up to 25 channels of this system are available for temperature measurements. The tracer gas data are collected independently by a different DAS system from INNOVA AirTech Instruments. The two DAS systems are controlled by two separate computers that are synchronized at the beginning of each experimental test.

Project Approach

Initially, a series of qualification tests are being conducted to achieve the following objectives:

- Fine-tuning the operation of experimental facility and mitigating/correcting potential problems, such as duct leakage and malfunctioning of equipment (valves, dampers, etc.)
- Debugging the instruments and data acquisition systems.
- Adjusting the electric heater's PID controller to provide a stable (non-oscillating) SA temperature and ensuring proper operation of the SA fan speed controller (variable-frequency drive).
- Identifying and quantifying sources of uncertainties with the measurements and performing preliminary uncertainty analyses.
- Analyzing the initial data to better define the future tests.

During the qualification phase, the "Auto Tuning" feature of the heater's controller at a given temperature setpoint was found to be quite effective in achieving a stable SA temperature (within less than $\pm$ 0.5^{o}F). However, any significant change to the setpoint resulted in an oscillatory SA temperature variation for a significant duration of time. The reliability of the SA fan VFD in adjusting the flow rate was also verified.

The experimental uncertainty analysis, which is important for meaningful and conclusive comparisons of the experimental and computational fluid dynamics results, will continue throughout the project.

In the early stages of the Qualification Tests, the indoor temperature measurements were limited to a few places along the centerline of the space. Later, a matrix was adopted to expand the temperature measurements in the test room, as illustrated in Figure 8. This test matrix will be further expanded to encompass other regions of the room as well.

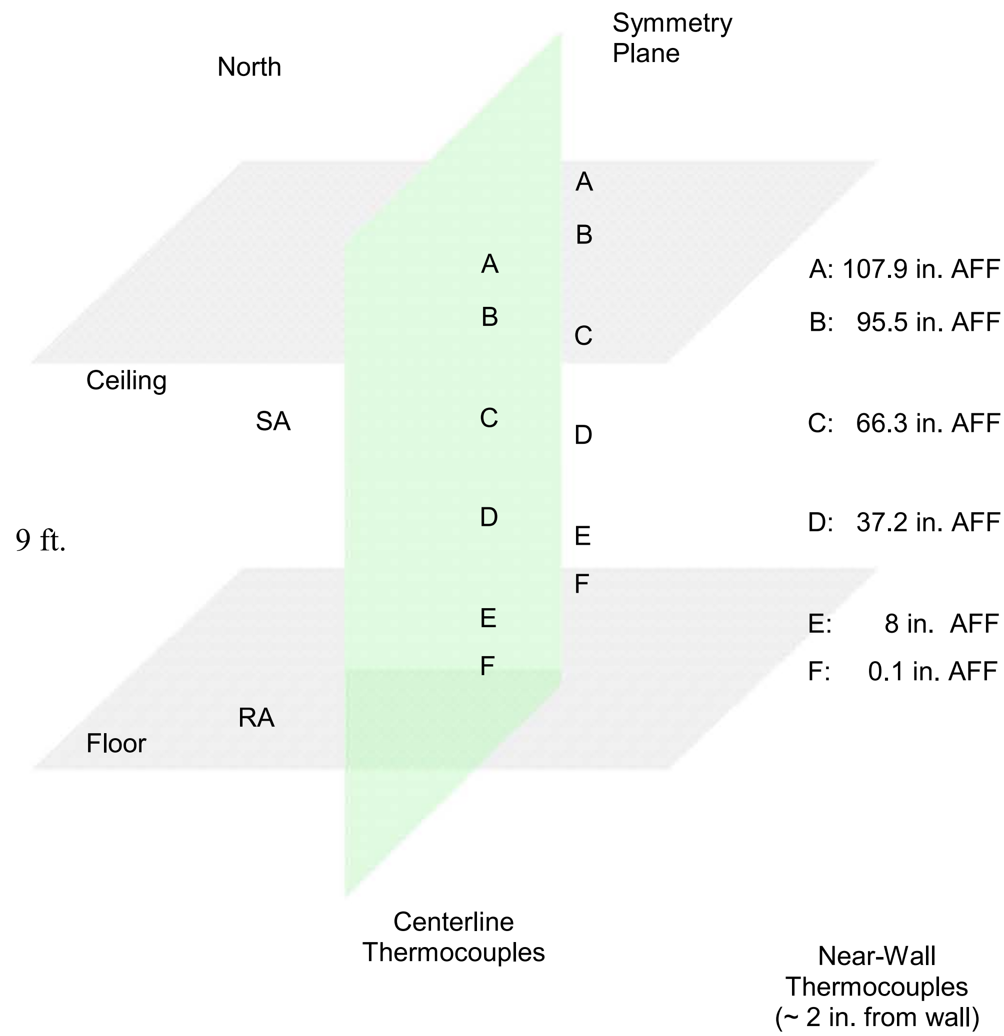

Figure 8. Test room instrumentation arrays

Preliminary Results and Discussions

Experimental data have been obtained for a number of tests as listed in Table 1 and described below.

Table 1. Summary of Preliminary Tests with Operating Conditions [(a)]

Experiment	SA Flow Rate (scfm)	SA Temp. in Plenum (°F)	Init. Rm Temp. (°F)	SA Gas Conc. (ppm)	SA Diffuser	Primary Objectives
Test #1 May 8, 06	85	110–115 [(b)]	64	0	8 × 4 [(c)]	IR Images (No tracer gas)
Test #2 May16, 06	95	105	65	9.6	8 × 4 [(c)]	SA and RA properties
Test #3 June 6, 06	95	105	67	9.6	8 × 4 [(c)]	Horizontal variation of tracer gas concentration Indoor temperature distribution
Test #4 June 8, 06	95	75	75	9.6	8 × 4 [(c)]	Isothermal test Vertical variation of tracer gas in test room
Test #5 June 14, 06	56	105	68	17.1	8 × 4 [(c)]	Vertical variation of tracer gas Indoor temp distribution

Notes:
[a] See the test results for variation of operating conditions throughout the test.
[b] The SA temperature was oscillating – the test was completed before adjusting the PID controller of the heater.
[c] J&J 90 V, 8 in. × 4 in., 0° deflection.

Test #1 (May 8, 2006)

In this test, the temperature distribution in the test room was evaluated using an IR camera. The SA flow rate was initially set at about 85–90 scfm when the bypass damper was open (no flow through the test room). Once the temperature reached the setpoint, the SA stream was allowed to flow into the room. As a result of an increase in the flow-path resistance, the flow rate decreased to about 83 scfm. The pressure difference between the test room and its surroundings was found to be virtually zero (-0.008 in.w. in the bypass mode and 0.0004 in.w. in the normal-flow test mode).

Because this test took place before adjusting the PID controller of the SA heater, the SA temperature oscillated in a sinusoidal fashion. The following compares the oscillatory SA temperature readings at three locations:

- The thermostatic controller downstream of the electric heater: 113°–118°F
- Immediately upstream of the bypass damper: 119°–124°F (from DAS)
- The SA plenum, upstream of the register: 112°F and 115°F (from DAS)

Based on these measurements, the following was concluded:

- Duct heat loss between the bypass and the SA plenum is not insignificant and should be taken into account for accurate setting of the SA temperature at the register.
- The thermal mass of the metal bypass assembly apparently has a damping effect on the oscillatory SA temperature.

The IR photos taken in this test are depicted in Figures 9 and 10. The following observations are made from examination of these photos:

- A high temperature region in front of the SA register is evident from the ceiling image.
- The vertical temperature profiles resulting from stratification seem to be consistent at the north and south walls.
- The IR image of the RA grille suggests presence of spatial temperature nonuniformity at the RA plenum. (This will be further discussed in this report.)
- The effect of the thermally conductive frames of the suspended ceiling is visible, but is not expected to interfere with the experiments. Further assessments may be needed.

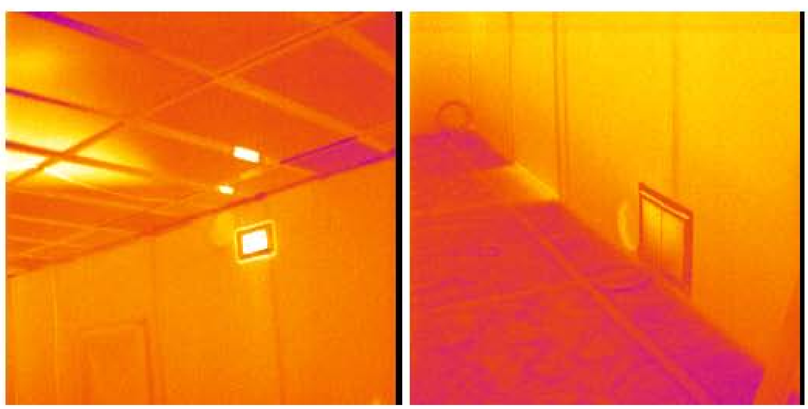

Figure 9. IR images of SA diffuser and RA grille

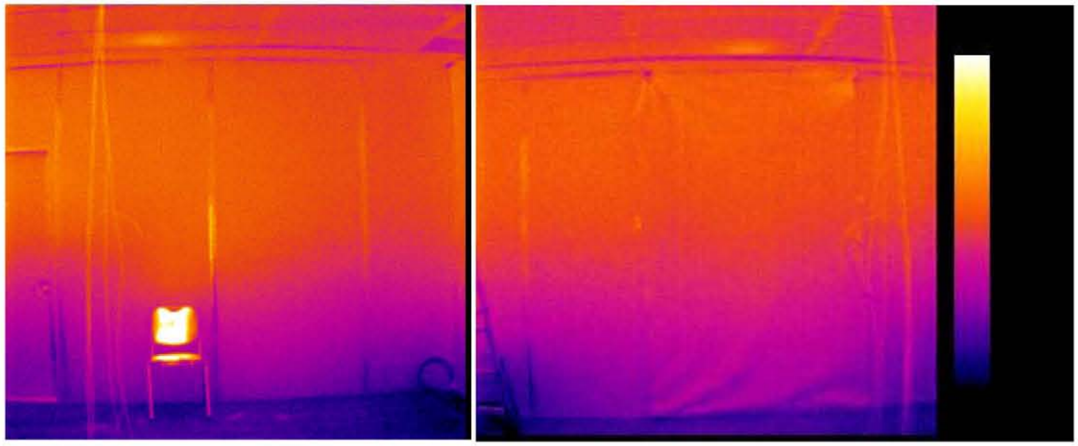

Figure 10. IR images of north and south walls

Test #2 (May 16, 2006)

This is one of the earliest tests that followed the fine-tuning of the PID controller for the SA electric heater. The primary objective of this test was to evaluate the time-dependent inlet and outlet (SA and RA) properties, including temperature and tracer gas concentration. The room temperatures were also measured at a few points along the centerline. The results are provided in Figures 11 and 12. These results were used to estimate the average gas concentration in the room and to evaluate the uncertainties of the SA and RA gas concentration data, as will be discussed later in this report.

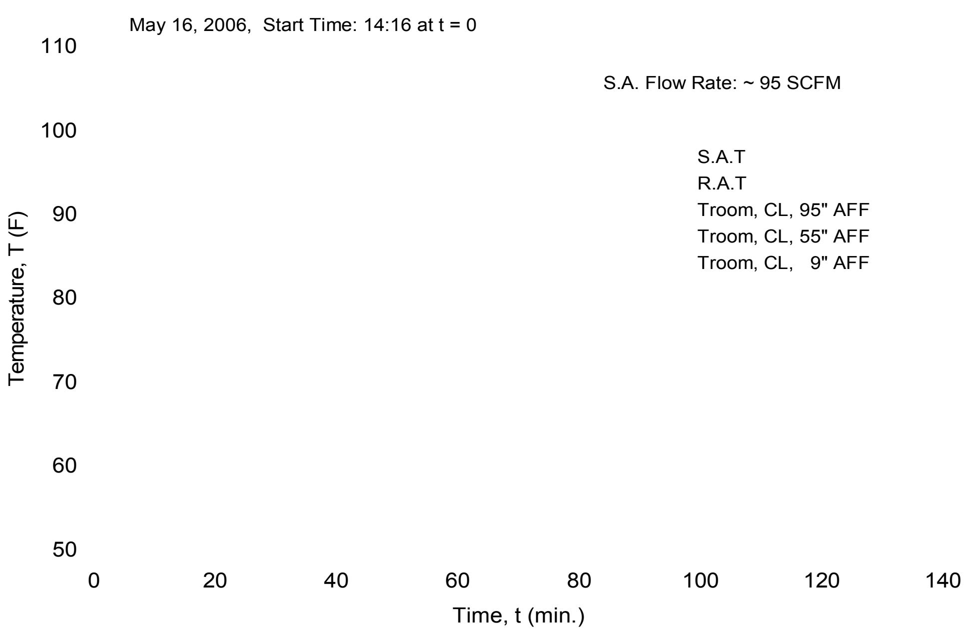

Figure 11. Temperature measurements, Test #2

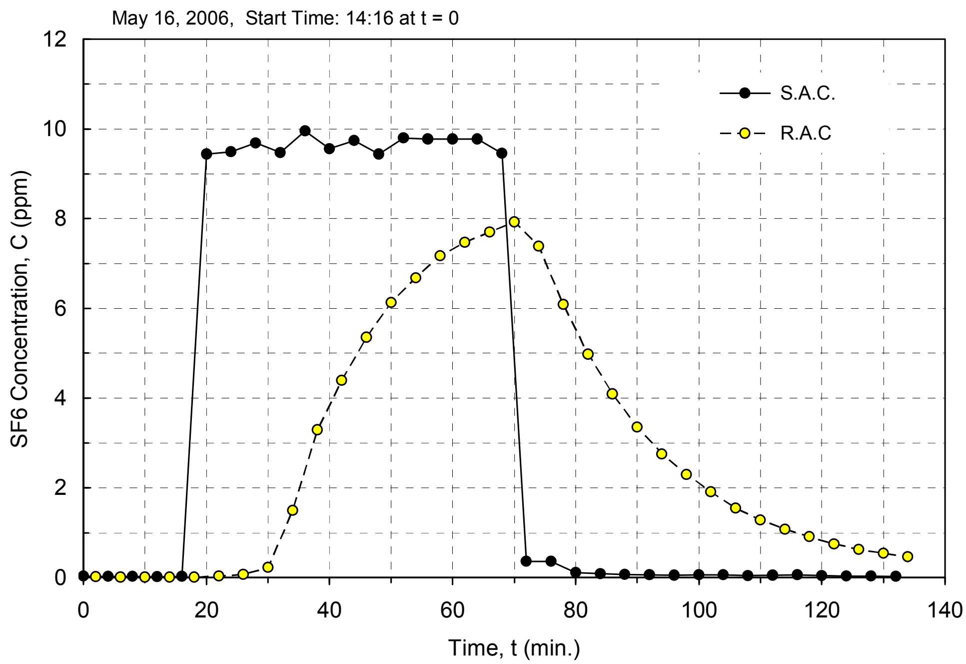

Figure 12. Gas concentration measurements, Test #2

Test #3 (June 6, 2006)

In this test, heated SA with a temperature of 105°F, a flow rate of about 95 scfm, and an SF_6 concentration of 9.6 ppm was introduced into the test room, which was initially pre-cooled to 67°F. Two sets of measurements were taken in the test room: (1) the gas concentration at two points, one on the center line and the other on the near-north-wall instrumentation array, both at about 66.3 in. above the finished floor (AFF); and (2) air temperatures along the centerline and north-wall arrays. The results of this test are illustrated in Figures 13 to 16. Figure 13 presents the S.A and RA temperatures and the SA flow rate variation under actual and standard conditions. Figures 14 and 15, respectively, demonstrate the air temperature profiles along the centerline and the line adjacent to the north wall (Figure 8). The results of the concurrent tracer gas test are shown in Figure 16. This test is characterized by the following sequence of operations:

1. Open the SA damper at minute 27 to allow flow of heated SA containing the tracer gas through the test room.
2. Stop the SA flow to the test room at minute 48 by redirecting it through the bypass line – commencing idle (no-flow) mode. At this point the electric heater is turned off, and the tracer gas valve is closed.
3. Close the bypass line and supply unheated air to the room – commencing the cool-down/purging process.

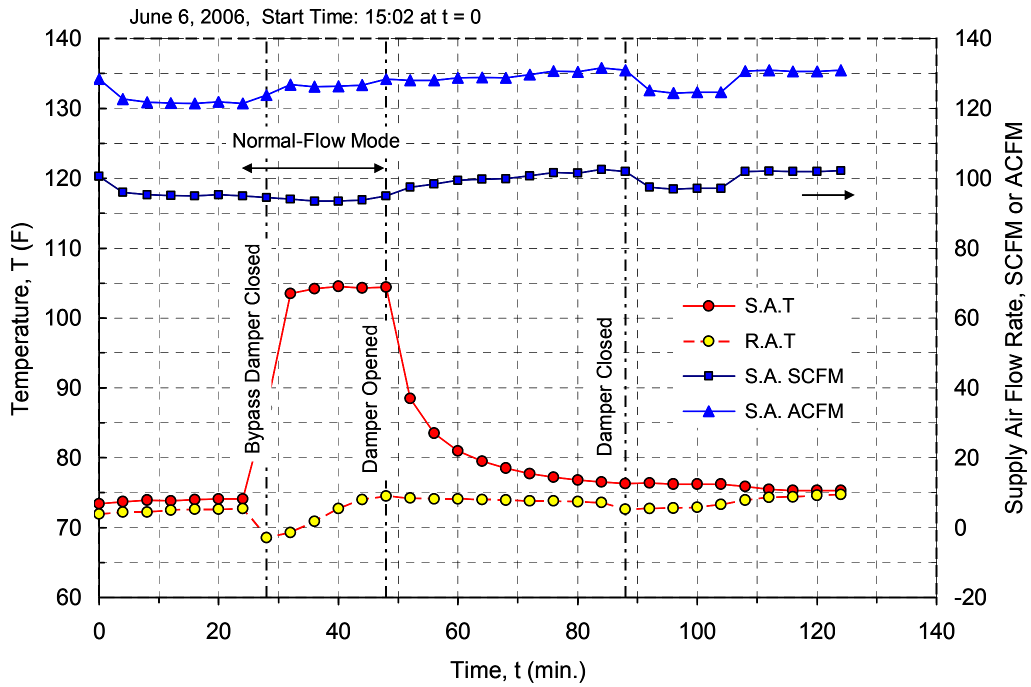

Figure 13. Operating conditions of Test #3

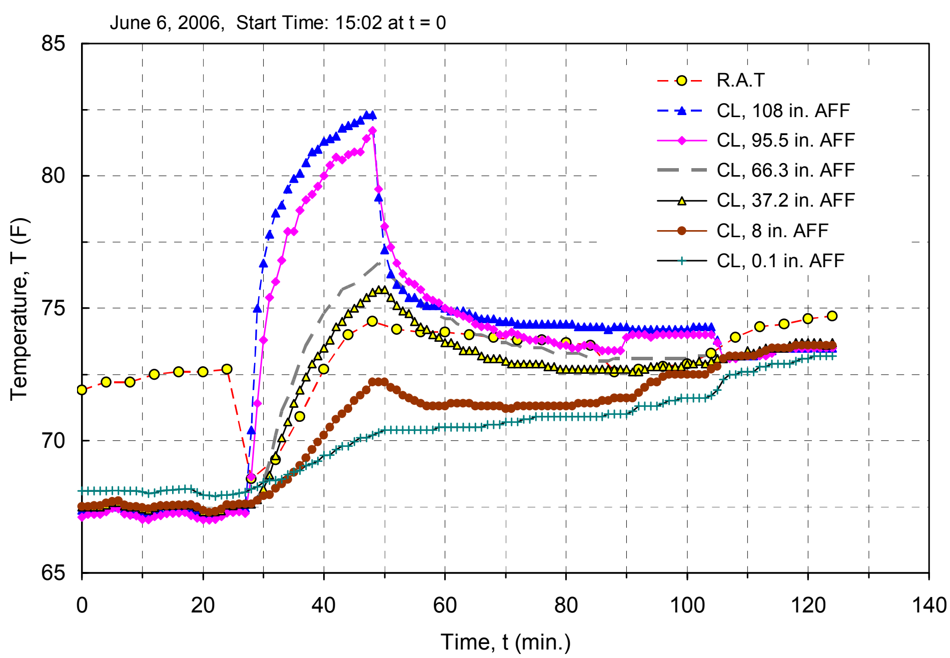

Figure 14. Centerline temperatures

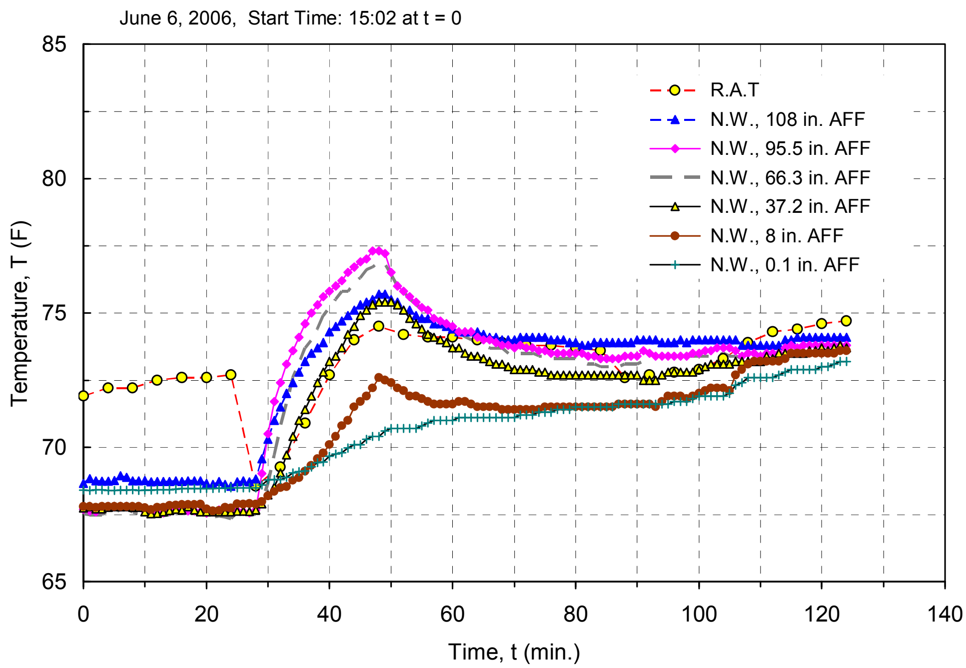

Figure 15. Temperatures near north wall, Test #3

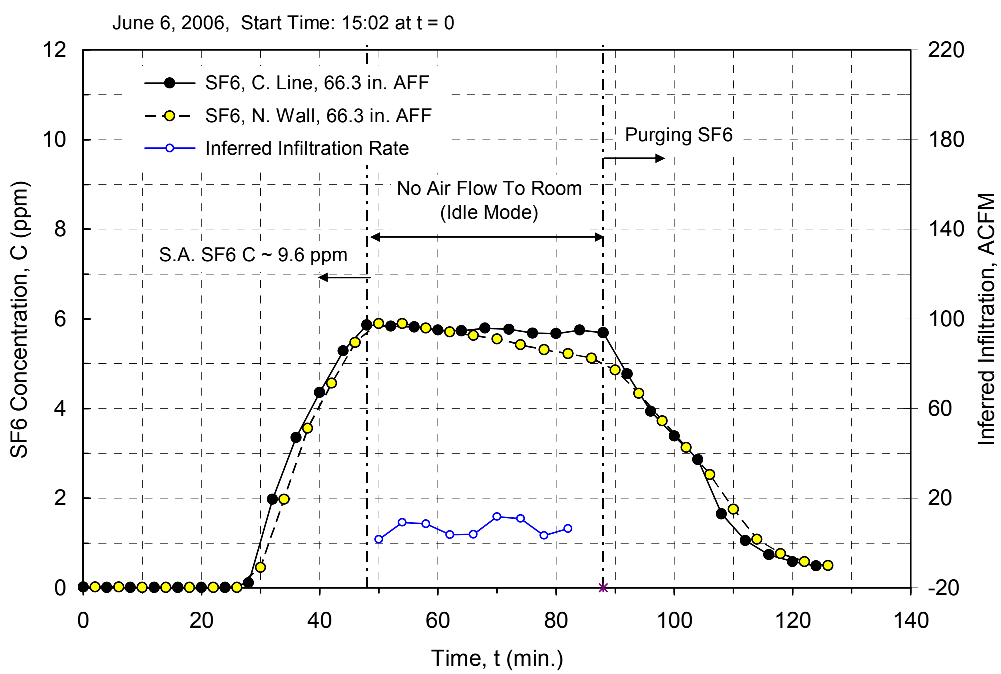

Figure 16. Gas concentration data, Test #3

For real-world applications where the heating operation is thermostatically controlled, the heating process would have been terminated by minute 40, as the room temperature at about 5 ft. AFF exceeds the typical setpoint range. Comparison of Figures 14 and 15 for the period of minute 27 to 48 reveals the following:

- The degree of stratification in the occupancy zone (the region below the horizontal plane C at 66.3 inches AFF – Figure 8) is about the same at the centerline and the near-north-wall array. However, considerably higher temperatures are observed along the centerline compared to those at the north wall line (Figure 14 and Figure 15). This finding is in line with the IR photos of Test #1 in that a cooler region of air exists in the upper zone in the vicinity of the north wall.

The notion of the relatively uniform thermal diffusion in the occupancy zone is seemingly supported by the results of the concurrent tracer gas test shown in Figure 16. The two gas concentration measurements at the centerline and north wall on test plane C (66.3 inches AFF) converge during the heating process. In the early part of the no-flow operation, the concentrations are about the same as well, but later they start diverging. In the purging/cool-down period, the readings are about the same for the most part. However, around the middle of this process, the concentration at the centerline is slightly less. Therefore,

- The horizontal variation of the gas concentration throughout the test, when the supply air is flowing, appears to be small in the occupancy zone.

Based on the rate of decay in the gas concentration during the no-flow operation, the infiltration for the test room has been approximated using the following equation:

$$\dot{Q}_{\inf ilt.} \cong \frac{V_{Room}\ dC_{SF6,Room} / dt}{\Delta C_{SF6}} \tag{1}$$

The variable ΔC_{SF6} is the gas concentration difference between the infiltrating air and the room air. The value of ΔC_{SF6} is approximately equal to the average room gas concentration $C_{SF6,Room}$ because the gas concentration of the ambient air outside the test room is nil. The finding is described as follows:

- The estimated infiltration at the no-flow operation (in bypass mode) ranges from 1 to 12 cfm, with an average of about 6.5 cfm. This estimate is based on an assumption that the average of the two concentrations at 66.3 inches AFF approximates the average room concentration. Although this assumption has not been validated yet, the inferred infiltration is in agreement with the finding of Test #4, as described below.

Test #4 (June 8, 2006)

This test is an isothermal test aimed at examining diffusion of the tracer gas in the test room. Figure 17 illustrates the results of this test. At about minute 43, the unheated supply air stream (at the room temperature of 75°F) with a flow rate of about 95 scfm and a gas concentration of 9.6 ppm starts flowing into the room. The gas concentration measurements are along the centerline at 95.5 and 8 in. AFF during the normal- and no-flow modes are presented in Figure 17. A comparison of these results with those of Test #3 (Figure 16) reveals that

- The average of the two vertical gas measurements (at 95.5 and 8 in. AFF) along the centerline closely tracks the average horizontal measurements (at 66.3 inches AFF) shown in Figure 16 in the normal- and no-flow modes. This finding may suggest that, at this flow rate, the thermal stratification may not have any significant effect on the tracer gas diffusion across the room.

- The average infiltration in the no-flow mode is estimated (from Equation 1) to be about 5 cfm, which is in agreement with the previous estimate made in Test #3.

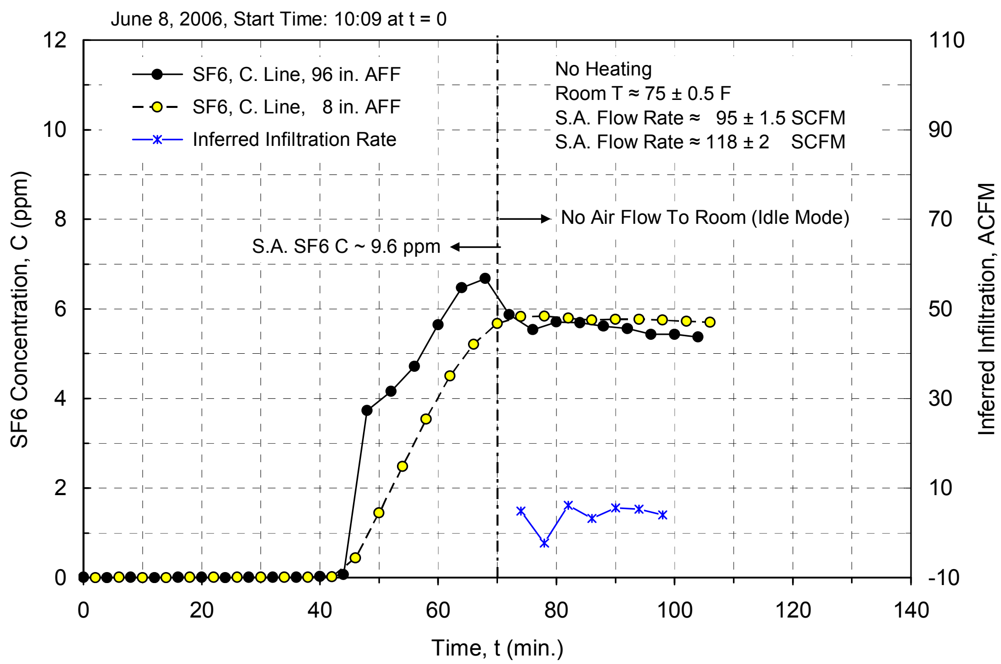

Figure 17. Gas concentration data, Test #4

Test #5 (June 14, 2006)

The purpose of this test was to examine the impact of reducing the SA flow rate on distribution/diffusion of the SA stream. The concentration of SF_6 in the SA stream was increased to about 16.5 ppm to maintain roughly the same rate of gas flow into the test room as in Test #3. Figures 18 to 22 illustrate the results of this test, in which the SA flow rate is about 60 scfm compared to 95 scfm in Test #3. The SA temperature of this test in the normal operating mode is 100^{o}F, about 5^{o}F lower than that in Test #3. Comparisons of these results with those of Test #3 (Figures 13 to 16) lead to the following findings:

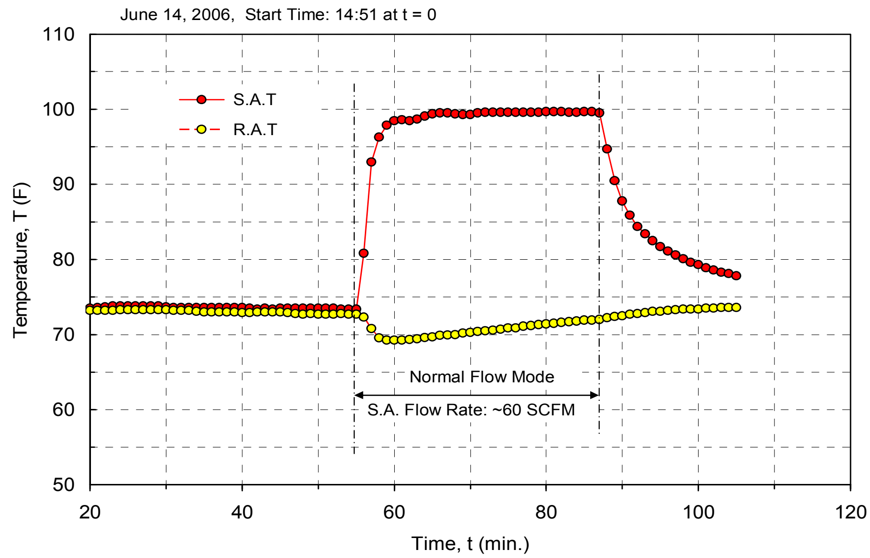

Figure 18. Operating conditions, Test #5

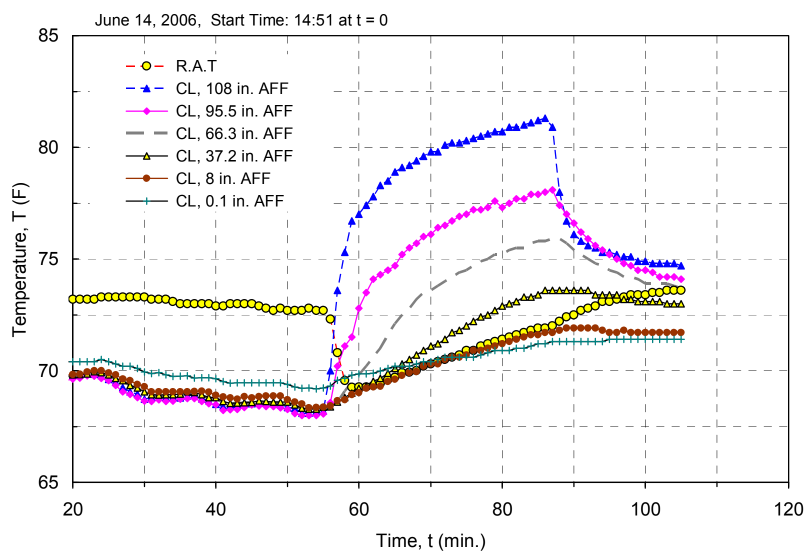

Figure 19. Centerline temperatures, Test #5

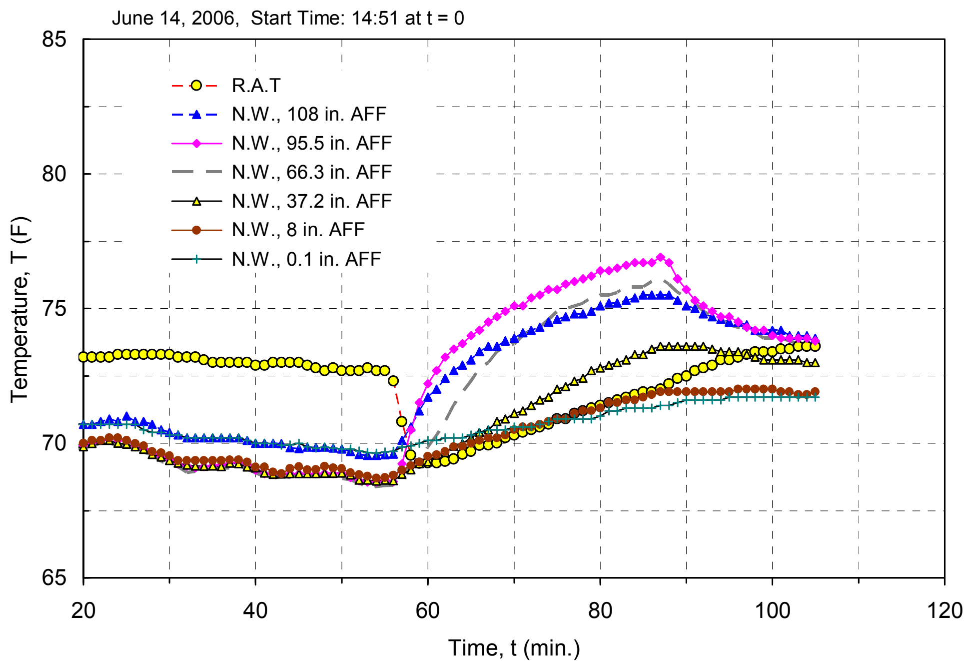

Figure 20. Temperatures near north wall, Test #5

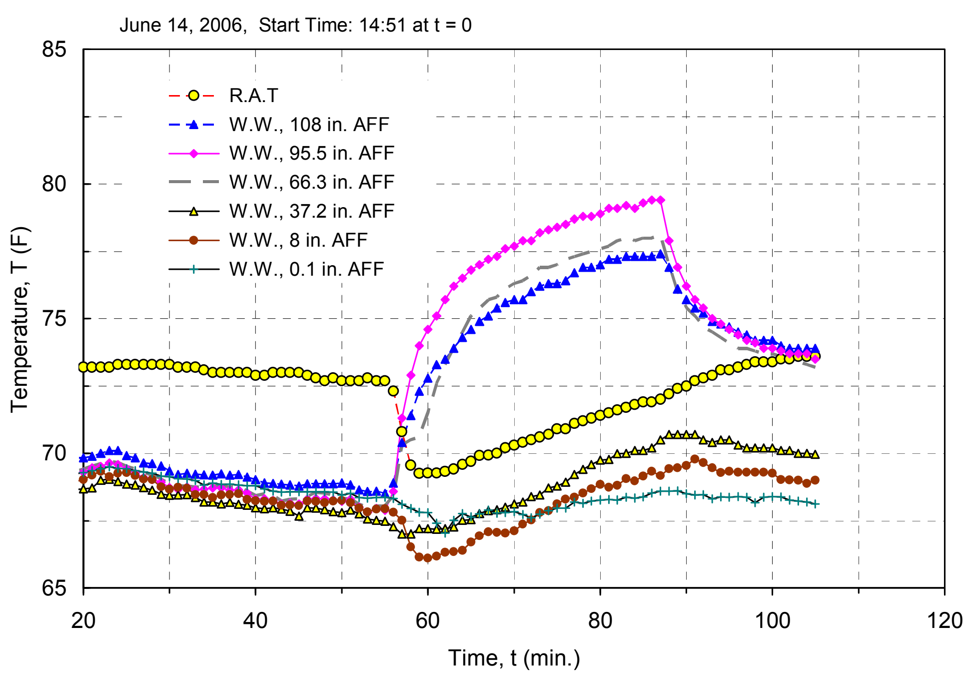

Figure 21. Temperatures near west wall, Test #5

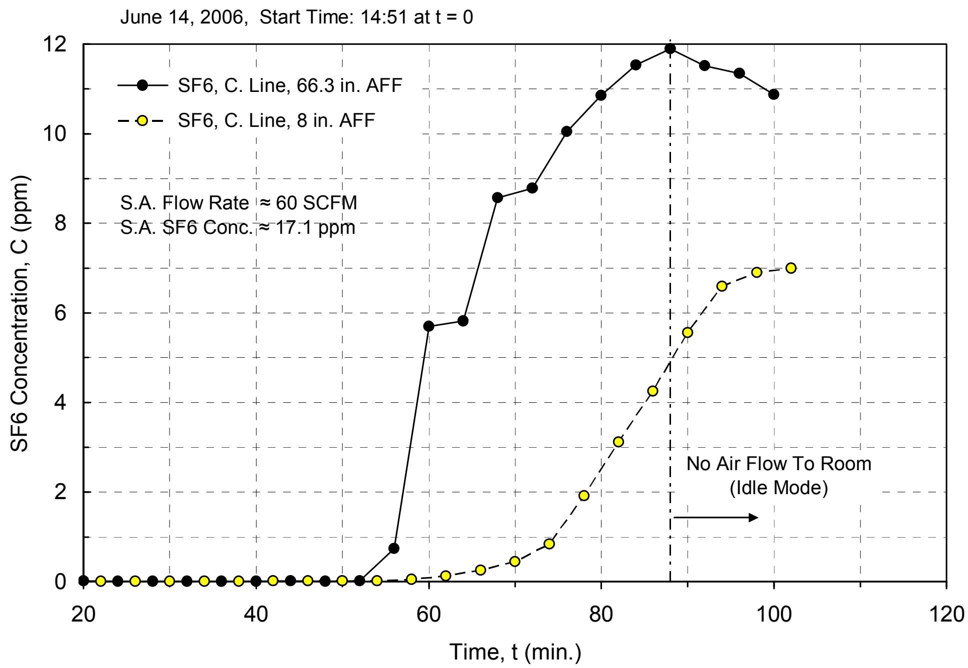

Figure 22. Gas concentration, Test #5

- The heating process is prolonged (i.e., the room temperature increases at a slower pace) for the case with the reduced flow rate. For example, it takes about 21 minutes for the temperature of the air at 66.3 in. AFF on the centerline to reach 75°F (Figure 19) compared to about 12 minutes for the scenario with the higher flow rate (Figure 14).
- At the centerline, from 37.2 in. AFF to near the ceiling, the vertical temperature distribution is more uniform for the case with the reduced flow rate (Figures 14 and 19). However, this finding does not apply to the near-north-wall array (Figures 15 and 20).
- The near ceiling region of cooler air observed at the north-wall array in Test #3 is also present in this test (Figures 15 and 20).

For this test, the temperatures near the west wall are also measured as shown in Figure 8. These results indicate the following:

- At elevations 66.3 in. AFF and higher, except for the near ceiling region, the temperature readings near the west wall are higher than the corresponding ones at the centerline and near the north wall (Figures 19 to 21). However, at elevations below 66.3 in. AFF, the temperature readings of the west-wall array are lower than those at the other two arrays by a few degrees. This effect could have been caused by some infiltration from the walk-in cooler through the circulating fan (Figure 7), which will be further examined. (Note that the glass panel shown in Figure 7 was covered with insulating boards for the tests of this report.)

- The temperatures at 37.2-in. level (test plane D) and the region below actually drop to some extent at the early stage of the heating mode before rising. A similar trend is observed with the RA temperature as well. This may be indicative of spatial temperature non-uniformity at the end of the pre-cooling process, unlike what is seen in Test #3. Furthermore, the decreasing trends of the temperatures at the lowest three points (37.2, 8, and 0.1 in. AFF) during the no-flow mode following the heating process may have also been caused (at least partly) by the infiltration from the walk-in cooler, as noted above. Potential flaws with installation of the insulation boards on the glass panel could also be a contributor to this behavior. Therefore, this test will have to be repeated with a well-mixed initial room air and other necessary improvements to the test setup.

The results of the concurrent tracer gas test (Figure 22) lead to the notion that

- The difference between the gas concentration measurements at 8 and 95.5 inches AFF along the centerline is much greater than that of Test #4 (Figures 17 and 22), despite the fact that the thermal stratification at this location is greater in Test #4. (For instance, accounting for the differences in the flow rates, compare the temperature readings at minute 40 for Test #4 and at about minute 77 for Test #5.) The gas concentration readings do not even converge at the end of the no-flow mode. A possible reason for this observation is that, at the reduced low flow rate, diffusion of the gas is significantly impeded, leading to heavy concentrations in the region around the elevation of 96 inches AFF at the centerline and possibly across the symmetry plane. (When Test #5 is repeated with the aforementioned improvements, a concurrent tracer gas test will also be planned to get more clues on the gas distribution within the room at the reduced SA flow rate.)

Combining Tests #2 and #3

The operating conditions of these tests are about the same. In both experiments the SA air temperature, the SA gas concentration, the SA flow rate, and the initial room temperature are about 105°F, 9.6 ppm, 95 scfm, and 65°F, respectively. The major factors differentiating these two tests are the duration of the heating mode and the locations of the gas concentration measurements. The purpose of combining the results of these two tests is to capitalize on the latter difference, as the gas concentration measurements are limited to two locations at any given test. The aggregated results leads to the availability of the gas concentration data for the SA and RA plenums (from Test #2) and for the centerline and near-north-wall test points at 66.3 inches AFF (from Test #3). These attributes provide an opportunity to further analyze the SF_6 distribution within the test room by capturing and comparing the data from the two tests during a portion of the heating process. Figure 23 demonstrates the similarities of the time-dependent SA and RA temperature variations during a part of the heating process. (Note that the time variable for Test #2 has been transformed to synchronize the beginning of the heating process with that of Test #3.)

Therefore, the aggregate of these two tests for a limited duration of the heating phase has yielded data for an equivalent hypothetical test in which the SF_6 concentration is measured at four locations: SA and RA plenums and 66.3 AFF at the centerline and the north-wall arrays. Then, based on the gas concentration measurements in the SA and RA plenums at any given time, an average room gas concentration can be derived from the following equation:

$$\dot{Q}_{S.A.}\left[C_{SF6,S.A.} - C_{SF6,R.A.}\right] \cong V_{Room}\frac{d\overline{C}_{SF6,Room}}{dt} \quad (2)$$

Where $\dot{Q}_{S.A.}$ is the actual SA volumetric flow rate, and $\overline{C}_{SF6,Room}$ is the average gas concentration within the room. The SA and RA temperatures, $T_{S.A.}$ and $T_{R.A.}$, are expressed in absolute temperatures. Note that Equation (2) neglects the room infiltration.

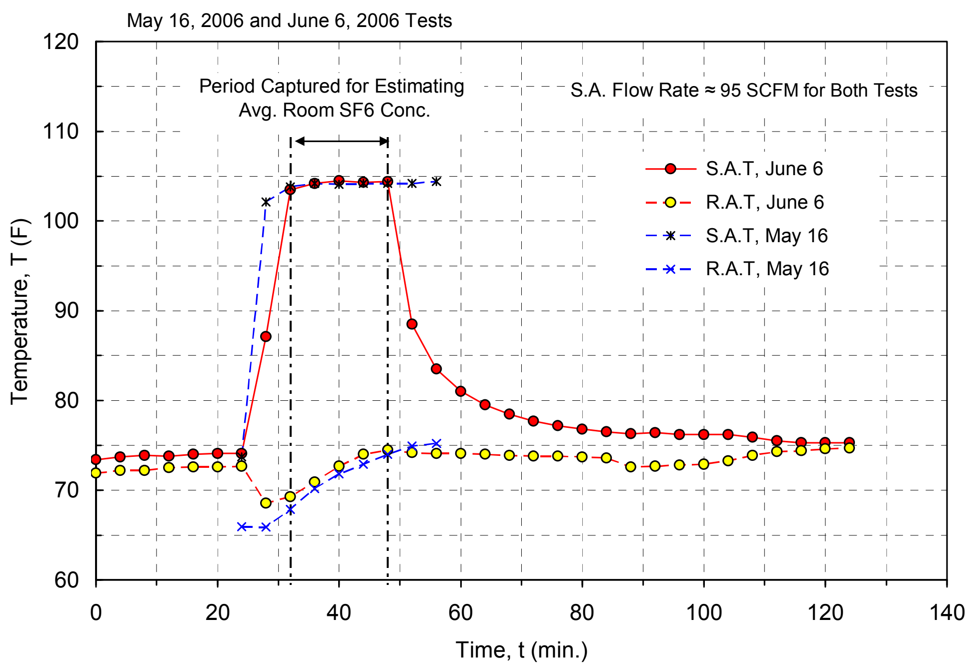

Figure 23. Comparison of Tests #2 and #3

Figure 24 presents the average room SF_6 concentration trend estimated from Equation 2, along with the measurements from the two tests. Comparison of these results suggests that the average room gas concentration closely tracks the average of the two measurements at the horizontal test plane C (i.e., 66.3 in. AFF at the centerline and north-wall arrays).

- Therefore, for the given operating conditions (SA properties) of Tests #2 and #3, the gas concentration readings at 66.3 in. AFF approximate the average concentration in the room.

- This finding may further validate the assumption made in estimating the infiltration rate in the no-flow mode, as previously discussed under Test #3.

(Note: A similar analysis can be performed with respect to the room average temperature.)

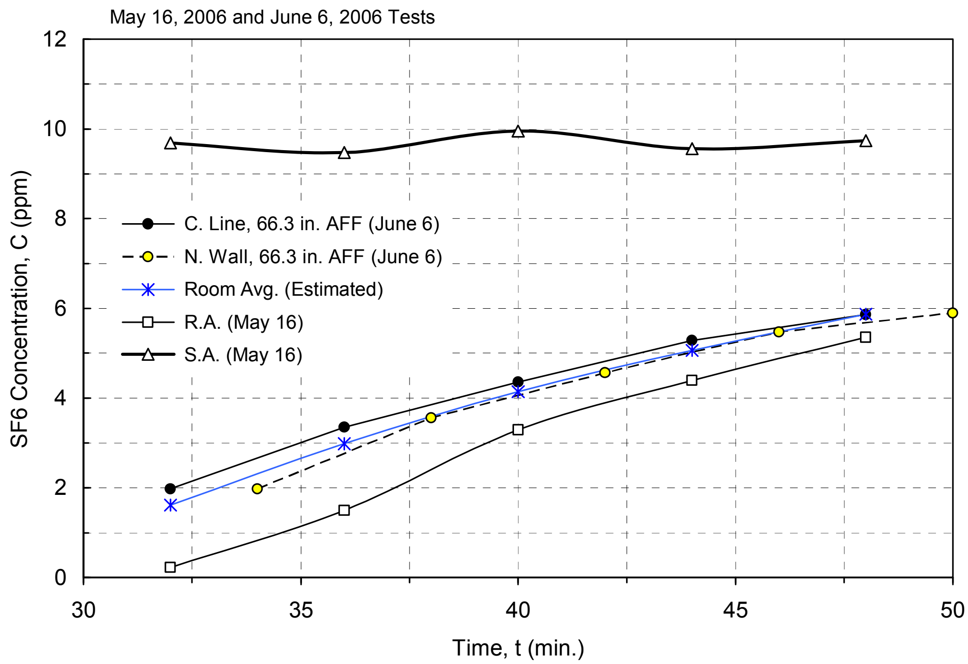

Figure 24. Comparison of estimated gas concentration with data

Uncertainties Analysis

Tables 2 and 3 list the experimental variables, their typical ranges, and the corresponding uncertainties.

Table 2. Experimental Variables and Uncertainties

Variable	Symbol	Range	Overall Uncertainty
Gas Concentration	C_{SF6}	0–20 ppm	See Table 3
Flow Rate	$\dot{Q}$	50–150 scfm	± 3%
Pressure Differential	$\Delta P_{Room/Amb.}$	0–0.1 in.w.g.	± 0.02 in.w.g.
SA Temperature	$T_{S.A.}$	60°–140°F	± 1°F
RA Temperature	$T_{R.A.}$	60°–75°F	± 1°F
Test Room Temperature	$T(x, y, z)$	60°– 100°F	Varies (Minimum: ± 0.2°F)

Table 3. Uncertainty Components of Gas Concentration Measurements

Gas Concentration Variables	Range of Variable	Elemental Systematic Uncertainties			Random Uncertainty (Estimated)
		Instrument (Mfg. specs)	Time Related		
			Transient Effects [(a, b)]	Synchronized	
Supply Air	10–20 ppm	± 2%	Negligible	Negligible	± 2%
Return Air	0–10 ppm	± 2%	Varies	Negligible	± 2%
Room Air	0–10 ppm	± 2%	Varies	Negligible	± 2%

Notes:
[a] The uncertainty of the gas sample delivery time is transformed to gas concentration uncertainty based on the transient behavior at a given time.
[b] The asymmetric uncertainty, varies with the rate of gas concentration change - only negative component for increasing concentration and only positive for decreasing trend.

Detailed uncertainty analyses will be provided in the final report. This section provides a preliminary evaluation of uncertainties as described below.

Tracer Gas Concentration

RA Stream

Three sources of systematic uncertainties are taken into account for the gas concentration measurements: (1) the instrumental uncertainty specified by the manufacturer of the gas sampler, (2) the uncertainty associated with the combined effect of the transient trend of the RA gas concentration and the uncertainty of the sample delivery time, and (3) the uncertainty resulting from the synchronization discrepancy between the two DAS systems. The synchronization error is assumed to be ± 1 s. Figure 25 depicts the overall uncertainties of the RA gas measurements for Test #2. The asymmetry of these uncertainties, as vividly seen for the minutes 36 and 40, stems from the uncertainty of the gas-sample delivery time in conjunction with the transient trend of the RA gas concentration. This source of uncertainty, however, will be minimized in the next phase of the project by resetting the input parameters of the sampler DAS system.

Supply Air Stream

Considering that a fairly constant SA flow rate is maintained during the tests, and a constant amount of SF_6 is injected into the stream throughout the tests, the systematic uncertainty of the SA gas concentration measurements is dominated by the instrumental uncertainty of the gas sampler specified by the manufacturer.

Room Air

The uncertainty constituents of the gas concentration measurements within the test room are qualitatively similar to those of the RA

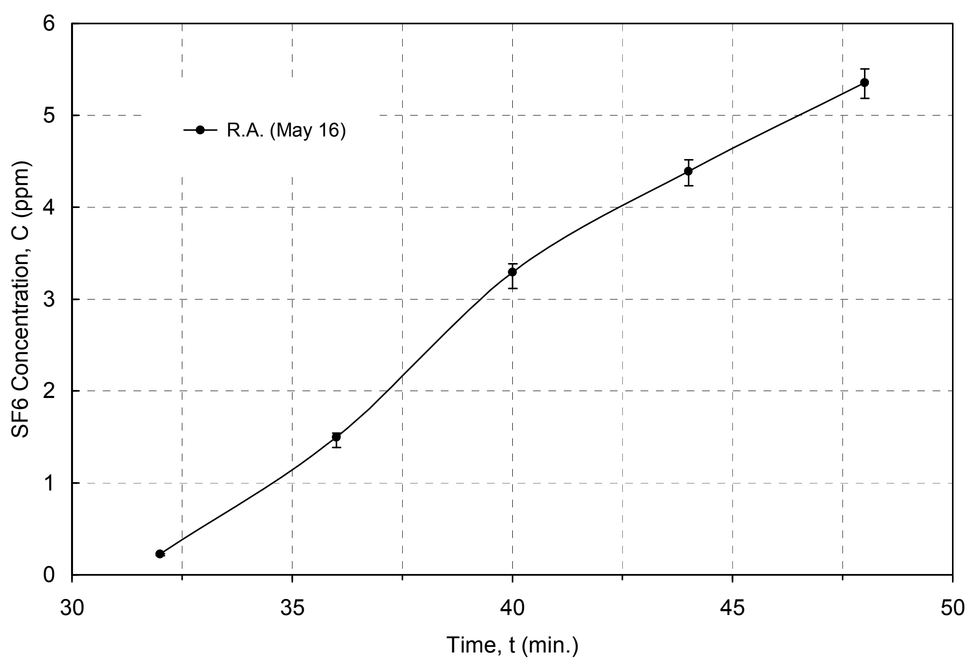

Figure 25. Uncertainties of RA gas concentration, Test #2

Supply and Return Air Temperatures

In all aforementioned tests, the reported SA and RA temperatures are based on a single measurement at or near the center of each plenum, which does not account for the spatial variations. An experiment was devised to examine the temperature variation within each plenum by taking measurements at various locations across the test cross section. The results of these tests are provided in Figures 26 and 27 for the SA and in Figures 28 and 29 for the RA plenum. The lateral thermocouples are about 1 in. from the respective inner walls of the plenums. The SA flow rate in this test varied from 80 to 105 scfm. The heater was turned off at about minute 30, but the SA continued flowing into the room.

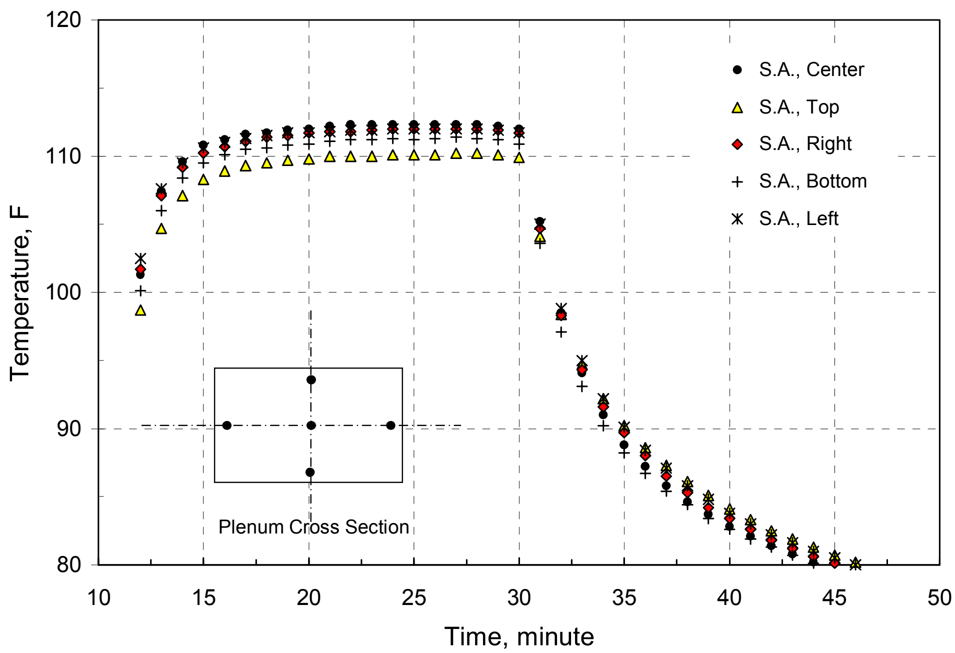

Figure 26. Supply-air spatial temperature variation

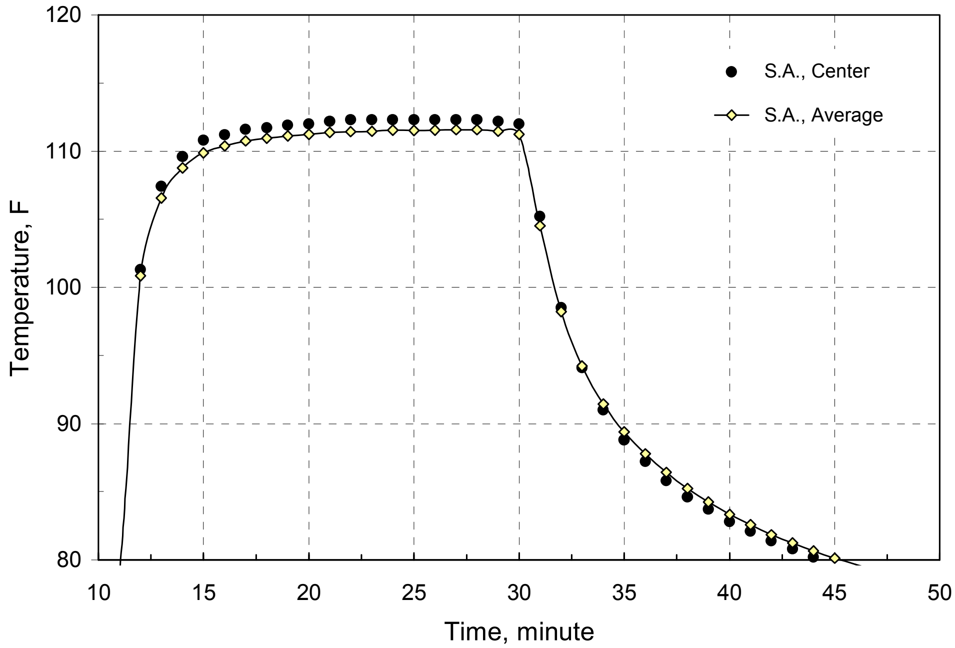

Figure 27. Comparison of SA centerline and average temperatures

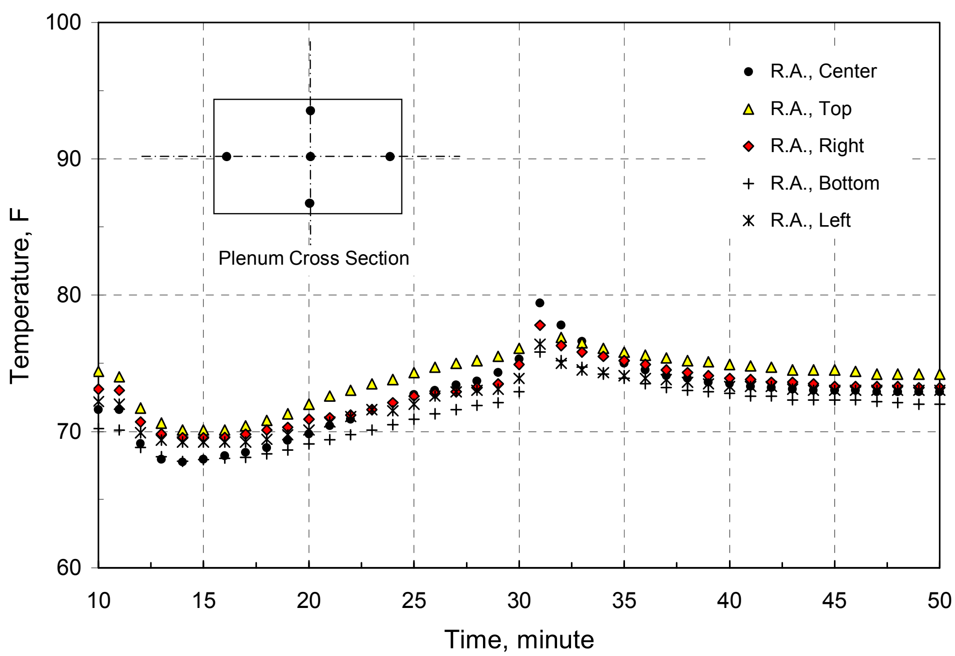

Figure 28. Return-air spatial temperature variation

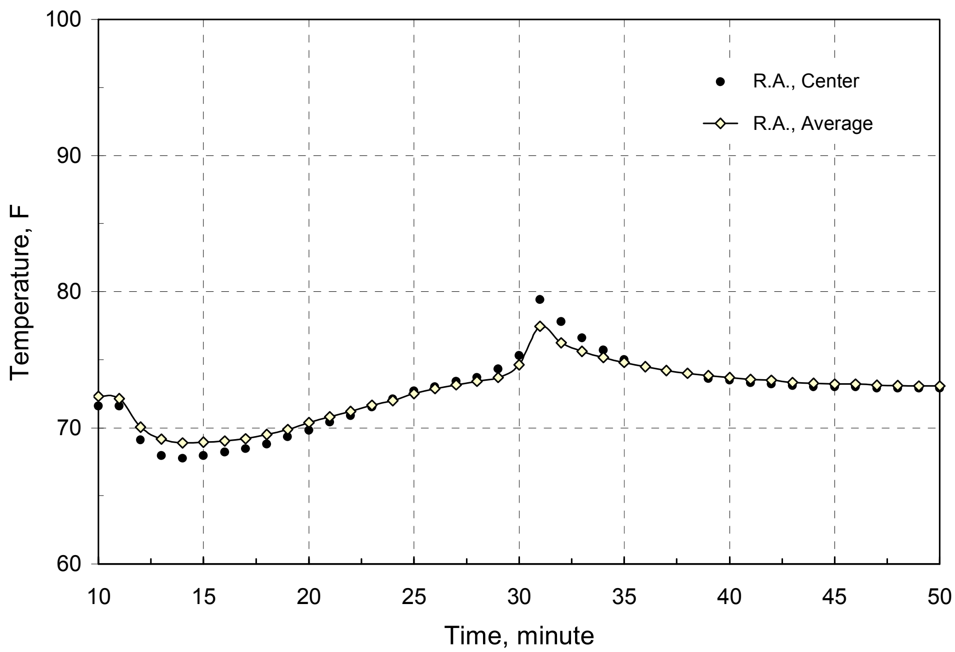

Figure 29. Comparison of RA centerline and average temperature

Except for the initial start-up period (about 3 minutes), the center thermocouple reading is the highest of all readings during the heating process (Figure 26). The largest difference is seen with the readings at the top and center, which is within less than 3^{o}F. However, the difference between the reading at the center and the average of all readings (including the central thermocouple) is less than 1^{o}F during the entire heating process and less than 0.5^{o}F for the cool-down period after minute 30 (Figure 27). These results may point to the appropriateness of assigning a different asymmetric uncertainty band for each operating mode. However, in the interest of simplicity, a single uncertainty estimate is currently applied to the entire process. Assuming that the average reading at any given time is representative of the mass-weighted average (in the absence of velocity profiles in the plenum), the following estimate has been made:

- Accounting for the two major elemental systematic uncertainties, i.e., instrumental and spatial temperature variation uncertainties, the overall uncertainty of the representative mean SA temperature based on a measurement at or near the cross sectional center of the plenum is ± 1^{o}F. The random uncertainties are found to be relatively negligible.

For the RA plenum, the spatial variation (Figure 28) is slightly higher than that of the SA The center-point temperature readings in the RA plenum also represent good approximations of the average values (Figure 29). The largest difference between the center-point reading and the average is about 2^{o}F, which occurs only within the first 2 minutes of the cool-down process. However, depending on the temperature distribution within the room (which is a function of the SA flow rate, the SA temperature, the initial room temperature, and the time), the discrepancy between the two may be greater in some cases – pointing to the need for further examination.

- For the time being, applying the same rationale for the uncertainty evaluation of the SA temperature measurements, the uncertainty of the RA temperature represented by a single measurement at or near the longitudinal centerline of the plenum is estimated to be ± 1^{o}F as well.

With respect to the uncertainty analyses, the following assessments are applicable to both SA and RA temperature readings:

- Considering the relatively small temperature variations within the RA and SA plenums and the fact that the plenum walls are made of insulating boards, the radiation effects of the inner wall surfaces are deemed to be negligible, particularly in the presence of the convection-enhancing air flows in the plenums.
- Given the small temperature variations, there is no need for installing a mixing device, such as mixing baffles, upstream of the instrumentation plane in either plenum.

Conclusions

This report describes the experimental facility and discusses the results of qualification tests in preparation for the next phase of the project aimed at evaluating the effectiveness of a specific air distribution system during a period of recovery from setback. In the initial phase of the project, the experimental facility was installed, debugged, and fine-tuned for proper operation. The uncertainties of the experimental variables and data were addressed and minimized, paving the way for a detailed uncertainty analysis of the results in the next phase where the actual tests will be conducted. The experimental approach includes evaluation of spatial temperature variations within the test room and concurrent tracer gas analysis that will be ultimately used for assessment of comfort indices and ventilation effectiveness of the system under various test conditions.

The following observations have been made during the qualification tests:

- Reducing the supply-air flow rate and, consequently, the velocity, adversely affects the temperature distribution in the test room in addition to prolonging the period of recovery from setback.
- The vertical temperature profiles across the room are noticeably different in areas that are directly affected by the SA stream.
- At the no-flow mode when the supply-air stream is bypassed, the average infiltration rate for the test room has been estimated to be about 5% of the flow rate, based on the tracer gas decay analysis.
- The systematic uncertainty of the gas concentration in the RA stream is asymmetric and is largely influenced by the transition effects and the duration of the gas sampling.
- Measurements of air temperatures at the centerlines of the SA and RA plenums represent the respective average temperatures with reasonable uncertainties that are dominated by the spatial temperature variations in the plenums.

The results of the qualification tests will be used to characterize the subsequent tests in the next phase of the research project.

Acknowledgments

The author thanks Ed Hancock of Mountain Energy Partnership, an NREL subcontractor, for his efforts in instrumentation and data collection. The work of Doug Powell in installation of the experimental facility is greatly appreciated as well. Finally, this study would not have been possible without the support and guidance from Ren Anderson.

Appendix A

SOP # 748
CENTER # 5500

SAFE OPERATING PROCEDURE
FOR
Air Flow Test Loop
At
Thermal Test Facility (TTF)

I. INTRODUCTION

A. Activity description

Air diffusion/distribution tests will be performed in the Building America's Air Flow Test Room, which is located in the Thermal Test Facility (TTF), as seen in Figure 1. The purpose of these tests is to characterize the diffusion/distribution of heated supply air in a residential room/space for the heating season in cold climate zones. In doing so, conditioned air will be supplied to the Test Chamber through a wall register near the ceiling. The room air will be continuously exhausted through a wall exhaust outlet near the floor, which simulates a typical return air grille.

The existing walk-in freezer unit attached to the west wall of the TTF Air Flow Test Room (Figures 1 and 2) will induce heat loss from the test chamber through the joint wall with a glass panel in order to simulate the thermal effects of ambient conditions in the heating season. When a rapid pre-cooling of the test chamber is required, a small fan (fractional hp, 90-W) will be used to circulate air between the walk-in freezer and the Test Chamber (Figure 2). The walk-in compartment will be cooled by the existing thermostatically controlled, water-cooled freezer installed on the roof of the compartment. The well-insulated exterior walls and roofs of the test room/freezer assembly are exposed to the conditioned TTF indoor space (Figure 1).

The existing supply-air apparatus illustrated in Figure 3 will be used to provide heated supply air to the Test Chamber at various flow rates (up to 200 scfm) at a temperature between 80^{o}F and 140^{o}F. The device consists of a 2-HP centrifugal fan with a variable frequency drive, a 6-kW electric heater, and a hot water heating coil in series. Only the electric heater will be used to achieve the desired supply air temperature. (The hot water heating coil may even be removed.) This apparatus, which is currently located in the TTF adjacent to the east wall of the Air Flow Test Room (Figures 1 and 3), will be repositioned to facilitate proper duct connections and air intake from the TTF indoor space.

A small in-line exhaust fan (fractional hp, 90-W) has been installed in the equipment room (Figure 2b) to exhaust the air from either the Test Chamber or the supply air duct to the outside through the existing exhaust system of the Thermal Conversion Laboratory (TCL), as seen in Figure 4. (Using the gate dampers of the duct system shown in Figure 2b, the supply air flow can be directed to bypass the test chamber.) The combined exhaust system (arranged in series) is intended to maintain a negative differential pressure in the Test Chamber – preventing leakage of the air into the TTF indoor space.

The Test Chamber adjacent to the walk-in freezer is formed by rearranging the existing movable foam-board partition shown in Figures 1 and 2. The remaining section of the TTF Air Flow Test Room will be designated for the experimental equipment. The foam board is a Gatorfoam Laminated Foam Panel (the trademark of a product from International Paper), which consists of a rigid polystyrene foam core bonded to smooth, moisture resistant, man-made wood fiber veneers on both sides. The removed ceiling tiles of the test chamber will be reinstalled before the tests. As illustrated in Figure 5, reinstallation of the ceiling tiles will not compromise the existing fire protection measures because half of the existing sprinkler heads pass through the suspended ceiling (ceiling tiles).

B. Location

The TTF Air Flow Test Room and the attached walk-in freezer are located in the northwest corner of the TTF. The experimental devices and the accessories will be installed both inside and outside the test room.

C. Process

The testing process will involve:

1. Supplying heated air/SF_6 gaseous mixture with a SF_6 concentration of up to 20 ppm into the test chamber for duration of 10 to 60 minutes, depending on the test objectives. The SF_6 concentration of the supply air will be measured using one of the ports of the aforementioned tracer gas sampler described in Section I.C.1. At the minimum, the SF_6 concentration will be measured in the supply and exhaust air streams using a six-channel tracer-gas sampler (INNOVA, Model 1303 Multipoint Sampler and Doser). (Note that SF_6 will not be used in all tests. In tests involving SF_6, the gas concentration will not exceed 20 ppm within the temporal and spatial confines of the experiments.)

2. Continuously exhausting the air/SF_6 mixture (SF_6 concentration < 20 ppm) from the chamber to the outside of the TTF using the existing exhaust duct of the TCL (Figure 4). <u>All tests, regardless of whether SF_6 is used or not, will be conducted during normal business hours and will be continuously attended by trained and qualified personnel.</u>

3. Taking measurements of the air properties at the supply and exhaust outlets and at various locations within the test room.

The variables to be measured in addition to the SF_6 concentration are air temperature within the Test Chamber and at the supply/exhaust air outlets, velocity profile at the supply-air outlet, and supply-air flow rate. Each test run is expected to last from 10 to 60 minutes and will be preceded by a preparatory/start-up period of up to about 2 hours, in which the Test Chamber will be cooled to a desired temperature. Each test cycle, comprising the actual test run and the start-up and shut-down procedures, may take up to 3 to 4 hours. The test runs will be conducted in compliance with the NERL safety regulations and will be scheduled in coordination with the TCL research staff to minimize interruption of their testing activities. The tentative plan is to complete all of the necessary tests within three months once the SOP is approved and the test facility is qualified.

D. Organizations involved

The tests will be conducted under the Building America Project managed by the Center for Buildings and Thermal Systems, Center 5500.

II. DESCRIPTION OF SAFETY & HEALTH HAZARDS AND CONTROLS

A. Hazardous Chemical/Materials

The only chemical to be used is Sulfur Hexafluoride (SF_6) characterized as:

- Non-flammable, inert, colorless, odorless, non-corrosive, and non-toxic.
- High vapor density, relative density of 5 (air = 1).
- Occupational Exposure Limits – TLV: 1000 ppm, TWA: 1000 ppm.
- Decomposes on heating above 500^{o}C (930^{o}F).
- Extinguishing media in case of fire: all known extinguishing agents allowed.
- The source of SF_6 will be a liquefied /compressed gas. Frostbite upon exposure to liquid contents is possible.
- SF_6 poses an asphyxiation hazard. Physical symptoms associated with over exposure include increased breathing and pulse rates, fatigue, and possibly unconsciousness.

Engineering Controls – To mitigate the inhalation risk, the following hazard controls will be in place:

- All gas system components will be compatible and properly rated for SF_6 service.
- The air/gas mixture will be continuously exhausted from the lowest part of the test chamber to the atmosphere outside the TTF during the tests. The exhaust system will minimize the possibility of air leakage from the Test Chamber to the TTF indoor space by maintaining a negative pressure in the Test Chamber. The speed of the supply air fan will be accordingly modulated using the variable frequency drive. The pressure of the test chamber relative to that of the TTF will be monitored using a differential pressure gauge.
- During any test involving SF_6, the gas concentration will be continuously measured and monitored at the points of supply and exhaust.
- The selected SF_6 bottle has only 8 oz of gas at 320 psig. Even if the entire gas content is accidentally released into the Test Chamber, the gas concentration would not exceed 550 ppm. (The volume of the test chamber under the suspended ceiling is about 2,900 cubic feet.)

Work Practice Controls – In addition to the Engineering Controls, the following measures will be taken:

- The Test Chamber will remain unoccupied during the tests. A thorough visual inspection of the entire test chamber will be performed prior to commencing each test.
- The main entrance door of the Test Chamber (facing the north wall of the TTF) and the access door at the partition will remain closed and sealed air tight using an appropriate adhesive tape during each test. Upon completion of each test involving SF_6 gas, the Test Chamber will be purged of the gas by shutting the gas bottle valve and running the supply and exhaust fans for 15 to 30 minutes before opening the doors. (The circulating fan between the Test Chamber and the walk-in freezer will also run during this purge period.)

Furthermore, the following gas cylinder safety requirements will also be met:

1. Each cylinder must be clearly labeled with the contents and appropriate hazard warnings. The label shall be visible while the cylinder is in use.
2. All gas cylinders in service or in storage shall be secured in an upright position.
3. The cylinder valve shall be kept closed at all times except when it is in use.
4. Attach the SF_6 regulator securely before opening the valve. Stand to one side when opening the valve. Open cylinder valves slowly.
5. Leak-check the gas delivery system. Check all mechanical connections to assure they are gas tight.
6. If a leaking gas cylinder is identified, move it outdoors to a well-ventilated area.
7. When storing or moving cylinders, have the protective caps (if applicable) securely in place to protect the valve stems.

B. Electrical

The electrical devices, including the electrical panelboards (DP-3 on the south wall and DP-5 on the north wall of the high-bay area) and the receptacles for the fans, are potential sources of electric shock and arc fault if they are not properly used. General electrical hazards such as electrocution exposure, ignition, and heat generation exist from the instruments and equipment, such as the heater and fans.

The electrical devices of the experimental apparatus are:

- An electric heater: 240 V, 3-phase, 6000 W, located in the supply-air apparatus (Figure 3)
- A centrifugal supply air fan controlled by a UL rated variable frequency drive (VFD): 230/460 V, 3-phase, 2 HP, located in the supply-air apparatus (Figure 3). The VFD specifications are: 380 – 460 V, 8.7 A, 50/60 HZ, 4.0 kW/5 hp.
- A UL rated exhaust fan: 115 V, single-phase, 90 W
- A UL rated circulating fan: 115 V, single-phase, 90 W
- Copeland freezer compressor/condenser unit: 460 V, 3-phase, 23 LRA

Engineering Controls

All existing and new electrical installations (equipment and wiring) will be in compliance with the applicable codes, including the National Electric Code (NEC) and NREL's Electrical Safety Program. All related circuit breakers will be labeled and checked for safe operation. The governing DOE/NREL's LO/TO procedures will be fully implemented for repair and maintenance of all electrical systems.

The existing temperature-limit controller will be calibrated and used to prevent overheating of the electric heater. The air temperature downstream of the heater will also be monitored by the data acquisition system. Furthermore, the electric heater will not be activated unless the supply air fan is activated first and the airflow is proven. Each power strip will be equipped with a ground-fault circuit interrupter (GFCI).

Work Practice Controls

Only NREL Site Operations Electricians are authorized to work on electrical devices, such as the freezer and the electrical panels and outlets. Work on energized equipment shall be avoided. However, taking voltage and current measurements is authorized provided that the worker is qualified and uses appropriate test equipment and the required personal protective equipment as specified in the NREL Electrical Safety Program. Energized work beyond this scope shall require an Electrical Safe Work Permit issued by the NREL ES&H Office. The electrical systems and components will be de-energized, locked and tagged out in compliance with the LO/TO procedure described in Appendix B. All high-voltage power lines and outlets are visibly labeled. All electrical instruments and equipment will be UL rated.

C. High Pressure

A compressed SF_6 bottle containing 8 oz of gas (Figure 1) and the necessary delivery system and accessories will be used to achieve the required gas concentrations in the supply air stream and the test chamber during the tests. The gas bottle will be equipped with a shut-off valve, a pressure regulator, and a gas flow meter with a digital display.

The compressed gas bottles to be used in the experiments are under 320-psig pressure. When released suddenly or under uncontrolled conditions, the potential for significant injury or property damage can occur. If not properly fastened, sudden release of high-pressure gas due to a damaged or malfunctioning valve can propel the bottle in an uncontrolled manner.

Engineering Controls

The installation and operation of the compressed SF_6 gas bottle will comply with the related safety guidelines established by the NREL Compressed Gas Safety Program. These guidelines encompass proper fastening of the bottle, valve protection, gas pressure regulators, etc. All gas system components are compatible and appropriately rated for SF_6 gas service.

Work Practice Control – See Work Practice Control in Section II.A.

D. Low Pressure

SF_6 gas will be injected into the supply air stream, immediately downstream of the supply-air apparatus through low-pressure (less than 2 in.w.g.) lines with proper compression fittings.

E. Temperature Extremes

The air temperature downstream of the heater in the supply-air apparatus (Figure 3) will be thermostatically controlled and will not exceed 140^{o}F.

Engineering Controls

The temperature-limit controller and the fan/heater interlock described in section II.B (Electrical) are the safety measures to prevent the heater from reaching excessive temperatures.

F. Machinery/Equipment

Potential contact with the moving blades and rotary parts of the 2-hp supply-air fan and the 90-W circulating and exhaust fans poses hazardous to the facility operators.

Engineering Control

The fans are equipped with full enclosures that prevent user contact with the moving parts. Under no circumstances can the enclosure guard be removed unless the fans are de-energized, locked and tagged out in accordance with the LO/TO Requirements described in Appendix B.

G. Noise

The sound levels of the supply and return air fans are not expected to exceed the sound levels of the fans used in the residential and light commercial air conditioning systems.

H. Radiation Sources (Non-Ionizing) – Not Applicable.

I. Natural Environmental Conditions – Snakes

Warm equipment may attract snakes when the reptiles are active. Rattlesnakes have been historically encountered around the TTF building.

Controls

The in-line heater in the supply-air apparatus is enclosed and externally insulated. The apparatus is positioned on a raised workstation in a manner that can be easily inspected from a distance for possible presence of snakes. If a snake is identified, the operator should not approach the snake. Call 1234 (outside phone number: 303-384-6811) to report the snake, keep other workers away, and monitor the snake from a safe distance until help arrives.

III. DESCRIPTION OF ENVIRONMENTAL HAZARDS AND CONTROLS

A. Air and Water Emissions

The maximum flow rate of the exhaust air (with a maximum SF_6 concentration of 20 ppm) will be about 200 scfm. At the end of each test cycle involving SF_6 gas, the test chamber and the ductwork will be purged of the gas by shutting the gas bottle valve and running the supply and exhaust fans for 15 to 30 minutes. The exhaust air temperature will not exceed 140^{o}F even when the heated supply air is directly exhausted through the bypass line.

The cooling water of the freezer condenser is not contaminated and is discharged through the existing floor drainage system at the TTF.

B. Hazardous Waste – Not Applicable.

C. Waste Minimization - Efforts will be made to minimize unnecessary use of water (for the water-cooled freezer) and SF_6 gas.

D. Decommissioning – At the conclusion of this experimental project, the facility will be decommissioned per requirements of the NREL ES&H Office. No significant decommissioning issues are envisioned.

IV. ASSEMBLY/OPERATIONAL PROCEDURES

<u>Start UP</u>

1. *Ensure proper connection/installation of experimental equipment and the safety devices in accordance with the safety measures described in Section II and the manufacturers' operating manuals. (Equipment: SF_6 gas bottle and delivery system, gas sampler, electric heater, fans, electrical outlets, instruments, and data acquisition system.)*

2. *Shut off the supply and exhaust gate valves and open the bypass gate valve in the Equipment Room.*

3. *Turn on the data acquisition system and instruments, including the temperature-limit controller of the electric heater. Plug the power strips and the power cords for the fans.*

4. *If pre-cooling of the Test Chamber is required:*

    - *Turn on the circuit breaker 23 on panelboard DP-5 located on the North wall of the TTF. Adjust the freezer thermostat and turn on the freezer power switch located in the freezer walk-in compartment.*
    - *Once the walk-in freezer temperature reaches about 50^{o}F, activate the circulating fan (by turning on the power strip #2) and run it until the Test Chamber is cooled down to a pre-determined temperature (e.g., 65^{o}F).*
    - *Turn off the circulating fan – unplug or turn off the power switch.*
    - *Turn off circuit breaker 23 on panelboard DP-5 located on the north wall of the TTF.*

5. *Activate the supply fan by turning on the VFD (on the east wall of the Air Flow Test Room) and the exhaust fan by the power strip on/off switch. <u>Confirm operation</u> of the fans by examining the flow measurements. Adjust the supply air fan speed by adjusting the VFD frequency to achieve the desired air flow rate and a negative gauge pressure (e.g., -0.05 in.w.g.) in the Test Chamber.*

6. *Adjust the heater thermostat (between 80^{o}F and 140^{o}F) and activate the heater by turning on circuit breakers 18, 20, and 22 on electrical panelboard DP-3 located on the south wall of the high-bay area.*

7. *For tests involving SF_6 gas, once the desired supply air temperature is reached, slowly open the gas valve (on the east wall of the Air Flow Test Room) and regulate the gas flow into the supply air stream to achieve a concentration of up to 20 ppm in the stream. (This will require a gas flow rate of about 0.0005 lbm/hr. per cfm of the supply air.)*

8. *Open the supply and exhaust gate valves and shut off the bypass gate valve in the Equipment Room to allow flow of air through the Test Chamber.*

9. *Begin the test and collect data.*

10. *Throughout the test, regularly monitor the key variables, including the SF_6 concentration and temperature of the supply and exhaust air streams.*

Shut Down

1. *Shut off the SF_6 gas bottle valve (on the east wall of the Air Flow Test Room).*

2. *Turn off the heater by turning off circuit breakers 18, 20, and 22 on electrical panelboard DP-3 located on the south wall of the high-bay area.*

3. *Allow the supply and exhaust fans to run for 15 to 30 minutes at a relatively high flow rate to purge the test chamber of the SF_6 gas.*

4. *Turn off the supply fan at the VFD controller on the east wall of the Air Flow Test Room.*

5. *Turn off the exhaust fan by the power strip on/off switch in the Equipment Room.*

6. *Properly shut down the data acquisition system and turn off all instruments as necessary.*

7. *Unplug all electrical power cords, including those of the power strips.*

8. *Open the entrance doors of the Air Flow Test Room and the walk-in freezer (after the freezer is turned off by circuit breaker 23 on panelboard DP-5 located on the north wall of the TTF – see item #4 of the Start Up procedure.)*

V. PERSONNEL TRAINING

The personnel must take the following training classes offered by the NREL ES&H Office:

- *Sulfur Hexaflouride (SF_6) Compressed Gas Safety*
- *Chemical Safety Waste Management & Minimization*
- *Electrical Safety*

- *Lockout/Tagout*

VI. EMERGENCY INFORMATION

In case of emergency, call extension 1234 and report the nature and location of the emergency. In the event of a fire, activate the building fire alarm system and call extension 1234 from a safe location. If using an outside phone, call 303-384-6811.

<u>Emergency shut down procedure:</u>

In case of emergency, shut down the main system components in the following order:

1. *The sulfur hexaflouride (SF_6) gas bottle valve on the east wall of the TTF Air Flow Test Room.*
2. *The electric heater of the supply-air apparatus – circuit breakers 18, 20, and 22 on electrical panelboard DP-3 located on the south wall of the high-bay area.*
3. *The fan of the supply-air apparatus – red push-button switch on the variable frequency drive located on the east wall of the TTF Air Flow Test Room*
4. *The exhaust fan – power strip switch.*
5. *The air circulation fan – power strip switch.*
6. *The walk-in freezer system – circuit breaker 23 on electrical panelboard DP-5 located on the north wall of the high-bay area.*

VII. AUTHORIZED PERSONNEL

The personnel authorized to operate the Building America Air Distribution/Diffusion Test Facility are:

• *Ed Hancock*	*Contractor*	*X6194*
• *Ali Jalalzadeh*	*Center 5500*	*X7562*
• *Ren Anderson*	*Center 5500*	*X7433*
• *Keith Gawlik*	*Center 5500*	*X7515*

Center Director: Ron Judkoff (X7520)

VIII. REFERENCES

All the available manuals for the equipment will be located on the mobile workstation outside the Air Flow Test Room.

IX. **Appendix B** – Lockout/Tagout (LO/TO) Procedures

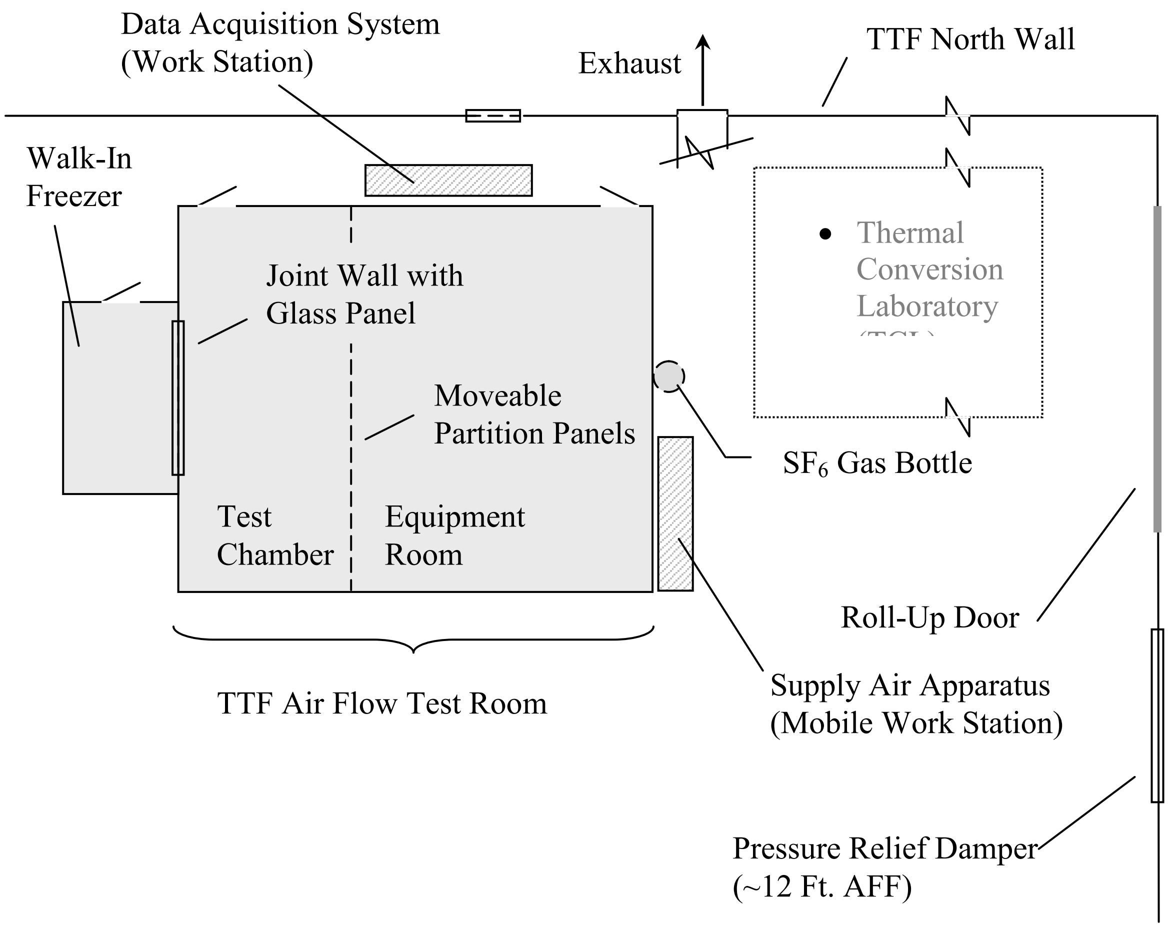

Figure 1. Test Facility Layout – Not To Scale

Figure 2. Test Facility – Test Chamber (a) and Equipment Room (b)

Total Length: ~ 12 ft.

6-kW Electric Heater
(Externally Insulated)

Instrumented
Transparent Duct

H.W. Heater
(Disconnected)

2-HP Fan
With VFD

(a)

Mobile Work Station

Supports

Transition to 8-in. Round Duct

Figure 3. Schematic (a) and Photo (b) of Supply Air Apparatus – Not To Scale

Figure 4. Exhaust Duct System of Thermal Conversion Laboratory at TTF

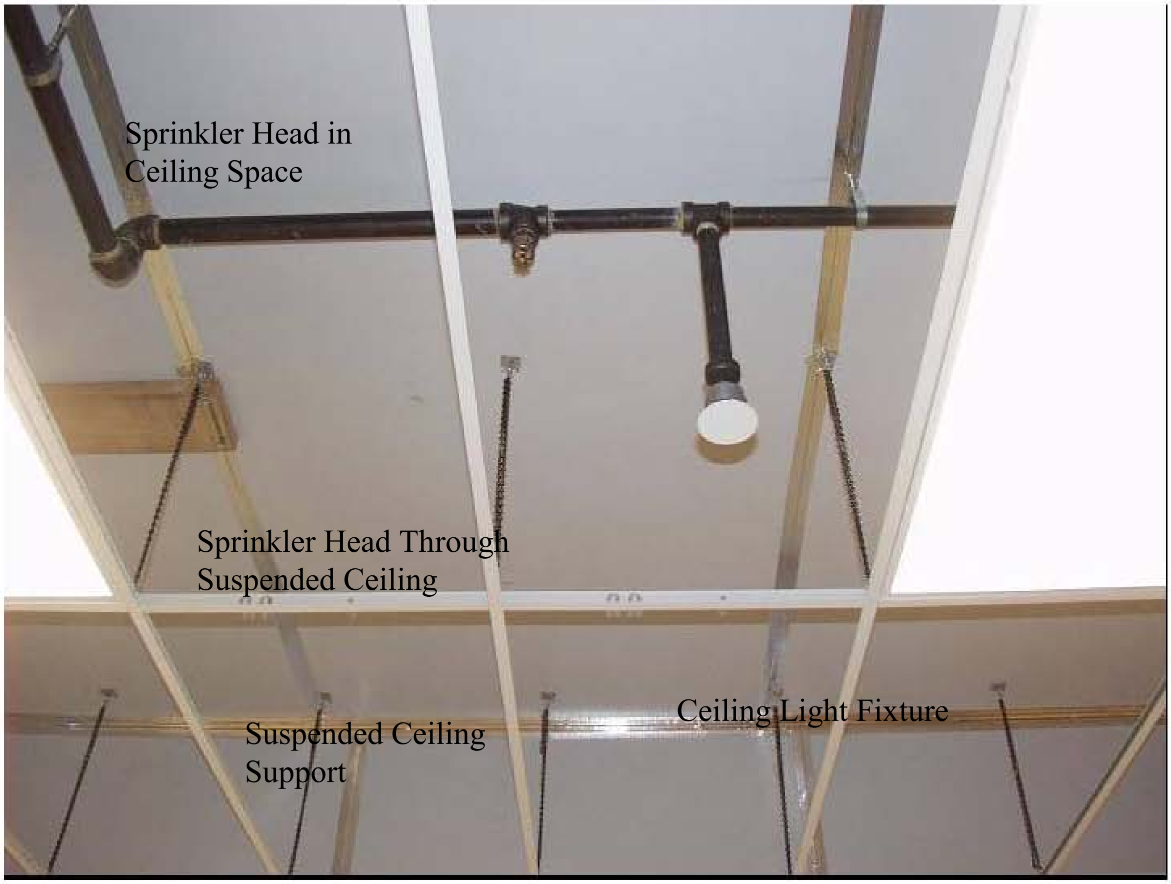

Figure 5. Existing Sprinkler System in Test Room

Appendix B - Lockout/Tagout (LO/TO) Procedures

Follow the procedure described below to de-energize and lock and tag out the systems/components per NREL LO/TO requirements. This procedure must be completed prior to performing repair, service, or maintenance to the experimental equipment.

1. Electrical

- Electric Heater: Turn off the circuit breakers 18, 20, and 22 on the 120/208-V panelboard (DP-3) on the south wall of the high-bay area. Apply breaker lockout devices and a properly completed NREL LO/TO tag and lock. Also, unplug the temperature-limit controller.

- Supply-Air Fan (2-hp motor): De-energize the motor by turning off the variable frequency drive and unplugging the cord. Apply power cord lockout devices and a properly completed NREL LO/TO tag and lock.

- Exhaust and circulating Fans (with 90-W motors): Unplug the fan motors at the power strip and apply power cord lockout devices and a properly completed NREL LO/TO tag and lock.

- Follow the Fan LO/TO Procedure if fan guards are removed for any purpose or electrical work is performed on the fan motor. The fan is de-energized by unplugging the power cord. As long as work is performed with the "plug" in the immediate and continuous control of the worker, no LO/TO is required. However, if the worker leaves the immediate area before the fan is restored to normal operating condition, LO/TO of the plug is required. Apply a plug LO/TO device with properly completed LO/TO tag and lock.

- Freezer: Turn off the circuit breaker 23 on the 120/208-V panelboard (DP-5) on the north wall of the high-bay area. Apply breaker lockout devices and a properly completed NREL LO/TO tag and lock.

2. Compressed Gas

- Shut off the valve of the SF_6 gas bottle located on the east wall of the TTF Air Flow Test Room. Apply clamshell LO/TO device and a properly completed NREL LO/TO tag and lock.

3. Conduct Work.

4. Inspect the area, verify that tools are removed and the equipment is ready to be returned to normal operation.

5. Return equipment to proper and safe operating condition. Replace guards, interlocks, and other equipment.

6. Notify affected workers that equipment will be starting.

7. Remove LO/TO locks and devices. Return operating controls and data acquisition system to "normal operating" position.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. **REPORT DATE** *(DD-MM-YYYY)*	2. **REPORT TYPE**	3. **DATES COVERED** *(From - To)*
December 2007	Technical Report	

4. **TITLE AND SUBTITLE** Experimental Evaluation of Indoor Air Distribution in High-Performance Residential Buildings: Part I. General Descriptions and Qualification Tests	5a. **CONTRACT NUMBER** DE-AC36-99-GO10337
	5b. **GRANT NUMBER**
	5c. **PROGRAM ELEMENT NUMBER**
6. **AUTHOR(S)** A.A. Jalalzedeh-Azar	5d. **PROJECT NUMBER** NREL/TP-550-40392
	5e. **TASK NUMBER** BEC78004
	5f. **WORK UNIT NUMBER**
7. **PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)** National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393	8. **PERFORMING ORGANIZATION REPORT NUMBER** NREL/TP-550-40392
9. **SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**	10. **SPONSOR/MONITOR'S ACRONYM(S)** NREL
	11. **SPONSORING/MONITORING AGENCY REPORT NUMBER**

12. **DISTRIBUTION AVAILABILITY STATEMENT**
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. **SUPPLEMENTARY NOTES**

14. **ABSTRACT** *(Maximum 200 Words)*
The main objective of this project is to experimentally characterize an air distribution system in heating mode during a period of recovery from setback. The specific air distribution system under evaluation incorporates a high sidewall supply-air register/diffuser and a near-floor wall return air grille directly below. With this arrangement, the highest temperature difference between the supply air and the room can occur during the recovery period and create a favorable condition for stratification. The experimental approach will provide realistic input data and results for verification of computational fluid dynamics modeling.

15. **SUBJECT TERMS**
air distribution; high-performance building; building america; supply air; return air; s.a.; r.a.

16. **SECURITY CLASSIFICATION OF:**			17. **LIMITATION OF ABSTRACT**	18. **NUMBER OF PAGES**	19a. **NAME OF RESPONSIBLE PERSON**
a. **REPORT**	b. **ABSTRACT**	c. **THIS PAGE**			
Unclassified	Unclassified	Unclassified	UL		19b. **TELEPHONE NUMBER** (*Include area code*)

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18