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Investigative Chemistry Geotechnical Construction Materials
Non Destructive Testing Failure Analysis Product Evaluation
Metallurgical Analysis Materials Testing Welder Qualification

**TEMPERATURE PERFORMANCE TEST OF
AKDUCT PLASTIC vs. PVC DUCTING
BY COHEAT TEST METHODOLOGY**

**Prepared for:
CDC ENTREPRISES, INC.
Attn: Mr. John Jungers
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Client Purchase Order Number: 1155

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The test results contained in this report pertain only to the samples submitted for testing and not necessarily to all similar products.

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INTRODUCTION:

This report presents the results of a thermostat-controlled temperature Thermal Distribution Efficiency (TDE) comparison test, based upon total energy utilization, conducted on two types of underground heating/AC duct pipe. The same Honeywell standard thermostat was used for all tests and the thermostat was set at 75° F for each test. Only the thermostat setting controlled the heating cycle of the furnace and electric heater to provide heat upon demand to maintain the a room temperature of 75° F. Included in the data is the total energy utilization of the thermostat-controlled coheat performance with the comparison of electric space heaters to determine the Thermal Distribution Efficiency (TDE) and total energy costs of the duct systems to a ductless system. The testing was requested by Mr. Jon Jungers of CDC Enterprises / AKDUCT on September 15, 2008.

The scope of work was limited to documenting the test set-up, parameters and results of a controlled temperature performance comparison test to substantiate that the self insulating nature of AKDUCT plastic duct pipe buried directly underground has an equivalent performance in comparison to the standard referenced design of PVC duct pipe insulated per Wisconsin Uniform Dwelling Code (UDC) & Commercial Building Code (CBC). The test was conducted within the East Central Solid Waste Commission recycling building in Mora, MN between October 1 and 15, 2008.

TESTING METHODOLOGY:

Testing the TDE of a forced air distribution system can be difficult because of differing characteristics between materials used for underground duct systems and the lack of uniform testing methodologies prescribed within ASTM testing standards for thermal transmittance. The protocol for this test is based upon the study; Measuring residential duct efficiency with short-term coheat test methodology. Conducted by Paul W. Francisco, Jeffery Siegel, Larry Palmiter and Bob Davis. The basis for their study was to determine a more accurate system of measurement of thermal efficiency of duct systems.

In the study it is stated on page 1077: *“Of the two efficiency metric, delivery effectiveness is the easier to measure”*. Delivery effectiveness is defined in ASHRAE 152 as; *“The ratio of the thermal energy transferred to or from the conditioned space to the thermal energy transferred at the equipment distribution system heat exchanger. Energy delivered to or from the conditioned space includes distributions losses to the conditioned space”*.

The stated Purpose in ASHRAE 152 of: *“This standard prescribes a method of test to determine the efficiency of space heating and/or cooling thermal distribution systems under seasonal and design conditions. The object is to facilitate annual energy calculations and heating and cooling capacity calculations”*. Many of the testing methodologies require a return as well as supply air system within a building and, the object of the prescribed method of testing is to provide estimates of the efficiency of thermal distribution systems including the heat exchanger. A method of testing only the duct system for thermal energy transfer was not found.

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TESTING METHODOLOGY: (cont')

The testing utilized two identical high-efficiency 60,000 BTUH Maytag Furnaces, Model #PGF1RL060C12A installed by a professional HVAC contractor onto identical AKDUCT plenums. Attached to one furnace and plenum were four sections of 12" ID standard PVC air duct pipes with each measuring ten feet in length. The duct pipes were installed with two inch thick R-10 extruded polystyrene foam insulation on the bottom, both sides and top as required for the standard referenced design in Wisconsin Codes. Attached to the other furnace and plenum were 5 sections of 12" ID AKDUCT air duct pipes with each measuring eight feet in length, which were installed without external insulation. Each forty foot length of 12" ID air duct pipe had three air supply fittings attached onto the pipe at identical locations of 13, 26 & 37 feet from the furnace plenum and identical 4" x 12" rectangular areas were cut into each pipe for the air supply fittings. After proper assembly was completed each underground air duct system was covered with sand in a trench which measured 53 feet in length by 7.5 feet in width by 6.5 feet in depth.

The limitations of the "Test Room" described below only allowed for testing the supply side of an air distribution system without a return system. In lieu of extensive calculations it was decided that specific measurements at strategic locations would be recorded and the best method of determining total energy consumption would be actual weight measurement and the recording of total pounds of liquid propane utilized for each test. This method would allow for thermal regain, as defined by ASHRAE 152 as "the fraction of distribution losses that are returned to the conditioned space", without additional calculations due to the test being controlled by the 75°F setting of the thermostat.

The forty foot by ten foot "test room" was constructed by placing two 20' x 10' tent canopies end-to-end and draping a roll of 12' x 100' clear plastic with a 5 mil thickness for walls. A return air system was not constructed, but a section of the roof was covered and not sealed between the two canopies allowing for pressurized air to escape which normally would have been returned to each furnace. The "test room" was located within a 180' long by 150' wide by 35' high structural steel building with a sheet metal exterior. The building was not heated, but it is insulated. Approximate area of the building exceeds 800,000 cubic feet and the "test room" was less than 4,000 cubic feet.

Each underground air duct system was tested for a 24 hour period and data was recorded every two minutes and stored on a Fluke Series II Hydra Data Recorder. The temperature readings were taken by using industry standard Type T thermocouples connected to the data recorder and placed in the following locations as listed in table on page 4.

TESTING METHODOLOGY: (cont')

Gauge Placement	
AK Duct	PVC Duct
Inside Plenum	Inside Plenum
Inside Duct, 12" from Plenum	Inside Duct, 12" from Plenum
1st Register, outside duct, bottom	1st Register, outside duct, bottom
1st Register, outside duct, top	1st Register, outside duct, top
1st Register, inside duct, bottom	1st Register, inside duct, bottom
1st Register, inside duct, top	1st Register, inside duct, top
1st Register, in air stream	1st Register, in air stream
2nd Register, in air stream	2nd Register, in air stream
3rd Register, outside duct, bottom	3rd Register, outside duct, bottom
3rd Register, outside duct, top	3rd Register, outside duct, top
3rd Register, inside duct, bottom	3rd Register, inside duct, bottom
3rd Register, inside duct, top	3rd Register, inside duct, top
3rd Register, in air stream	3rd Register, in air stream
Furnace Return Air	Furnace Return Air
Room Temp at Thermostat	Room Temp at Thermostat
8" from centerline of duct, 4-5" below surface.	8" from centerline of duct, 4-5" below surface.
Ambient air (near logger)	Ambient air (near logger)
Furnace heat call	Furnace heat call

Each test for the AKDUCT system and the standard referenced design of PVC insulated with R-10 prescribed by the WCBC used liquid propane to fuel the furnace. Each 100 pound liquid propane tank was weighed prior to the test using a Lebow 200.00 lb load cell scale and each was weighed again after completion of the 24 hour test and the amount of liquid propane used by each furnace was recorded. The tests were scheduled with at least one day between testing to negate any thermal influence from the previous testing in the "Test Room". A 24 hour test minimizes external factors such as outside temperatures that were recorded on two minute intervals throughout each day of testing. The location of the "test room" within a building 200 times larger than the "test room" minimizes temperature fluctuations, solar influence (no windows in the structural steel building) and wind.

Every effort to make the testing identical was taken and the methodology used is based upon similar testing methods for delivery effectiveness, thermal distribution efficiency and thermal regain of the underground duct systems and were incorporated into the testing protocol. The coheat test from the study: *Measuring residential duct efficiency with short-term coheat test methodology*; was also performed to collect data for the determination of thermal distribution efficiency of the duct systems compared to ductless heating. It is noted that Paul W. Francisco, one of the researchers participating in the referenced study of coheat test methodology, is the Chairman of the ASHRAE 152 Committee.

Tests for air flow within the air duct pipe and at each of the three air supply registers were conducted and the data from the readings at multiple settings of the furnace blower are included in this report.

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SUMMARY OF RESULTS:

The thermostat-controlled temperature performance test conducted demonstrated an apparent equivalency of the AKDUCT system with consistent and comparable performance of the PVC system for this series of tests when insulated per standard referenced designs prescribed by Wisconsin codes: Uniform Dwelling Code requires R-5 insulation on the bottom, both sides and the top of the underground duct and the Commercial Building Code requires R-8 insulation on the bottom, both sides and the top of the underground duct. This test was conducted by using R10 insulation on the bottom, both sides and the top, which exceeds the requirements for insulation for both the Wisconsin UDC & CBC codes.

The AKDUCT ½” HDPE that is a self-insulating material, shows a significant difference for thermal conductivity by maintaining consistently larger interior-to-exterior duct surface temperature differentials compared to PVC duct as illustrated in the Duct Surface table below and portrayed on the two, two-hour expanded time graphs on pages 9 & 10. The test is a demonstration of heat transfer through a pressurized air duct system and shows the other factors that may contribute to the complexity of heat conduction measurements, such as: thermal transmittance that includes convection plus radiation; pressurized air movement; radiation through a cylindrical surface, emmisivity of the duct surface, thermal diffusivity of underground air ducts; and all could contribute directly or indirectly to the total fuel utilization efficiency of the duct system.

Duct Surface temperatures of PVC versus AK DUCT													
	Mean Average Outlet Air Temp, °C	Duct Temp at Start 2 Minutes into Test, °C				Duct Temp at End of Test/Last Cycle Peak, °C				Mean Average Temp over 24hrs, °C			
		Top - Inside	Top - Outside	Bottom - Inside	Bottom - Outside	Top - Inside	Top - Outside	Bottom - Inside	Bottom - Outside	Top - Inside	Top - Outside	Bottom - Inside	Bottom - Outside
PVC													
Register 1	38.1	13.9	13.9	14.1	14.2	48.7	45.5	48	42.9	43	42.5	41.9	40.6
Register 3	38.1	14.7	14.7	14.5	14.8	44.6	42.3	43.3	40	41.3	40.2	38.9	38
Sand Temp*		13.7				18.4				17.1			
Duct Temp**		13.9				50.2				42.5			
AKDUCT													
Register 1	34.7	14.4	14.2	14.7	15.1	42.2	30	43	28	38.3	27.4	37.6	26.3
Register 2	35	14.2	13.8	14.6	15.1	36.3	28.5	35	25.2	32.8	25.8	31.5	23.1
Sand Temp*		13.6				27.7				24.3			
Duct Temp**		14.1				51.1				41.4			

*8" from centerline of duct, 4-5" below surface.
 **Center of duct, 12" from plenum.

SUMMARY OF RESULTS: (cont')

The systems from the energy utilization data obtained during the testing at comparable air flows (see table below and on page 7) also, indicated that the AKDUCT system showed an apparently better energy utilization comparable to the PVC system.

Fuel Utilization Over 24hr Period					
	Liquid Propane Usage		Kilowatt usage		Estimated Total Cost** per 24hrs
	lbs per 24hrs	BTU* Energy	KW per 24hrs	BTU* Energy	USD
PVC 1st Run	52.4	4,787,120	8.72	29,753	\$41.04
PVC 2nd Run	43.9	4,008,070	7.58	25,863	\$34.42
AK DUCT	38.4	3,140,720	6.63	22,633	\$30.11
Coheat Test	n/a - see note #2		121.8	831,300	\$34.10

Note #1 – First 24 hr test run of project where temperature data failed to record correctly on the recorder but, the furnace KW recorded and the weight of propane was obtained as precursor to second test run.

Note #2 – Test Room size reduced to 825 cubic feet from the 1,650 cubic foot duct test room size. The room was heated using five (5) 900 watt space heaters, four constantly “On” for the 24 hour period and one connected to the thermostat to cycle on & off to help maintain the room temperature. The actual Kilo Watt value recorded during the test was 25.38 KW of energy consumed by one of the heaters constantly “On” for the 24 hour period. This value was also assumed as the consumption for the other (3) constantly “On” heaters. The thermostat controlled heater was estimated at 80% (20.30 KW) “On” time energy consumption and the calculated BTU usage doubled to reflect a 1,650 room size.

* BTU values obtained using 1 lb propane = 91,300 BTU and 1 kilo watt = 3,412 BTU.

** Estimated Cost values obtained using \$0.76 / lb of propane (\$3.30/gal) and \$0.14 / Kilo Watt Hour.

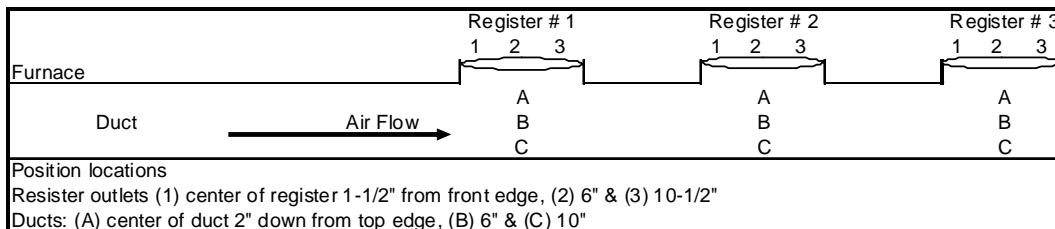
Tests for air flow within the air duct pipe and at each of the three air supply registers were conducted with a Thermal Anemometer with the furnace blower at the lowest setting of 800 CFM, medium setting of 1180 CFM and the highest setting of 1310 CFM and show that the Friction Loss/Pressure Drop for the PVC Duct and the AKDUCT were comparable and uniform at Registers #1 and #2, but slightly more favorable for AKDUCT at Register #3. The TDE tests were all conducted with the furnace blower at the lowest setting of 800 CFM because of the small test room area.

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SUMMARY OF RESULTS: (cont')

Flow Test with Thermo-Anemometer									
Furnace Setting	800 CFM*								
	Register 1			Register 2			Register 3		
	Position #1 (f/m)	Position #2 (f/m)	Position #3 (f/m)	Position #1 (f/m)	Position #2 (f/m)	Position #3 (f/m)	Position #1 (f/m)	Position #2 (f/m)	Position #3 (f/m)
PVC (at Register)	260	985	1590	470	1240	1440	355	1460	1450
AK (at Register)	260	840	1235	390	1180	1590	580	1580	1700
	Position #A (f/m)	Position #B (f/m)	Position #C (f/m)	Position #A (f/m)	Position #B (f/m)	Position #C (f/m)	Position #A (f/m)	Position #B (f/m)	Position #C (f/m)
PVC (in Duct)	1380	1360	1380	1040	1080	1010	920	490	490
AK (in Duct)	1360	1320	1380	1190	1060	1005	780	540	440
PVC (at Register, avg)		945			1050			1088	
AK (at Register, avg)		778			1053			1287	
PVC (in Duct, avg)		1373			1043			633	
AK (in Duct, avg)		1353			1085			587	
Furnace Setting	1160 CFM*								
	Register 1			Register 2			Register 3		
	Position #1 (f/m)	Position #2 (f/m)	Position #3 (f/m)	Position #1 (f/m)	Position #2 (f/m)	Position #3 (f/m)	Position #1 (f/m)	Position #2 (f/m)	Position #3 (f/m)
PVC (at Register)	380	700	1560	450	1540	1900	350	1760	1800
AK (at Register)	300	680	1851	340	1380	1830	600	1760	1900
	Position #A (f/m)	Position #B (f/m)	Position #C (f/m)	Position #A (f/m)	Position #B (f/m)	Position #C (f/m)	Position #A (f/m)	Position #B (f/m)	Position #C (f/m)
PVC (in Duct)	1750	1675	1590	1510	1200	1150	740	560	550
AK (in Duct)	1830	1850	1920	1280	1210	1160	700	590	545
Furnace Setting	1310 CFM*								
	Register 1			Register 2			Register 3		
	Position #1 (f/m)	Position #2 (f/m)	Position #3 (f/m)	Position #1 (f/m)	Position #2 (f/m)	Position #3 (f/m)	Position #1 (f/m)	Position #2 (f/m)	Position #3 (f/m)
PVC (at Register)	680	865	1525	500	1640	1820	350	1680	1750
AK (at Register)	580	800	1800	500	1500	1900	430	1700	1850
	Position #A (f/m)	Position #B (f/m)	Position #C (f/m)	Position #A (f/m)	Position #B (f/m)	Position #C (f/m)	Position #A (f/m)	Position #B (f/m)	Position #C (f/m)
PVC (in Duct)	1580	1530	1560	1275	1195	1140	810	570	495
AK (in Duct)	1750	1725	1780	1310	1200	1180	760	575	530

*Furnace flow settings are presented as printed on manufacturers literature, actual flow from each furnace not verified by TCT



SUMMARY OF RESULTS: (cont')

Register output flows using a Balometer Flow Hood were also taken with the furnace blower at the lowest setting of 800 CFM, medium setting of 1180 CFM and the highest setting of 1310 CFM.

Air Flow Test with ALNOR LoFlo Balometer Hood									
Furnace Setting	800 CFM*			1160 CFM*			1310 CFM*		
	Duct 1 (cfm)	Duct 2 (cfm)	Duct 3 (cfm)	Duct 1 (cfm)	Duct 2 (cfm)	Duct 3 (cfm)	Duct 1 (cfm)	Duct 2 (cfm)	Duct 3 (cfm)
PVC	189	211	259	230	251	313	246	271	325
PVC w/VENT	235	257	252	243	259	289	255	266	300
AK	190	226	282	225	274	339	230	275	348
AK W/VENT	211	228	243	261	287	299	259	289	300

Flow hood system was provided by CDC Enterprises, Inc.

*Furnace flow settings are presented as printed on manufacturers literature, actual flow from each furnace not verified by TCT

CONCLUSIONS OF THE SUMMARY:

The testing conducted demonstrates that the thermal characteristics are comparable for the AKDUCT™ as the PVC duct, with the R-10 insulation configuration on the bottom, both sides and the top, which is currently the standard referenced design method of installation for underground air duct systems per Wisconsin Code.

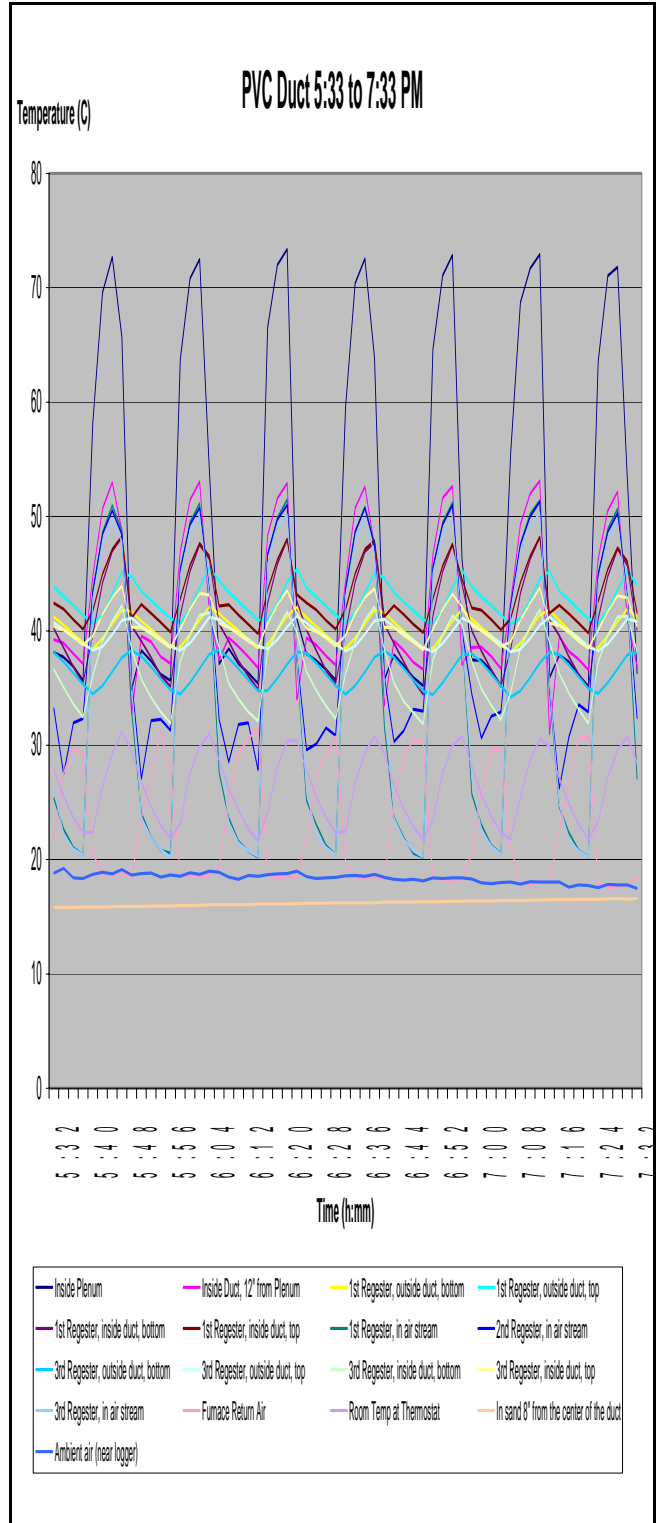
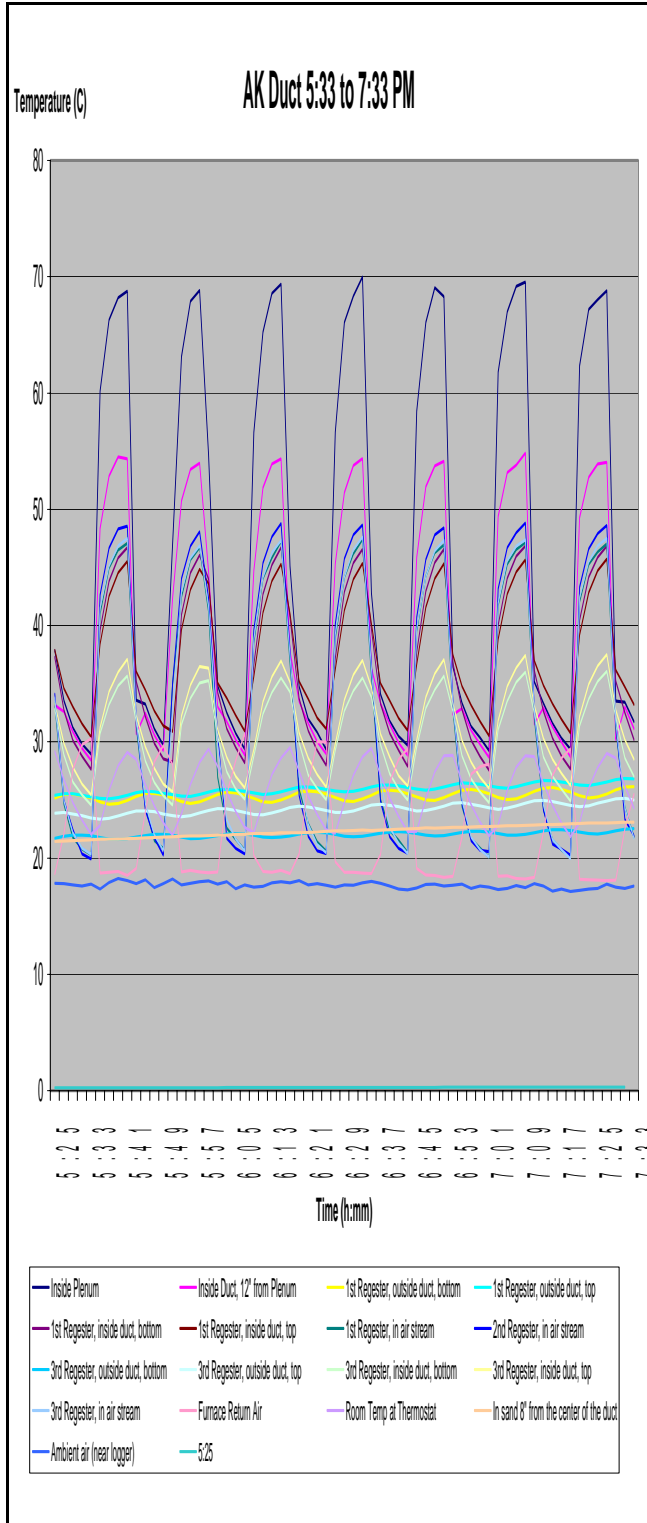
Both systems cycled normally and provided adequate heat delivery effectiveness throughout the 24 hour testing cycle. The All Points Data Graphs from 4--6 hours after the start of each test on page 9 illustrates nearly identical cycles and similar readings for most temperature measurements. In contrast, the All Points Data Graphs from 16--18 hours after the start of each test (see page 10) is significantly different for the PVC Duct insulated with R-10, showing much longer running cycles and greatly reduced temperature readings as compared to the AKDUCT system continued to cycle close the same parameters of the 4—6 hour data points.

The chart on page 6 for the Total Fuel Utilization shows more favorable energy usage by the oil-filled electric heaters if selecting only for total BTU's of energy. If the selection is made by Estimated Total Cost per 24 hours the AKDUCT system is clearly favored. In all fairness the coheat test would not favor the oil-filled heaters if a return air system had been assembled and the heat exchanger equipment (furnaces) were located within the Test Room envelope as in a standard building installation.

The testing results from the data obtained indicates an equivalency of thermal distribution efficiency and delivery effectiveness of the AKDUCT system and the PVC Duct insulated with R-10 in a standard reference design for code compliance.

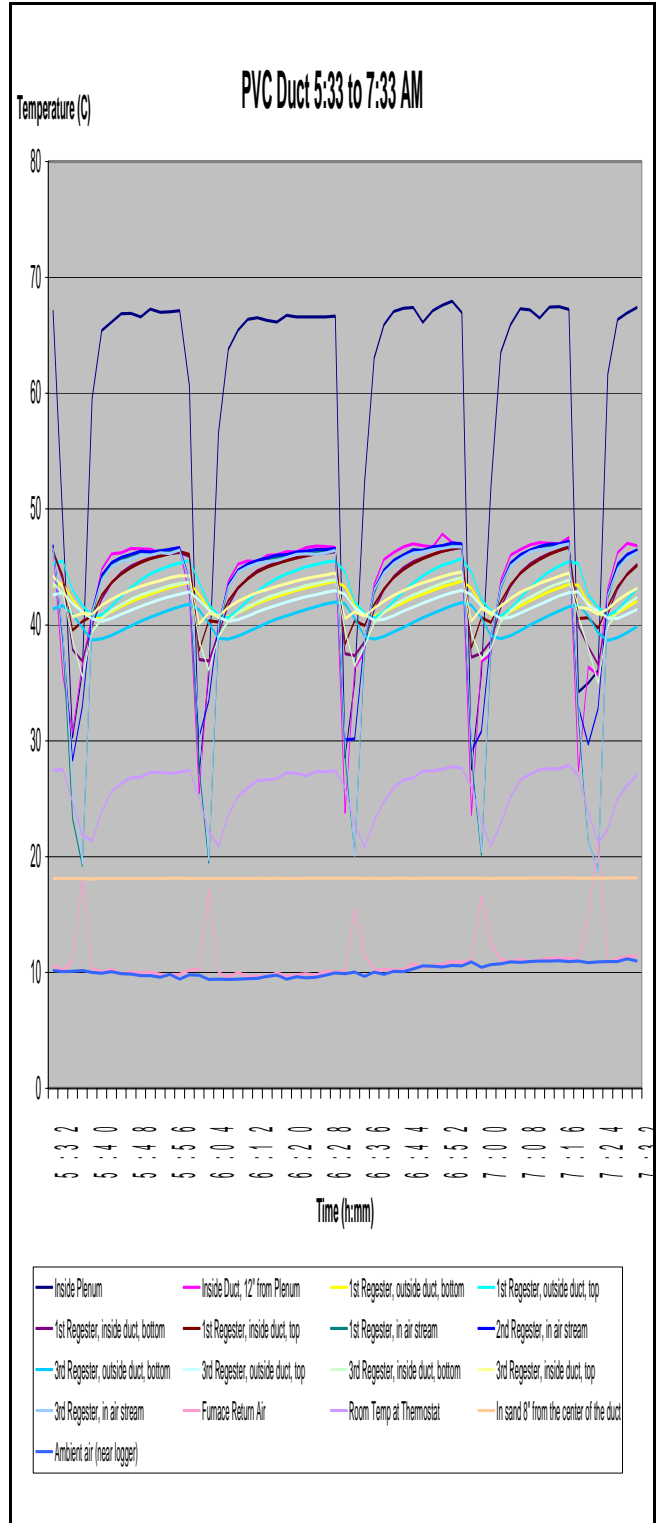
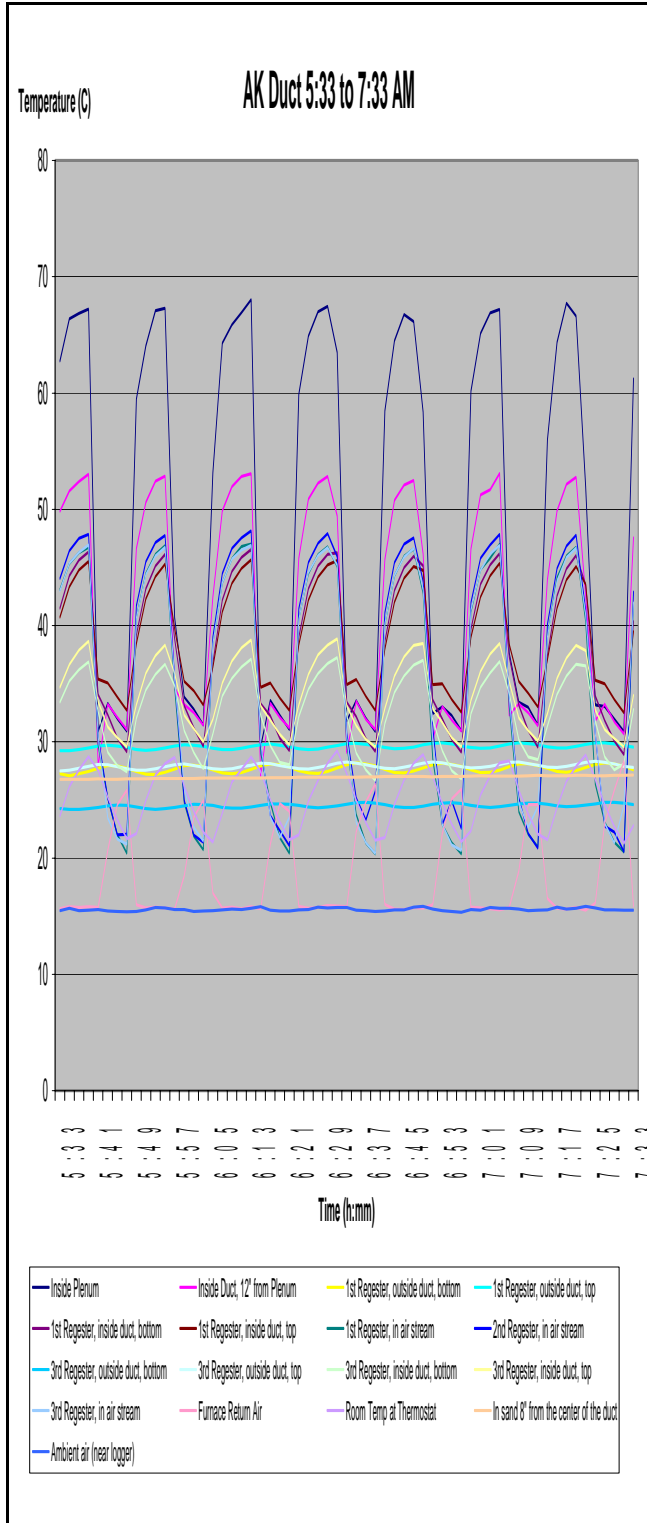
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TEST DATA: All Points Data from 4 – 6 hours after start of each test



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TEST DATA: (cont') All Points Data from 16 – 18 hours after start of each test



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The entire data base of All Data Points with 720 readings of temperature measurements at each location and a series of three graphs for AKDUCT, PVC with R-10 and the Electrical test may be obtained upon individual request by contacting Dan Stevens at CDC Enterprises, Inc. or by e-mail at dstevens@cdcei.net

PHOTOGRAPH:

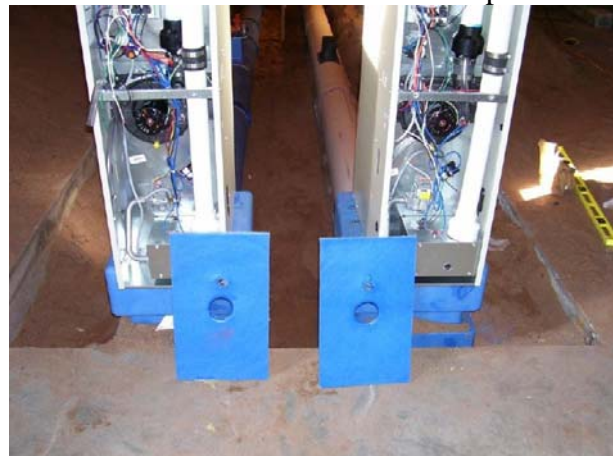
Coheat test set-up partially under way showing orientation of the furnaces, plenums, ducts, 1st register locations and insulating system of the PVC duct.



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PHOTOGRAPHS:

Duct and furnace attachment to the plenums



Register attachment to the two duct systems

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R-10 PVC duct insulating system prior to final back filling.



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The identical furnaces outside the test room each with 100 lb LP tanks



Furnaces viewed from inside test room

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View of inside of test room from register #3 showing completed installation of duct systems.
The furnaces thermostats are located on post between registers 1 & 3.



View of electrical heat test set-up



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View of air outlet in canopy of test room instead of return air duct system to furnaces



View of air outlet covered but not sealed



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View of the test room pressurized by furnace blower during testing

**TEST EQUIPMENT:**

Temperature: Fluke Hydra Series II, 20 channel Data Logger Tology # 92705

Air Flow: Dwyer Series 471 Digital Thermo Anemometer

LP Tank Weights: 200.00 lb Lebow Load Cell, TCT# MM110-001

Electrical Power: Kill-A-Watt™ Model P4400, S/N SI 76585 Watt Meter:

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