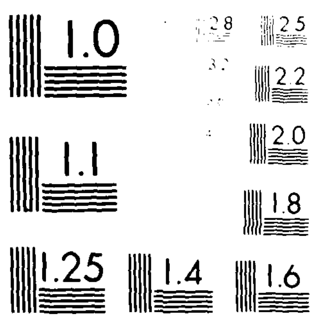
AD-A113 484 JOHNS-MANVILLE SALES CORP DENVER CO RESEARCH AND DEV--ETC F/G 13/1
EFFECT OF OUTSIDE COMBUSTION AIR ON GAS FURNACE EFFICIENCY.(U)
OCT 81 T E BRISBANE, K L HANCOCK DAAK70-78-D-0002

UNCLASSIFIED USAFESA-TS-2104 NL

1 OF 2
AD A
113484


1.0
2.8
2.5
3.2
2.2
2.0
1.1
1.8
1.25
1.4
1.6

(13)

US Army Corps of Engineers

Facilities Engineering Support Agency

REPORT FESA-TS-2104

AD A113484

EFFECT OF OUTSIDE COMBUSTION AIR ON GAS FURNACE EFFICIENCY

THOMAS E. BRISBANE
KATHLEEN L. HANCOCK
JOHNS-MANVILLE SALES CORPORATION
RESEARCH & DEVELOPMENT CENTER
KEN-CARYL RANCH, DENVER, COLORADO 80217

OCTOBER 1981

FINAL REPORT FOR PERIOD 18 SEPTEMBER 1980 - 15 OCTOBER 1981

APPROVED FOR PUBLIC RELEASE/DISTRIBUTION UNLIMITED

PREPARED FOR:

U. S. ARMY FACILITIES ENGINEERING SUPPORT AGENCY
TECHNOLOGY SUPPORT DIVISION
FORT BELVOIR, VIRGINIA 22060

82 04 15 057

Notice

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official indorsement or approval of the use of such commercial products. The findings of this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

Comments

Comments on the contents of this report are encouraged, and should be submitted to:

Commander and Director
US Army Facilities Engineering Support Agency
Fort Belvoir, Virginia 22060

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
FESA-TS- 2104

2. GOVT ACCESSION NO.
AD-A113 484

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
Effect of Outside Combustion Air on Gas Furnace Efficiency

5. TYPE OF REPORT & PERIOD COVERED
Final
18 Sept 1980-15 Oct. 1981

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Thomas E. Brisbane, Kathleen L. Hancock

8. CONTRACT OR GRANT NUMBER(s)
DAAK 70-78-D-0002

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Johns-Manville Sales Corporation
Denver, Colorado 80217
Colorado State University
Fort Collins, Colorado 80521

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
0015

11. CONTROLLING OFFICE NAME AND ADDRESS
U.S. Army Facilities Engineering Support Agency, Technology Support Division
Fort Belvoir, Virginia 22060

12. REPORT DATE
15 Oct 1981

13. NUMBER OF PAGES

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release, Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Gas Furnace, Energy Conservation, Retrofi[illegible]ustion, Air, Efficiency

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Retrofit enclosure of gas furnaces to supply outside combustion and dilution air may save up to 6 percent of natural gas usage in cold climates. The cost effectiveness of this retrofit should be calculated for each opportunity as installed costs will vary widely depending on local building codes and furnace location. A freezing hazard exists for water heaters and lines which might be enclosed with a furnace.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

SUMMARY

Retrofit enclosure of gas furnaces to supply outdoor combustion and dilution air may save up to 6 percent of natural gas usage in cold climates. Retrofit must be in accordance with local building codes and the National Fuel Gas Code, NFPA 54. Cost effectiveness of this type of energy conserving retrofit will be quite variable and should be carefully calculated for each candidate building before a decision is reached. Comparisons with other retrofit alternatives such as vent dampers and derating should be made before a final retrofit decision is made. Gas water heaters in cold climates may preclude furnace combustion air retrofits because the furnace enclosure which should include the gas water heater will nearly reach outside air temperature which could freeze pipes and cause expensive damage.

A natural gas furnace test facility at Colorado State University was modified to test the effect the delivery of unheated outdoor combustion and dilution air has on thermal efficiency. Tests were scheduled over the winter months so that the resulting efficiency with cold temperatures in the furnace room could be determined. Resulting efficiencies were compared to a "baseline" case where combustion and dilution air were tempered indoor air.

A furnace "model" produced from the actual data was interfaced with a computer simulation program called "TRNSYS" to test the effect of outdoor combustion air on annual fuel consumption. This "TRNSYS" simulation program was developed by the University of Wisconsin at Madison and uses actual weather data tapes, called "Typical Meteorlogical Year" data to drive the models.

The data obtained from the furnace testing showed an overall reduction in furnace cyclic, thermal efficiency as outdoor air temperature decreased. This reduction in efficiency was most extreme for the short 10 percent duty cycle and least extreme for the 100 percent (steady state) duty cycle. Wind induced draft was found to have no appreciable effect on furnace efficiencies. However, the computer simulation results indicated that annual fuel savings of around 5 percent can be achieved with outdoor combustion air despite the reduction in furnace thermal efficiency with cold outdoor air temperatures. These savings were accomplished because of the reduced air

infiltration into the house normally required to replenish combustion and dilution air drawn up the stack from indoor air. Also wind induced draft, even when the furnace is off, provides a further penalty since it causes additional air intrusion into the heated space.

It is also reasonable to assume that during severe cold weather the furnace is not operating at the short duty cycles; and therefore, the reduction in efficiency is at a minimum. Conversely, the furnace is likely to operate for short duty cycles when the outside air temperature is higher and the reduction in efficiency will be less severe even at the 10 percent duty cycle.

Temperatures in the furnace room were quite cold, below freezing at times, and stayed cold even while the furnace was firing at 100 percent duty cycles. Since the natural inclination is to place a gas fired hot water heater in the same enclosed space as the furnace, some care and thought must be exercised. Any additional plumbing which coincidentally passes through the furnace space must also be either protected or moved since freezing is a definite possibility.

PREFACE

The laboratory study of gas furnace efficiency with outside combustion air was conducted at Colorado State University by Mr. Thomas E. Brisbane assisted by Ms. Kathleen L. Hancock, both of the Research Institute of Colorado staff.

Computer analysis was accomplished on the Control Data Cyber 172 computer at Colorado State University for both data reduction and simulation.

Appreciation is expressed to Ms. Diane Riggi, a student at CSU, who gave willingly and generously of her time and energy, particularly during the most adverse of weather conditions.

Thanks and admiration to Stuart Waterbury, a graduate student at the Solar Energy Application Lab, CSU for the ease with which he was able to model and fit the furnace data to an existing and excellent simulation program. His intimate familiarity with the simulation yielded the essential results of the study.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Page

LIST OF TABLES

INTRODUCTION

Report FESA-TS-2072, "Energy Saving Devices for Gas Furnaces", described the performances of three types of devices designed to improve furnace seasonal efficiency. Report FESA-TS-2070, "Techniques for Control of Air Infiltration in Buildings", suggested that provision of outside combustion air could provide insurance against the risks of retrofitting a house "too tightly". Outside combustion air was claimed by some authorities to provide another means for improving furnace seasonal efficiency. Accordingly, the objective of this Task Order No. 15 was to determine the effect on furnace efficiency when outside air is used for combustion and dilution air. The impact of outside furnace air on home energy use and heating cost was to be determined.

It has also been proposed by some that providing outside combustion air to an enclosed furnace room can substantially reduce air infiltration into the heated envelope whether that infiltration is intentional to allow for adequate combustion or unintentional through all the typical cracks and leaks in a house. The effect on furnace efficiencies at greatly reduced outside temperatures, zero ^{o}F and below is of particular interest as this is when the benefit of reducing air infiltration may be greatest. The benefit of reduced air infiltration into the heated envelope may not pay off if furnace efficiencies are drastically reduced by this low temperature combustion and dilution air. Therefore, just finding what effect the outside combustion air has on the furnace does not answer the entire question. The complete problem involves the overall interrelationship between efficiencies and air infiltration.

In order to obtain this information computer simulation of a furnace/house model would be required for both the inside and the outside combustion air. Further, this furnace/house should be operated in several parts of the country to determine if an indicated solution only works in certain climates and not in others. For example, the outside combustion air may pay off in milder climates but might not prove feasible in the cold northeast.

Tests of furnace thermal efficiency with outside air were conducted over a range of outside air temperatures and simulated wind conditions. Tests were also made for thermal efficiency with inside air provided to the furnace room for comparison. Temperatures, heat gains, and air flow rates were among the parameters measured to describe furnace performance. The wind which creates a larger draft effect up the stack was simulated for two wind speeds by using a two-speed induced draft fan on the stack. The furnace was operated through a full range of duty cycles for each selected outdoor temperature and wind condition.

Once the effect of outside combustion air was known, the furnace performance was simulated in a computer model which included a typical house and appropriate losses. The computer models compared the annual fuel consumption for two similar houses, one with outside combustion air and one with inside combustion air for three locations around the country. Actual meteorological data tapes are played against the model to determine this annual fuel utilization figure for Boston, MA; Great Falls, MT; and Albuquerque, NM.

This report describes the details of the testing for furnace efficiency and the results of those tests. The effect of outside combustion air on overall heating performance is then judged by comparing the annual fuel utilization using outside and inside combustion air in a typical house for five different locations around the U.S. This is the result of the output of the computer simulation program which models the furnace according to the results of the earlier tests. The test facility, test procedures and instrumentation are described in Appendix A. Key data are displayed in Appendix B. Equations are in Appendix C and the computer program is described in Appendix D.

DISCUSSION

Testing Method

The test facility consisted of a "furnace room" 6 feet wide and 12 feet long and an instrumentation room the same size located adjacent to the furnace room. The "room air" for the test furnace was supplied from laboratory space and heated air was delivered to the lab space at 8 feet above the floor and directed in an opposite direction from the cold air intake. The air temperature near the floor of the laboratory varied between 65°F to 70°F which is representative of return air temperature in a heated building.

A requlated natural gas supply line already existed within the building and was easily extended to the test rooms for operation of the furnace. The combustion vent was run through an office balcony located immediately above the test rooms and vented into a space near the "roof" inside the building. A vent fan, operating whenever the furnace was operating, then pulled the combustion gases outside the lab building. To simulate a wind induced draft through the vent, a two-speed vent fan was used. Combustion air for the furnace room was drawn through one of two alternate sources: (1) for outside combustion air tests, the air was drawn in through holes drilled in the common concrete lab wall directly to outside air, and (2) for inside combustion air tests, tempered indoor air was drawn in from the main lab floor.

The furnace was a standard model which included a four speed blower and a standing gas pilot light and all burner controls, fan switches and 24 volt control wiring.

Each air duct monitor consisted of total and static pressure probe arrays which were separately manifolded to an outlet port.

The following data were taken for the analysis of the effect of outside combustion and dilution air to the furnace room:

1. Temperatures throughout the system.

2. Temperature gains across key elements of the system.

3. Air flow rates in the room air circuit.

4. Vent stack flow rates during and before burner operation.

5. Wet and dry bulb temperatures in the laboratory, outside the furnace test room.

6. Gas consumption during each furnace test.

7. Combustion gas samples for CO_2, O_2 and CO.

8. Natural gas samples for heating value analysis.

A detailed description of testing apparatus, the test set-up, and data acquisition appears as Appendix A.

The testing matrix for determining the effect of outside combustion air on furnace efficiency was as follows:

Outside Air Temperatures °F	Vent Fan	Duty Cycle Percent
-10,0,10,25,40,55	OFF	10,20,30,50,75,100
	LOW	10,20,30,50,75,100
	HIGH	10,20,30,50,75,100
Indoor Tempered Air °F		
65 to 70	OFF	10,20,30,50,75,100
	LOW	10,20,30,50,75,100
	HIGH	10,20,30,50,75,100

The low and high stack fan settings were selected to simulate the effect of two different winds blowing on the stack outlet on the roof and inducing a draft in the stack. The low fan speed simulated a wind speed of about 25 MPH. A high fan speed simulated a wind speed ranging from 40 to 50 MPH. With the stack fan off, the draft effect was that of the combustion process only as if in still air.

Data were recorded in digital form on magnetic tape. The magnetic digital tapes created during each day's run were turned into the University Computer Center which has a remote terminal, batch desk reader and interactive terminals located at the Engineering Research Center. Once a tape was in the computer center, a simple and quick program was run to verify that the data on the tape were correct in format and that the tape was readable by the computer. The data on the tape were then transferred to a "master" tape contained internally at the computer center. All actual data analysis was done from the master tape.

All data channels were sampled at a rate of about one scan per 2.25 seconds resulting in about 800 discreet points per data channel for each 30 minute test run. The advantage of computer analysis in this case is obvious in the quantity of data processed during analysis. The short time interval between data samples thus permitted close tracking of rapid temperature changes in various parts of the system.

Calculations required knowledge of mass flow rates, temperatures and temperature differences across the furnace. Thermocouple and thermopile outputs were recorded in order to determine the heat impact from the furnace. Thermocouples were recorded directly in absolute temperature relative to the ice point of water and the thermopiles were recorded as a voltage.

The thermopile voltage, or generated EMF is a function of the difference in temperature between the two ends of the thermopile and the number of junctions making up the thermopile. Because thermocouples are not linear in output with temperature, the procedure for calculating the ΔT being measured requires a knowledge of the absolute temperature at one end of the thermopile. This temperature becomes the thermopile reference temperature for a series of calculations to determine the ΔT at the thermopile.

National Bureau of Standards[1] equation describing the characteristics of T-type thermocouples were used in these calculations. The reference temperature is first converted to an equivalent EMF relative to 32°F. Assuming that the reference thermocouple is reading the low temperature side of the thermopile, this EMF is then added to the thermopile voltage divided by the number of thermocouple junctions in the thermopile.

$$EMF_{\text{T-PILE}} = EMF_{\text{REFERENCE}} + \frac{\text{T-PILE VOLTAGE}}{\text{N}^{\text{o}}\text{ JUNCTIONS}}$$

$EMF_{\text{T-Pile}}$ is now treated as though it were itself a thermocouple voltage and using the NBS equation which relates Temperature to EMF the high side thermopile temperature is calculated. Then ΔT is this high side calculated temperature minus the original reference temperature.

The Datametrics Barocel differential pressure sensor was calibrated at the Engineering Research Center Instrumentation Shop just prior to the furnace testing.

---

1 NBS Monograph 125 (Thermocouple Reference Tables Based on the IPTS- 68), U. S. Department of Commerce, National Bureau of Standards, March, 1974.

The output voltage of this unit is related to a differential pressure across whatever flow device is being selected by both a sconivalue multi-port switch and both the switch position and the P voltage are recorded. From this information, mass flow rates in the system are calculated in order to finally arrive at heat delivery calculations. In the computer program, these calculations are carried out for every 2.25 second increment and summed up for the total furnace output.

Furnace thermal efficiency was defined as the heat delivered to the room circuit divided by the total gas input Btu's.

$$\text{PERCENT EFF} = \frac{\text{HEAT DELIVERED TO ROOM, BTU X 100}}{\text{GAS INPUT, BTU}}$$

The jacket loss and direct losses in the furnace room were not considered as usable heat in the calculations.

All flow rates and heating values were converted to standard conditions prior to calculating efficiency. The gas heating value was determined from gas chromatograph analysis compared to a reference standard. During the testing period, the heating value of the gas varied from a low ot 1051 Btu/Ft^3 to a high of 1059 Btu/Ft^3. The actual heating values were inserted in the computer program for analyzing the data even though this was a very small change at less than 1 percent.

An energy balance was performed for the furnace using the data available in the computer program. As a check on the results obtained, Gas input = Heat delivered to rooms + Heat up the stack + Jacket losses.

The heat delivered to the rooms is made up of two components. The difference in air flow measured by the return air monitor and the delivery air monitor is the leakage component into the system at the blower cabinet. This value was typically around 180 Ft^3/min and this quantity of flow is raised from furnace room temperature to room air delivery temperature. The significantly larger component is that flow delivered directly through the room circuit and this flow is raised from room return temperature to room delivery temperature for heat flow calculations. Jacket losses were taken to be 1 percent ot the value of all other heat quantities combined.

Closure of the energy balance varied with duty cycle. The biggest error in closure was for the 10 percent duty cycles and was typically somewhere between 12 to 38 percent otf. for the longer duty cycles of 75 and 100 percent, closure was usually within 2 or 3 percent, but occasionally as high as 5 percent off.

The output from the computer program was a complete table of temperatures, flows, calculated temperature differences and indication of time into cycle and thermostat and blower status indication. Additionally, the program would output selected temperature plots displaying temperature changes through the entire 30 minute duty cycle. Average outdoor temperature was calculated and printed as were results of the energy balance along with the individual values used in the balance calculation.

Results

Appendix D contains a complete description of the furnace simulation program used to determine the seasonal effects of outside combustion air on furnace performance. Table 1 is a compilation of the key results from the simulation program for Boston, MA; Great Falls, MT; and Albuquerque, NM. Two types of thermostats were used in the simulation, one which kept the house at a constant 70°F 24 hours a day, and one which included a setback to 60° from 11 PM to 7 AM each night. In every case, the outside combustion air reduced the seasonal efficiency calculated by the simulation program (modeled seasonal efficiency). Fuel use, however, was reduced by outside combustion air because of the reduction in templered air use during furnace on cycles and the reduction in tempered air loss up the stack during furnace off cycles.

TABLE 1

ANNUAL FUEL USAGE AND MODELED SEASONAL EFFICIENCY

		Inside Combustion Air			Outside Combustion Air		
Location	Thermostat Type	Gas Input Btux10^{-6}	Room Air Delivery Btux10^{-6}	Modeled Seasonal Efficiency %	Gas Input Btux10^{-6}	Room Air Delivery Btux10^{-6}	Modeled Seasonal Efficiency %
Albuquerque, NM	No Night Setback	187.5	131.4	70.1	180.3	124.0	68.8
	Night Setback	161.6	114.0	70.5	155.7	107.8	69.2
Boston, MA	No Night Setback	192.6	134.3	69.7	183.2	125.0	68.2
	Night Set back	169.6	119.2	70.3	161.4	111.1	68.8
Great Falls, MT	No Night Setback	163.8	113.7	69.4	153.9	103.1	67.0
	Night Setback	146.6	103.0	70.3	137.9	93.5	67.8

Comparing just the results for no setbacks on the thermostat, the furnace located in Albuquerque ran at an efficiency of 70.1 percent and used 187.5 million Btu of gas to heat the modeled house with inside combustion air. With outside combustion air, the efficiency of the furnace dropped slightly to 68.8 percent but the gas input needed to heat the house also droplped to 180.3 million Btu.

Using Boston weather tapes, the same trend was indicated with the furnace having a 69.7 percent efficiency compared to 68.2 percent and a gas input of 192.6 million Btu compared to 183.2 million Btu for inside compared to outside combustion air respectively. The same results for Great Falls, Mt, were 69.4 percent compared to 67.0 percent for efficiency and 163.8 million Btu compared to 153.9 million Btu for inside compared to outside combustion air.

The reduction in gas consumption as the weather conditions become more severe is the result of sizing the house load to the furnace model for each location. Table 2 shows the design parameters used at each location as well as the actual minimum low temperature obtained on the weather tapes.

For Albuquerque, the minimum design temperature was exceeded at least once while for Boston, it was equalled at least once. For Great Falls, MT, however, the minimum design temperature was never exceeded or equalled. This, combined with sizing the house load at each location to the furnace, accounts for what might first appear to be an incorrect trend for gas consumption in the simulation results.

Table 3 presents information on the savings achieved for each of four different comparisons. Concentrating only on the comparison of indoor to outdoor combustion air with no setback on the thermostat, a 3.8 percent savings is achieved for Albuquerque while for Boston the savings are 4.88 percent and for Great Falls, MT, they are 6.04 percent. This same ranking applied to the comparison of inside and outside combustion air with a setback thermostat although the savings are slightly reduced.

As a matter of interest, the savings comparisons for the setback and nonsetback thermostat were compared and can be found as Columns C and D in Table 3. These savings show a difference from the comparisons to outdoor and indoor air. That is, the largest percent savings now occur in Albuquerque and the smallest percent savings take place in Great Falls, MT.

Table 4 shows the actual annual savings calculated from Table 3 using the October 1981 consumer gas price in each of the three locations. Annual savings attributable to inside versus outside air were in the $20-50 range. This suggests that payback periods for retrofit would be well over ten years.

TABLE 2

LOAD DESIGN PARAMETERS

Design Temperature °F	Actual T_o Min °F	Load UA BtuH/°F
14.0	8.9	1050
6.0	6.0	920
-20.0	-17.0	650

TABLE 3

COMPUTED SAVINGS FOR THE VARIOUS TEST CASES

SAVINGS %

Location	A	B	C	D
Albuquerque	3.84	3.65	13.81	13.64
Boston	4.88	4.83	11.94	11.90
Great Falls	6.04	5.93	10.50	10.40

A. Inside vs. Outside Combustion Air - No Setback Thermostat $\left(\frac{\text{Inside-Outside}}{\text{Inside}}\right)$

B. Inside vs. Outside Combustion Air - With Setback Thermostat $\left(\frac{\text{Inside-Outside}}{\text{Inside}}\right)$

C. Setback vs. No Setback Thermostat - Inside Air $\left(\frac{\text{No Setback-Setback}}{\text{No Setback}}\right)$

D. Setback vs. No Setback Thermostat - Outside Air $\left(\frac{\text{No Setback-Setback}}{\text{No Setback}}\right)$

TABLE 4

DOLLAR SAVINGS FOR THE VARIOUS

TEST CASES, $ PER YEAR

Location	A	B	C	D	E
Albuquerque	$28.80	$23.60	$103.60	$ 98.40	$127.20
Boston	54.05	47.15	132.25	125.35	179.40
Great Falls	48.51	42.63	84.28	78.40	126.91

A. Inside vs. Outside Combustion Air - No Setback Thermostat

$$\left(\frac{\text{Inside-Outside}}{\text{Inside}}\right)$$

B. Inside vs. Outside Combustion Air - With Setback Thermostat

$$\left(\frac{\text{Inside-Outside}}{\text{Inside}}\right)$$

C. Setback vs. No Setback Thermostat - Inside Air

$$\left(\frac{\text{No Setback-Setback}}{\text{No Setback}}\right)$$

D. Setback vs. No Setback Thermostat - Outside Air

$$\left(\frac{\text{No Setback-Setback}}{\text{No Setback}}\right)$$

E. No Setback, Inside Air vs. Setback, Outside Air

$$\left(\frac{\text{No Setback, Inside - Setback, Outside}}{\text{No Setback, Inside}}\right)$$

Table 5 is a listing of all furnace cycle thermal efficiencies measured during the testing program. The values in the table are listed under column headings of the appropriate outdoor air temperature under which the test runs fall. Listed with each value of efficiency is the actual average outdoor air temperature during the individual test runs. These values vary somewhat from the actual column heading but are grouped under the nearest temperature heading for placement in a table format. Gaps in data shown for the higher temperatures are typically the result of test runs presumed to be that temperature at the time the test was run, but on analysis of the data, to be closer to an adjacent column heading.

Testing began 26 January 1981 and continued through early April 1981 with data acquisition proceeding as described in Appendix A. Because of the need to obtain cold outdoor air temperatures as they became available at this time of year, testing began immediately with the outdoor vents open rather than testing of the so called "baseline" or indoor vent condition.

There was an unusually mild winter through the Rocky Mountain Region and the extreme cold temperatures (zero degrees F and below) were not obtainable until a single cold period on the 10th and 11th of February. Testing proceeded 24 hours a day in order to obtain all data possible during this cold snap. These were the only two days of near zero or sub-zero temperatures for the entire winter. Obviously, data for test runs which were not obtained during this two-day period were not available.

Figures 1 through 6 are plots of the data from Table 5. Each duty cycle from 10 percent to 100 percent is represented as a separate plot with thermal efficiency plotted against outdoor air temperature for all wind conditions.

Wind appears to have little or no effect on furnace efficiencies. Points representing moderate and high wind, as shown in Table 6, for given temperatures, fall within the same range of efficiencies for no wind. Later, in examining plots of actual temperatures in the system, there is noted an effect on stack temperatures. The effect of wind is apparently confined primarily to dilution air at the draft hood and does not alter the actual combustion or efficiency or the heat exchanger. Table 2 shows the measured effect of wind on stack flow.

Cold outside combustion air has the most dramatic effect on furnace efficiencies for the short duty cycles. Figure 1, the plot of efficiency versus outdoor temperature for the 10 percent duty cycle, shows a range of efficiencies from about 42 percent for a -5°F outdoor temperature to a high of about 58 percent for 60°F outside temperature. There is considerable scatter in the data for the 10 percent test as also indicated by the largest error in the energy closure equations for this duty cycle. The general shape and slope of the curve fit to these points is carried forward from the plots of the longer duty cycles where scatter is considerably less. The 10 percent duty cycle shows a total change in efficiency of 16 percent from -5°F to 60°F.

As the "burner on" duty cycle increases, the low and high values of efficiency for the same temperatures, -5°F and 60°F, gradually improve until the best efficiencies are obtained at a 100 percent duty cycle , Figure 6. At -5°F outside air temperature, the furnace efficiency for the 100 percent duty cycle is approximately 69 percent and this improves by only 3 percent to a value of 72 percent for 60°F outside air.

TABLE 5

FURNACE THERMAL EFFICIENCIES

	Percent Duty Cycle	Combustion & Dilution Air: Outside Air, Temperature °F -10	0	10	25	40	55	Inside Air
NO WIND	10	--	45.5 (-0.1)	48.4 (12.1)	60.9 (21.9)	57.4 (47.2)	57.7 (53.6)	53.8
	20	--	56.4 (-1.3)	55.5 (11.7)	60.8 (24.0)	64.5 (45.3)	60.7 (58.7)	62.2
	30	61.2 (-4.2)	62.1 (-3.0)	61.2 (11.1)	67.3 (22.6)	64.0 (36.7)	66.0 (57.3)	67.7
	50	65.2 (-4.6)	66.7 (-2.9)	67.1 (11.7)	69.5 (26.7)	68.9 (45.7)	69.3 (60.1)	70.1
	75	67.4 (-6.8)	68.4 (-3.5)	69.6 (15.1)	72.4 (26.7)	72.6 (41.5)	--	72.6
	100	66.6 (-6.9)	70.0 (0.3)	67.0 (18.7)	69.2 (27.2)	--	72.2 (55.8)	73.8
MODERATE WIND	10	--	--	--	--	59.2 (44.0)	52.8 (56.7)	52.7
	20	--	--	--	--	64.4 (48.0)	62.6 (50.4)	56.8
	30	--	59.8 (-4.0)	--	--	67.8 (48.0)	68.6 (51.0)	65.1
	50	--	65.7 (1.0)	--	65.9 (32.7)	70.4 (41.1)	71.1 (51.6)	71.2
	75	--	68.3 (1.9)	--	69.7 (31.4)	72.9 (46.3)	--	74.0
	100	--	--	72.7 (6.8)	70.5 (32.5)	--	70.97 53.3	74.4
HIGH WIND	10	--	41.6 (4.8)	--	41.8 (25.4)	58.7 (44.9)	--	59.7
	20	--	--	55.9 (6.0)	60.1 (23.4)	64.1 (41.3)	61.6 (61.8)	65.3
	30	--	--	62.1 (9.2)	63.4 (19.4)	65.0 (39.8)	65.4 (57.7)	69.0
	50	--	--	66.2 (6.3)	66.1 (23.0)	69.8 (42.3)	71.6 (58.8)	68.8
	75	66.7 (-6.8)	--	69.1 (18.5)	--	71.3 (40.4)	--	72.6
	100	72.9 (-9.1)	--	--	66.1 (20.9)	71.3 (40.8)	73.2 (57.3)	72.6

Thermal Efficiency
(Actual Outdoor Temperature)

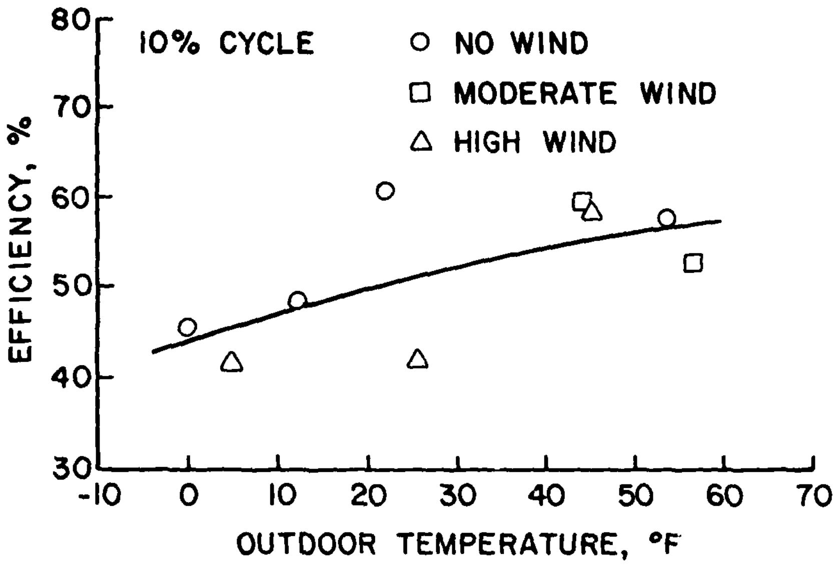


FIGURE 1. Plot of Cyclic Thermal Efficiency Versus Outdoor Temperature for 10 Percent Duty Cycle, Using Outdoor Combustion and Dilution Air. Difference in Efficiencies is 16 Percent, From -5° to 60°.

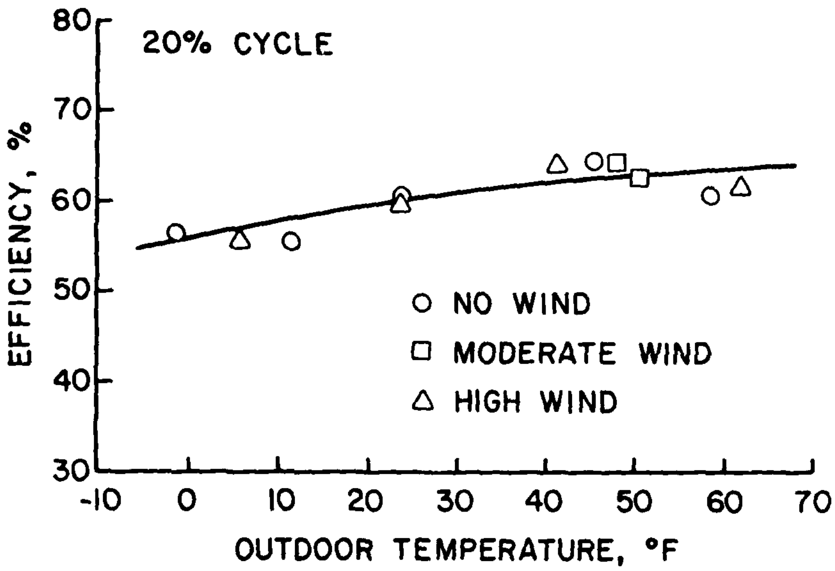


FIGURE 2. Plot of Cyclic Thermal Efficiency Versus Outdoor Temperature for 20 Percent Duty Cycle, Using Outdoor Combustion and Dilution Air. Difference in Efficiencies is 9 Percent, From -5° to 60°.

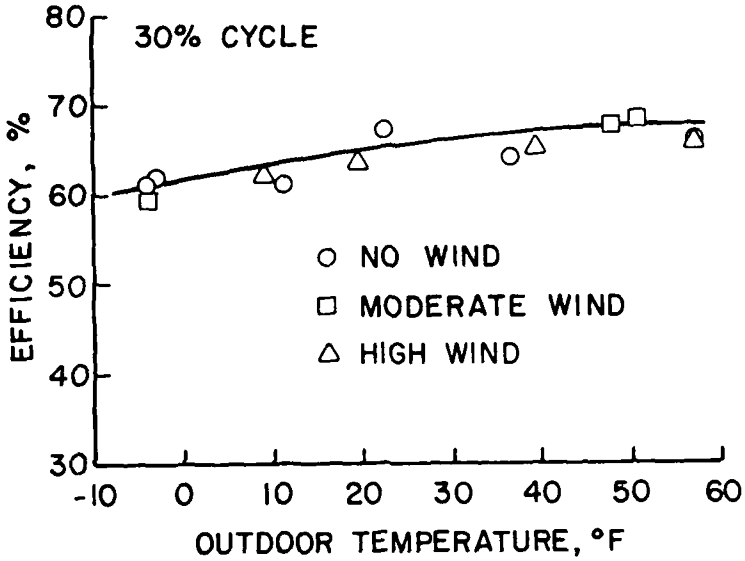


FIGURE 3. Plot of Cyclic Thermal Efficiency Versus Outdoor Temperature for 30 Percent Duty Cycle, Using Outdoor Combustion and Dilution Air. Difference in Efficiencies is 7 Percent, From -5° to 60°.

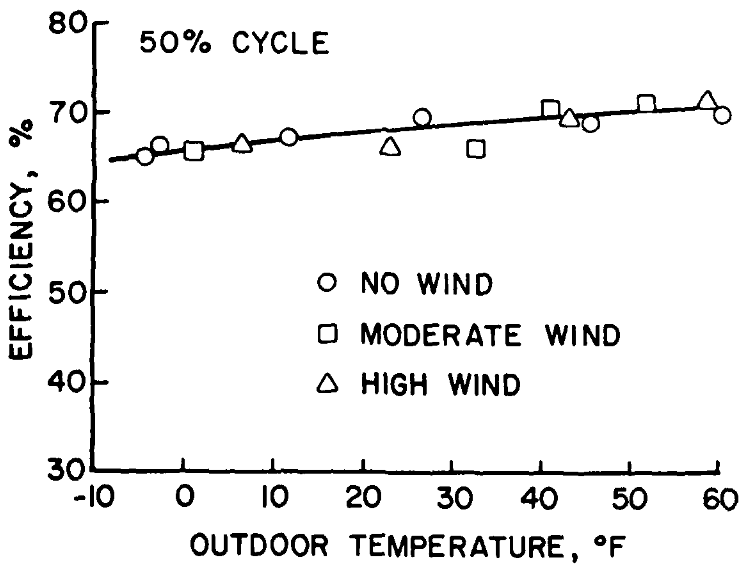


FIGURE 4. Plot of Cyclic Thermal Efficiency Versus Outdoor Temperature for 50 Percent Duty Cycle, Using Outdoor Combustion and Dilution Air. Difference in Efficiencies is 6 Percent, From -5° to 60°.

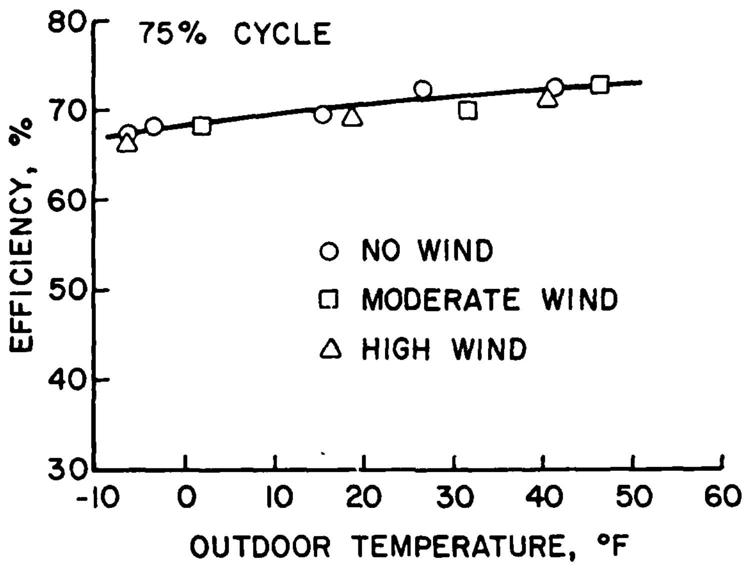


FIGURE 5. Plot of Cyclic Thermal Efficiency Versus Outdoor Temperature for 75 Percent Duty Cycle, Using Outdoor Combustion and Dilution Air. Difference in Efficiencies is 6 Percent, From -5° to 60°.

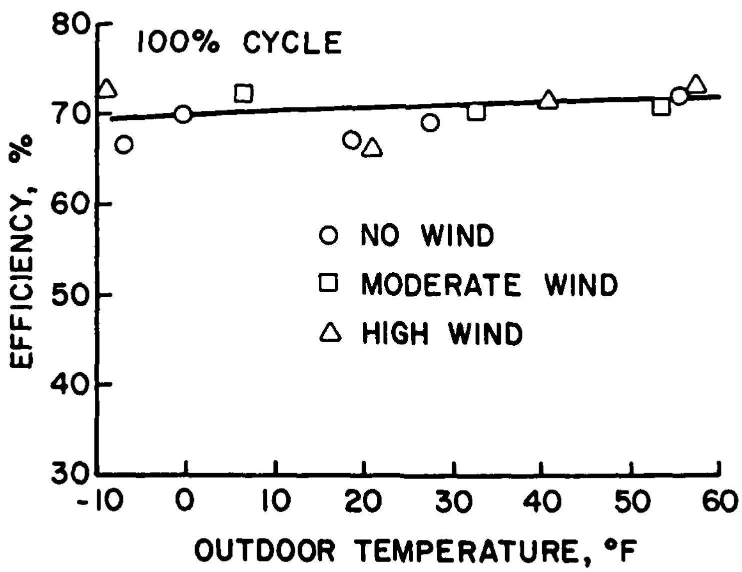


FIGURE 6. Plot of Cyclic Thermal Efficiency Versus Outdoor Temperature for 100 Percent Duty Cycle, Using Outdoor Combustion and Dilution Air. Difference in Efficiencies is 3 Percent, From -5° to 60°.

TABLE 6

WIND INDUCED DRAFT EFFECT

	Vent Stack Flow Rates		
	No Wind	25 MPH Wind	40-50 MPH Wind
Burner Off	20 ft^3/min.	55 ft^3/min.	70 ft^3/min.
Burner On	65 ft^3/min.	90 ft^3/min.	100 ft^3/min.

The change in efficiency over the -5oF to 60oF temperature range is highest for the 10 percent duty cycle and gradually decreases through longer duty cycles; 16 percent change at 10 percent duty cyle, 9 percent change at 20 percent duty cycle, 7 percent change at 30 percent duty cycle, 6 percent change for both 50 percent and 75 percent duty cycles, and finally, only a 3 percent change at 100 percent duty cycle. At the same time, the actual efficiencies covered by the ranges gradually increase with longer duty cycles; 42 to 58 percent for 10 percent duty cycle, 55 to 69 percent for 20 percent duty cycle, 61 to 68 percent for 30 percent duty cycle, 65 to 71 percent for 50 percent duty cycle, 66 to 72 percent for 75 percent duty cycle, and 69 to 72 percent for 100 percent duty cycle.

Figures 7 through 12 are plots of the same test runs as Figures 1 through 6 but instead of outdoor air temperature, furnace efficiency is plotted versus furnace room temperature. This furnace room temperature is the average temperature during the run, but even at the 100 percent duty cycles, it did not vary appreciably. Also, the average furnace room temperature at a given time was the average of 5 sensors located around the furnace room. These figures do not display any new information even though the real variable affecting furnace performance would be the actual air temperature in the furnace room. The plots are presented, therefore, as a matter of interest.

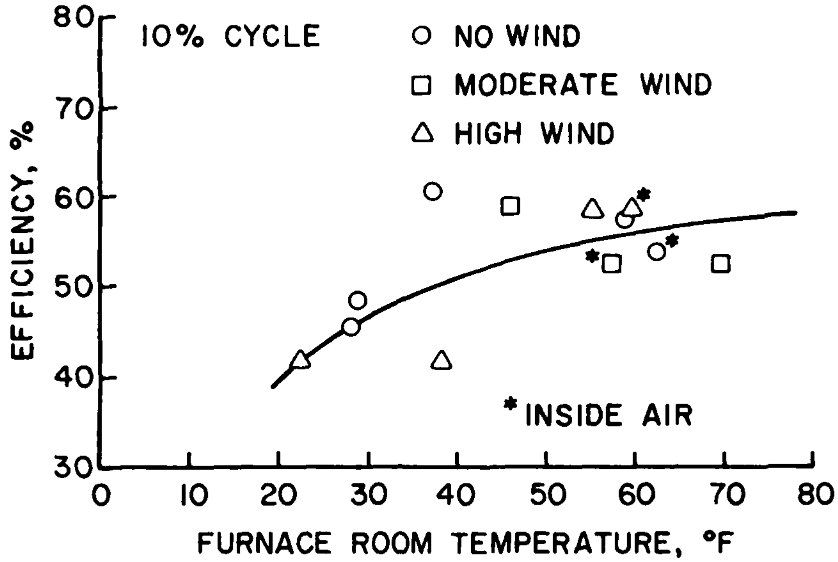


FIGURE 7. Plot of Cyclic Thermal Efficiency Versus Furnace Room Temperature for 10 Percent Duty Cycle, Using Indoor and Outdoor Combustion and Dilution Air. Difference in Efficiencies is 19 Percent, From 20° to 80°.

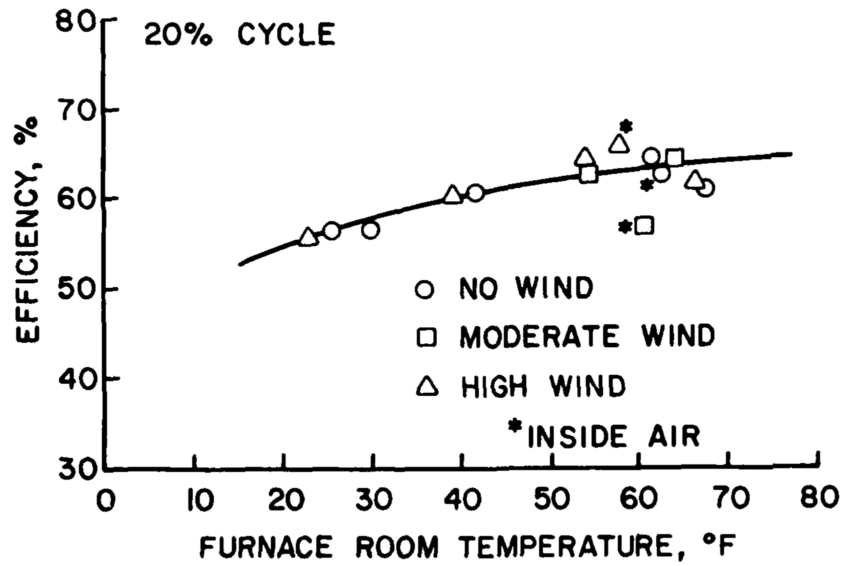


FIGURE 8. Plot of Cyclic Thermal Efficiency Versus Furnace Room Temperature for 20 Percent Duty Cycle, Using Indoor and Outdoor Combustion and Dilution Air. Difference in Efficiencies is 12 Percent, From 20° to 80°.

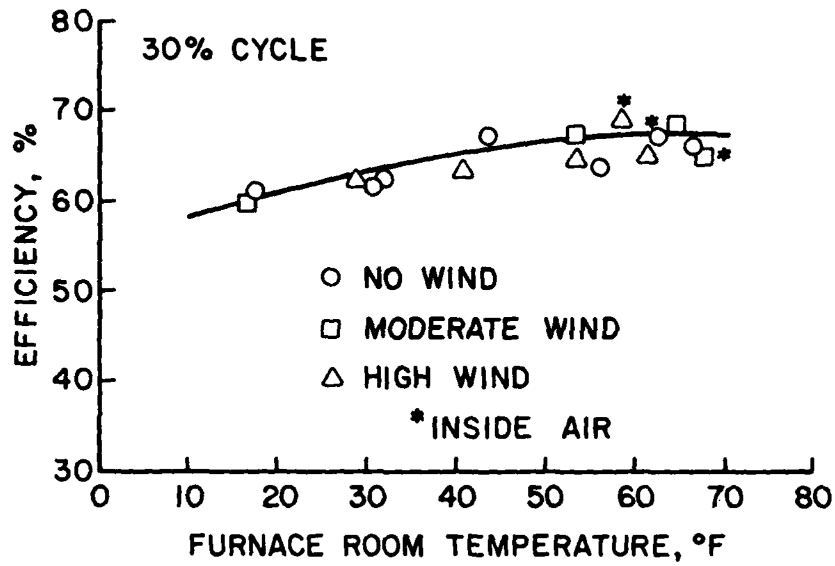


FIGURE 9. Plot of Cyclic Thermal Efficiency Versus Furnace Room Temperature for 30 Percent Duty Cycle, Using Indoor and Outdoor Combustion and Dilution Air. Difference in Efficiencies is 10 Percent, From 20° to 80°.

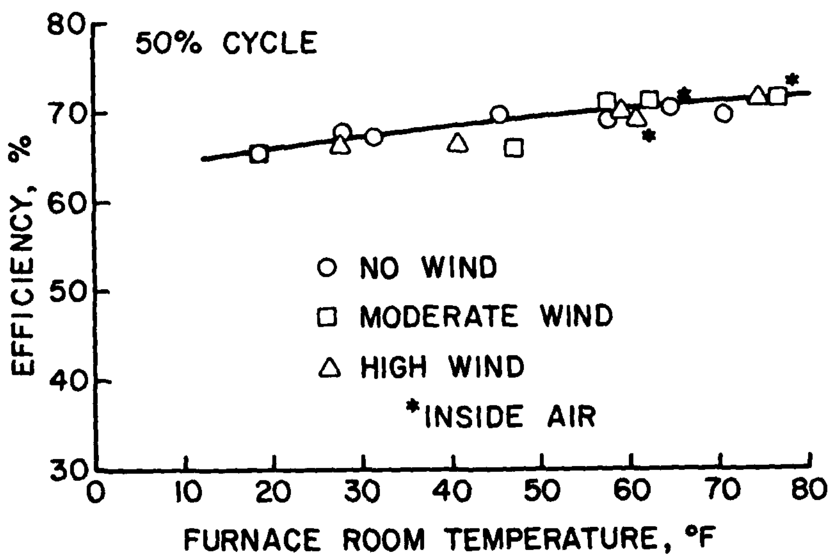


FIGURE 10. Plot of Cyclic Thermal Efficiency Versus Furnace Room Temperature for 50 Percent Duty Cycle, Using Indoor and Outdoor Combustion and Dilution Air. Difference in Efficiencies is 6 Percent, From 20° to 80°.

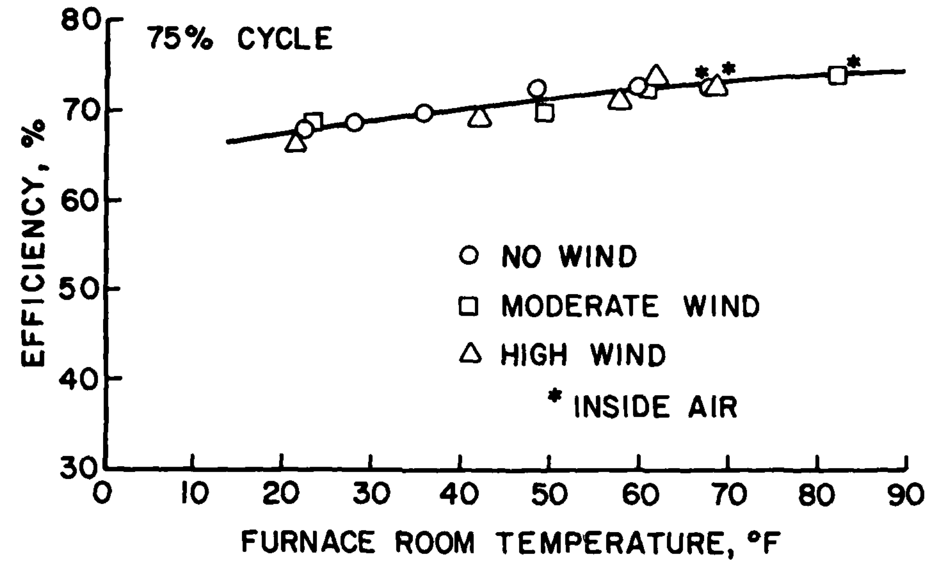


FIGURE 11. Plot of Cyclic Thermal Efficiency Versus Furnace Room Temperature for 75 Percent Duty Cycle, Using Indoor and Outdoor Combustion and Dilution Air. Difference in Efficiencies is 7 Percent, From 20° to 80°.

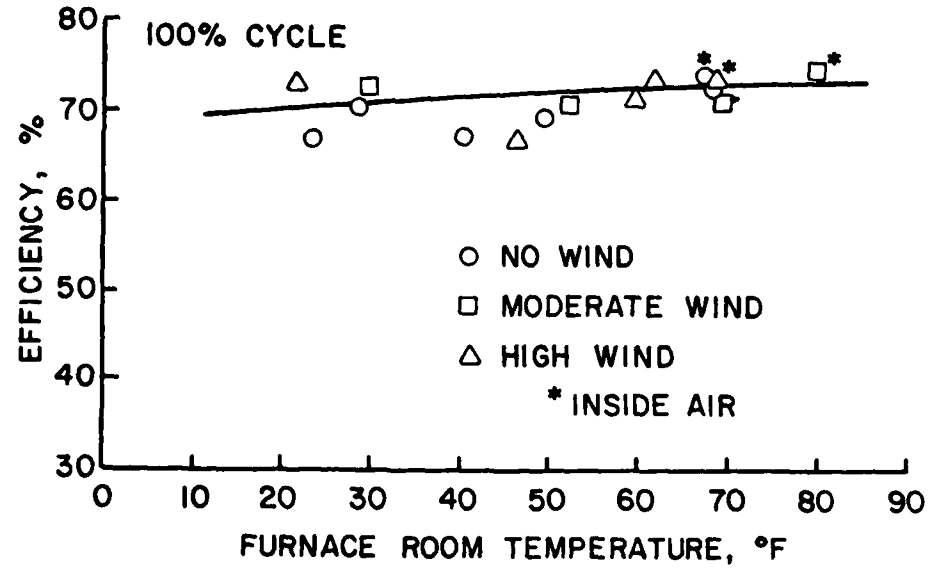


FIGURE 12. Plot of Cyclic Thermal Efficiency Versus Furnace Room Temperature for 100 Percent Duty Cycle, Using Indoor and Outdoor Combustion and Dilution Air. Difference in Efficiencies is 3 Percent, From 20° to 80°.

Temperature profiles for the 30-minute test cycle for selected test runs are shown as Figures 13 through 22. These plots are shown for various test duty cycles and for various outdoor temperatures and wind conditions.

Figures 13 and 14 are temperature profile plots for a 10 percent duty cycle with outside air. Figure 13 is for still air conditions while Figure 14 is for a high wind condition. With the exception of only one recorded temperature, the plots are essentially similar. Temperatures in the air delivery duct, the furnace plenum and the furnace room are essentially the same from plot to plot. Only the vent stack temperature shows any appreciable effect from the cold outside combustion air combined with wind effect. This temperature has dropped nearly 65°F from a value of 265°F with no wind to 200°F with a high wind blowing.

Figures 15 and 16 are plots of a 10 percent duty cycle with the combustion air source as inside tempered air. Figure 15 is a still air condition, and Figure 16 is a high wind condition. Almost the same situation takes place as with the outside combustion air except the wind condition stack temperature is not quite as low. In this case, the stack temperature with no wind is about 260°F which then drops about 50°F to a value of 210°F with a high wind. The furnace room temperatures are substantially different for the outside compared to the inside combustion air which accounts for the change in stack temperature lows in the high wind case.

Figures 17 and 18 demonstrate the same effect for a slightly longer duty cycle of 30 percent. In this case, the wind is a moderate one and the effect registers only on stack temperature. The other temperatures plotted in the figures are virtually identical in the two tests and the computed furnace efficiencies are within 2 percent at 62.1 percent and 59.8 percent, respectively.

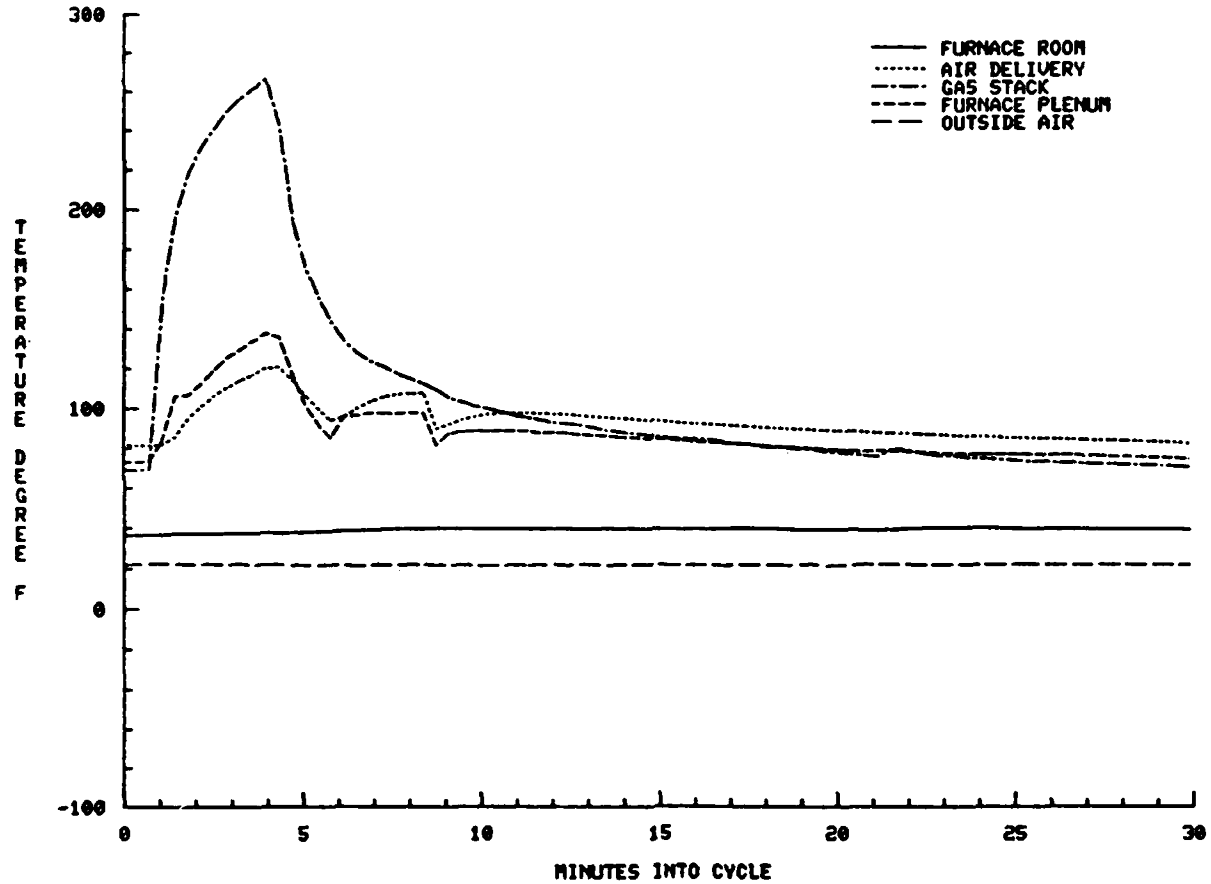


FIGURE 13. Plot of Temperatures Versus Time into Cycle for 10 Percent Duty Cycle With No Wind, Using Outside Combustion and Dilution Air. Furnace Efficiency is 60.9 Percent.

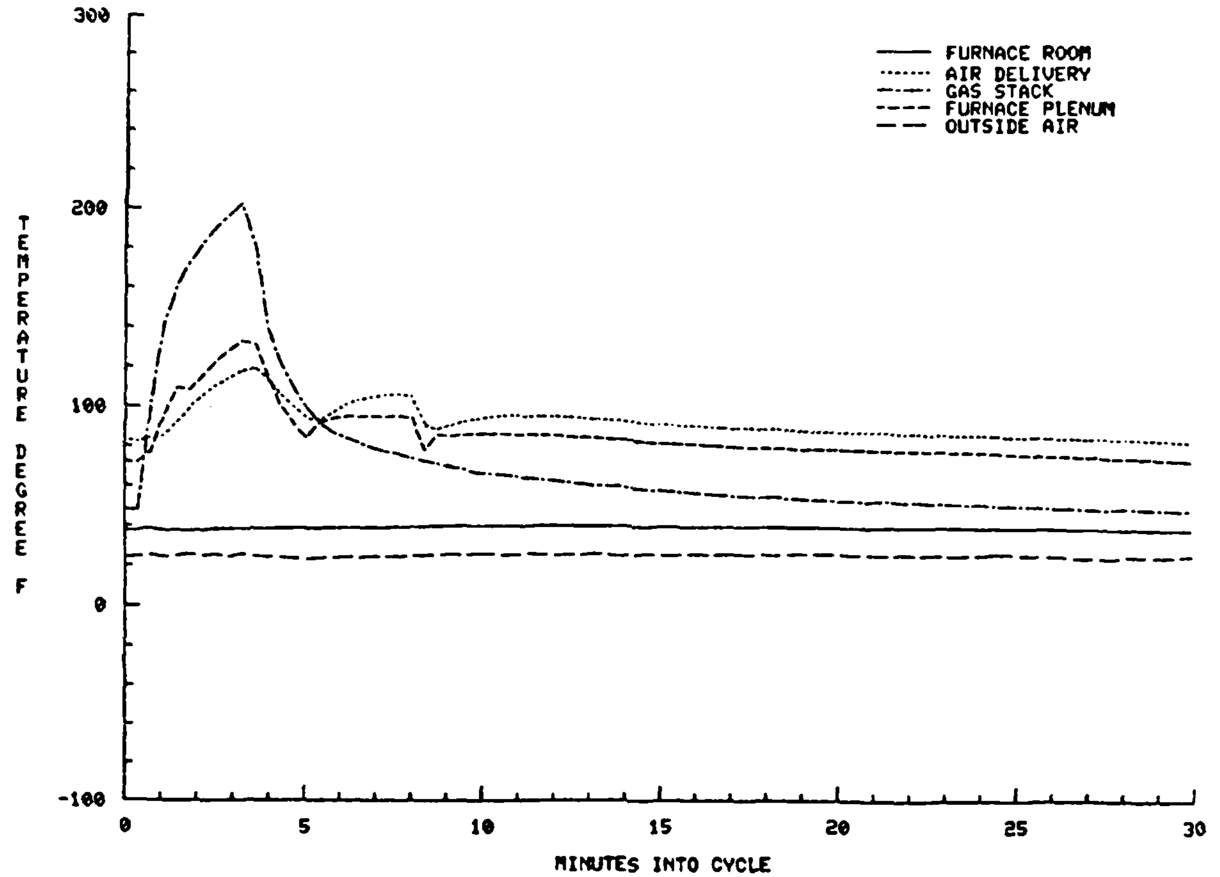


FIGURE 14. Plot of Temperatures Versus Time into Cycle for 10 Percent Duty Cycle With High Wind, Using Outside Combustion and Dilution Air. Furnace Efficiency is 41.8 Percent.

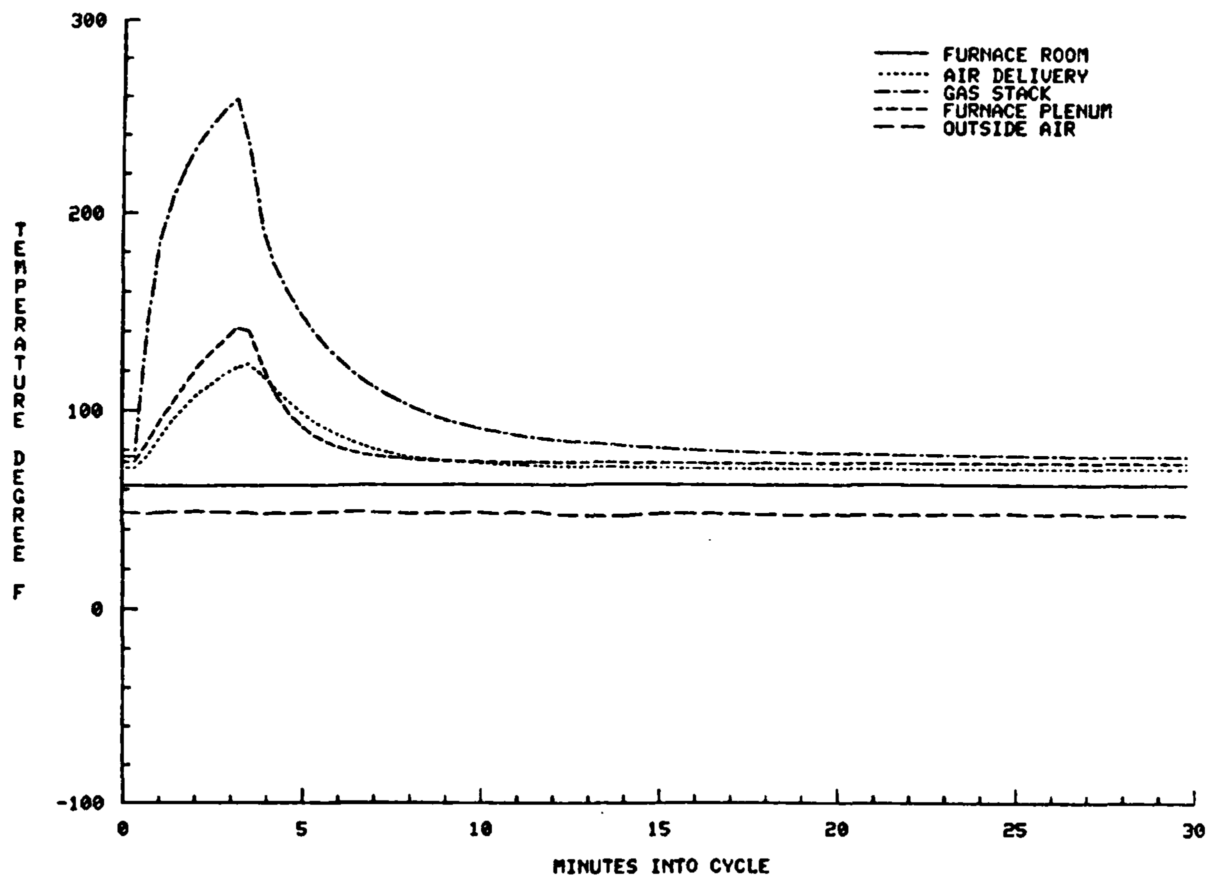


FIGURE 15. Plot of Temperatures Versus Time into Cycle for 10 Percent Duty Cycle With No Wind, Using Inside Combustion and Dilution Air. Furnace Efficiency is 53.8 Percent.

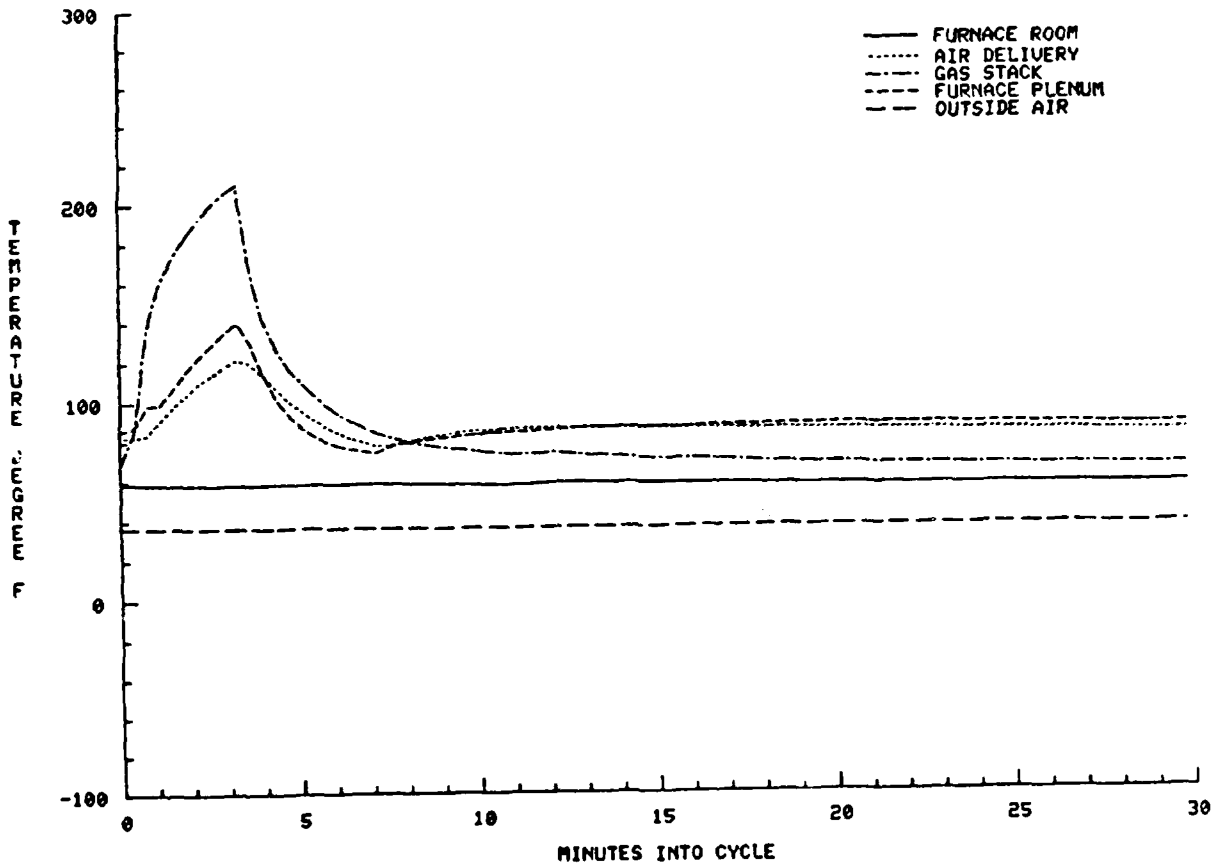


FIGURE 16. Plot of Temperatures Versus Time into Cycle for 10 Percent Duty Cycle With High Wind, Using Inside Combustion and Dilution Air. Furnace Efficiency is 59.7 Percent.

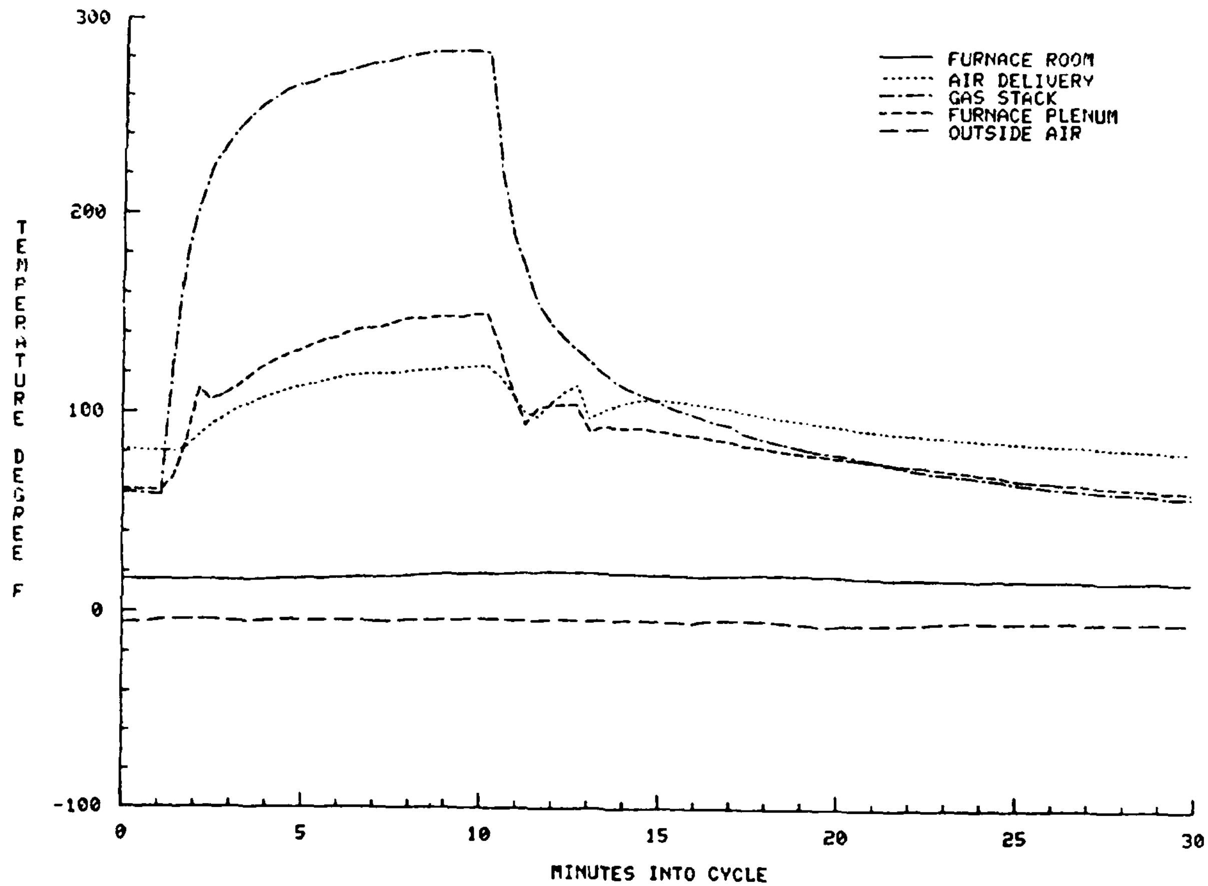


FIGURE 17. Plot of Temperatures Versus Time into Cycle for 30 Percent Duty Cycle With No Wind, Using Outside Combustion and Dilution Air. Furnace Efficiency is 61.2 Percent.

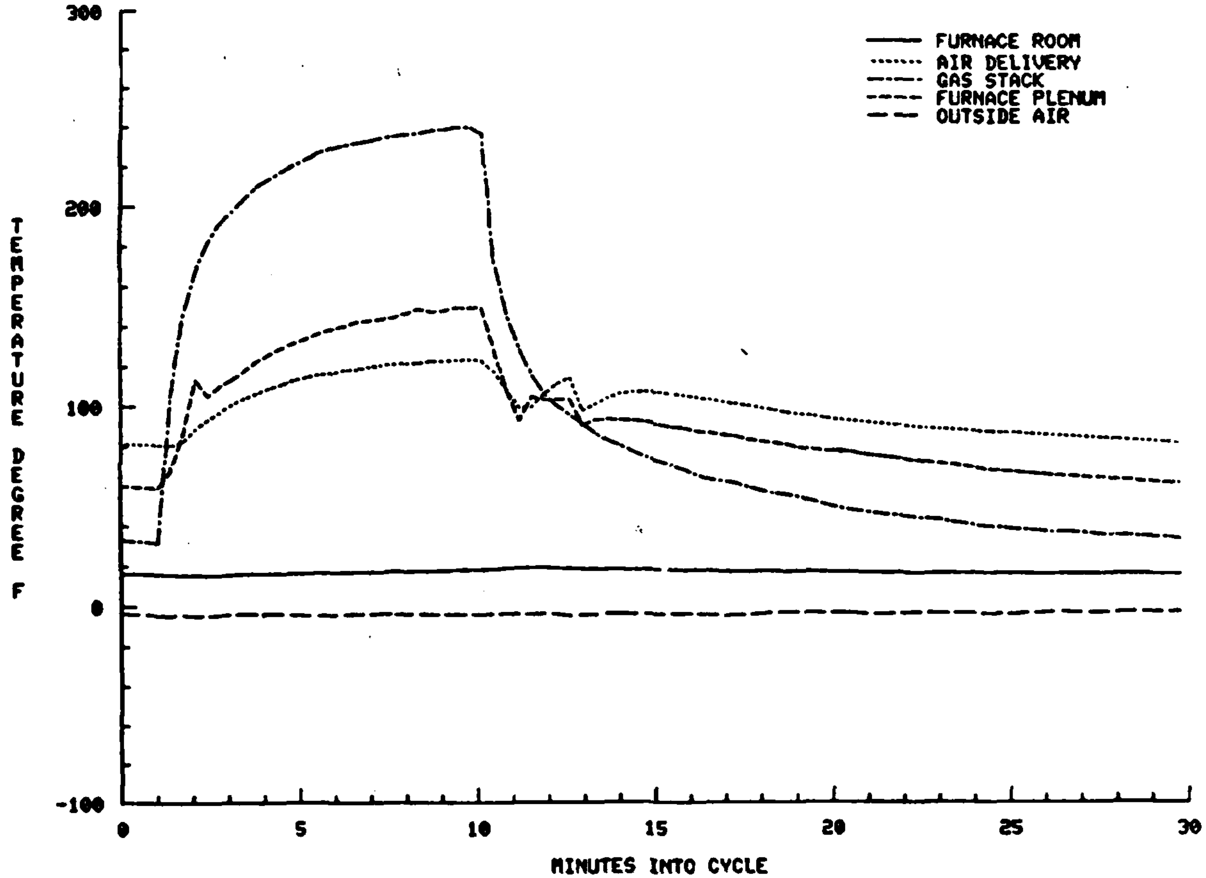


FIGURE 18. Plot of Temperatures Versus Time into Cycle for 30 Percent Duty Cycle With Moderate Wind, Using Outside Combustion and Dilution Air. Furnace Efficiency is 59.8 Percent.

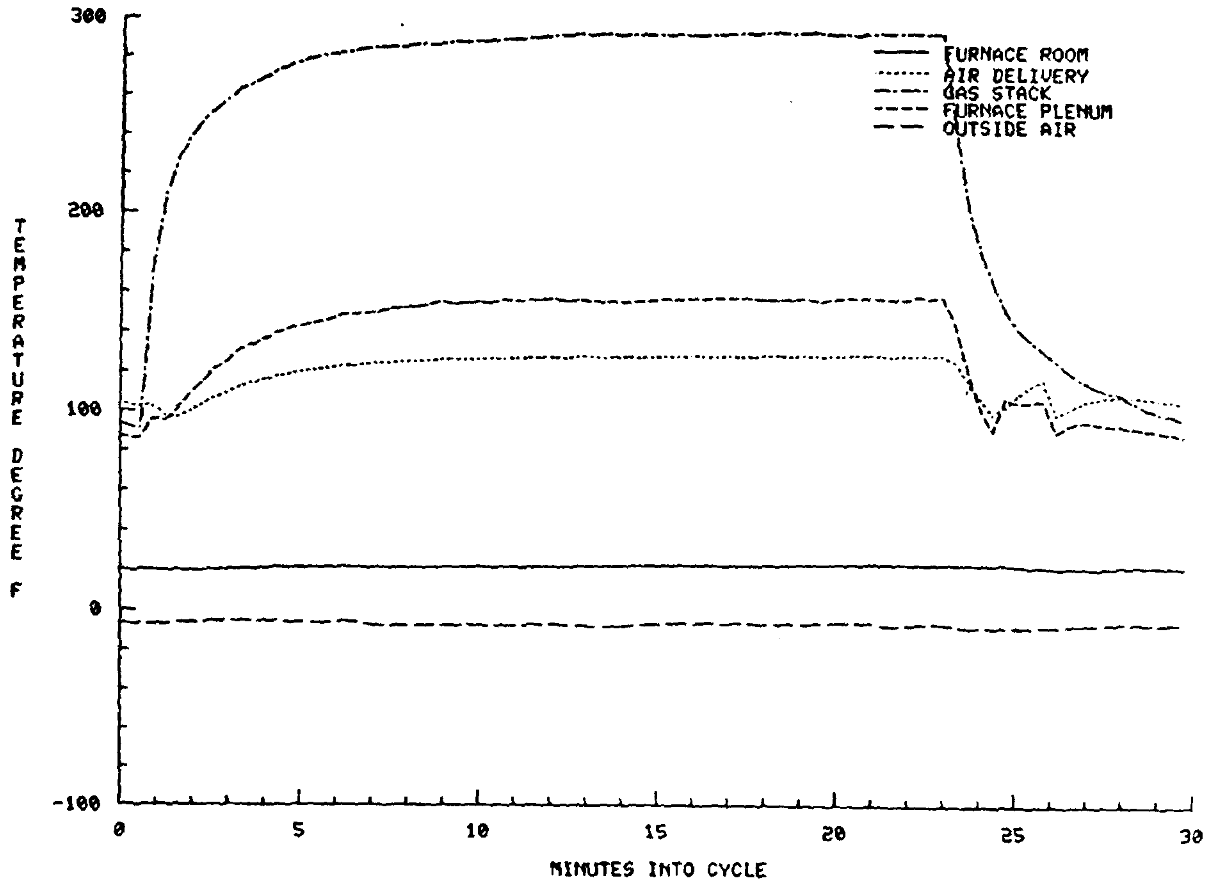


FIGURE 19. Plot of Temperatures Versus Time into Cycle for 75 Percent Duty Cycle With No Wind, Using Outside Combustion and Dilution Air. Furnace Efficiency is 67.4 Percent.

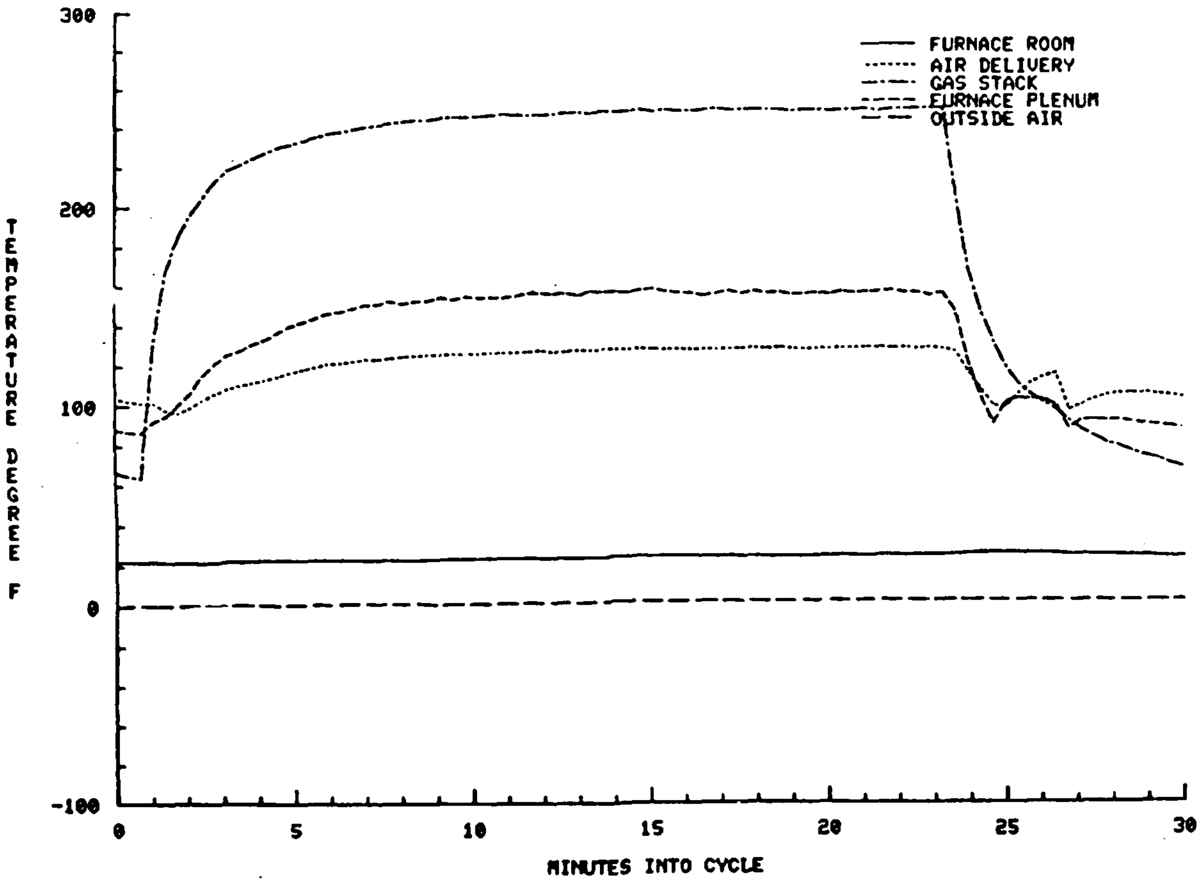


FIGURE 20. Plot of Temperatures Versus Time into Cycle for 75 Percent Duty Cycle With Moderate Wind, Using Outside Combustion and Dilution Air. Furnace Efficiency is 68.3 Percent.

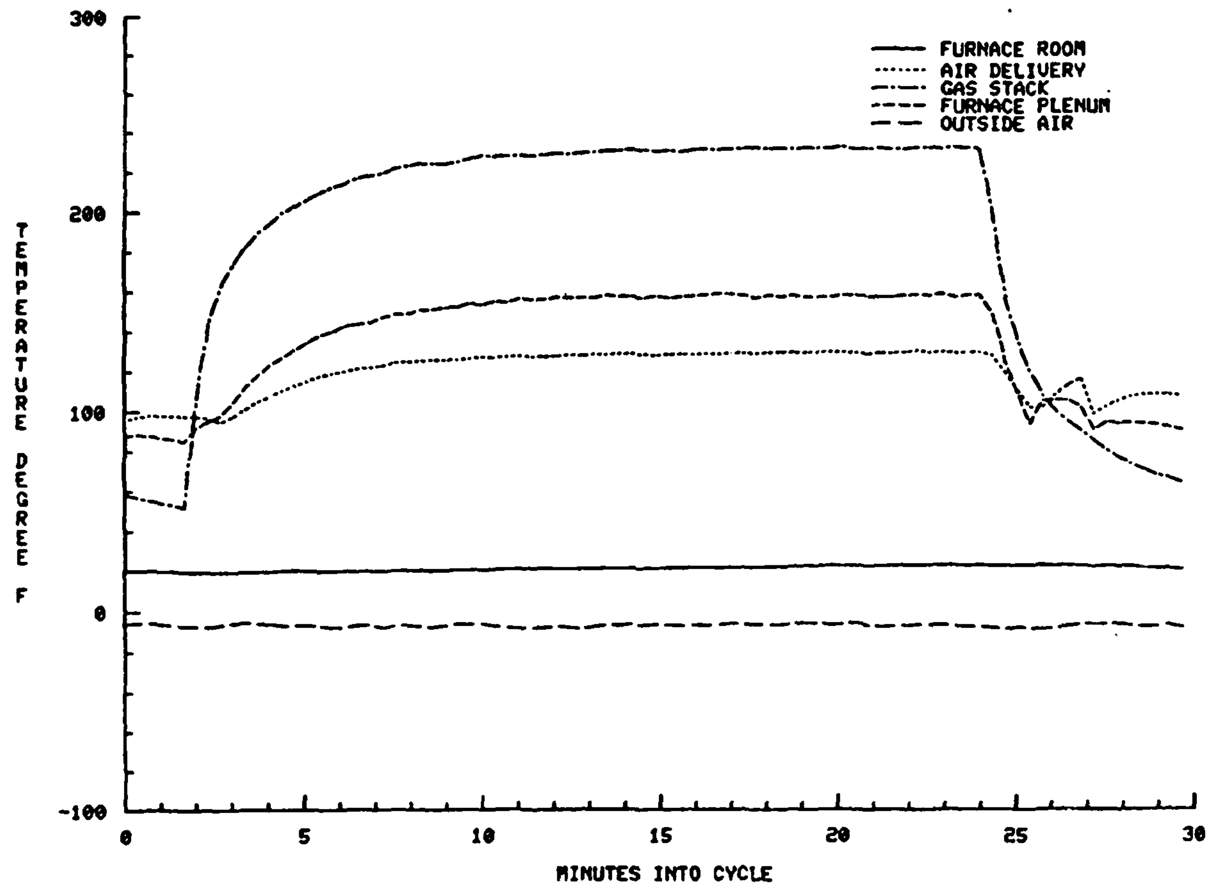


FIGURE 21. Plot of Temperatures Versus Time into Cycle for 75 Percent Duty Cycle With High Wind, Using Outside Combustion and Dilution Air. Furnace Efficiency is 66.7 Percent.

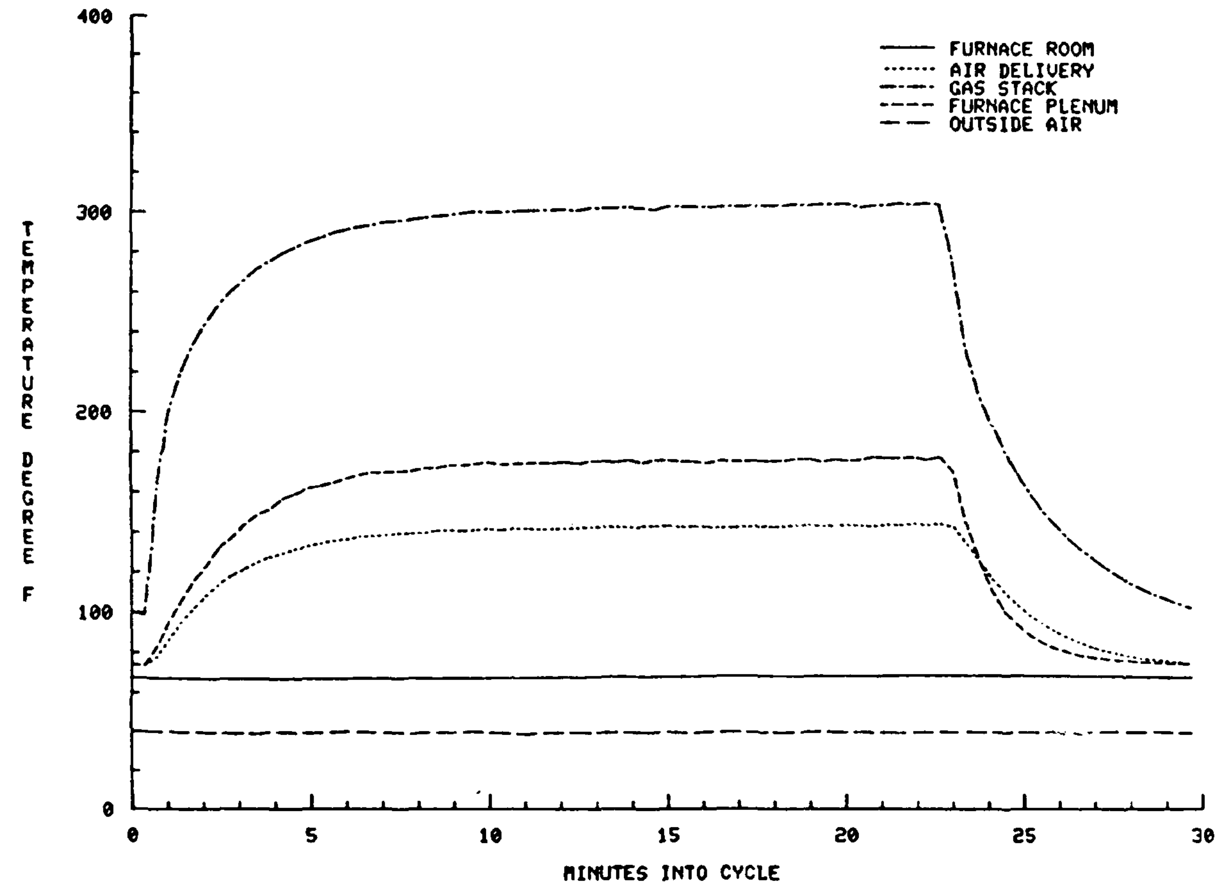


FIGURE 22. Plot of Temperatures Versus Time into Cycle for 75 Percent Duty Cycle With No Wind, Using Inside Combustion and Dilution Air. Furnace Efficiency is 72.6 Percent.

Figures 19, 20 and 21 are 75 percent duty cycle runs with outside combustion air at 0°F or below. The furnace efficiencies for these test runs were 67.9 percent, 68.3 percent and 66.7 percent, respectively for still air, moderate wind and high wind. Again, no significant effect on furnace efficiency is indicated with only the vent stack temperature showing any change from plot to plot. Figure 22 is a plot of inside combustion air and no wind for a 75 percent duty cycle for comparison to the previous three figures. The furnace efficiency for this test run was 72.6 percent and the furnace room temperature was about 70°F.

CONCLUSIONS

Furnace cyclic, thermal efficiency decreased with colder outdoor temperatures when outdoor combustion and dilution air was brought into the furnace room.

The decrease in furnace efficiency with decreasing outdoor temperature was most pronounced for the 10 percent duty cycle where efficiency changed by 16 percent within the tested temperature range. There was significantly less drop in efficiency with decreasing outdoor temperature as the duty cycle increased until at 100 percent duty cycle, the change in efficiency was only 3 percent over the temperature range tested.

When outdoor combustion air was being used, temperatures within the furnace room dropped below freezing even during the 100 percent duty cycle. This could present problems in locating a gas-fired water heater in the furnace room, sharing a common vent, because of possible freezing. Also losses from the water tank to the cold surrounding air may be substantially increased unless additional insulation is applied to the tank.

Wind-induced draft had no effect on furnace cyclic, thermal efficiency even when the temperature in the furnace room was quite low.

Computer simulations run for a furnace model and house at three locations in the U.S. showed that outside combustion air resulted in an annual fuel savings, ranging from nearly 4 percent to a little better than 6 percent, when compared to a furnace and house using inside combustion air.

The savings achieved by using outside combustion air were largest for the coldest climate tested and smallest for the more moderate climate.

RECOMMENDATIONS

Retrofit of residential gas furnaces should be considered in all climates based upon a cost-effectiveness study of each furnace circumstance.

Cost of retrofit should be calculated based upon compliance with the local building/mechanical codes and NFPA 54, the National Fuel Gas Code.

Consider automatic vent dampers as an alternative to outside combustion air and compare these two candidate retrofits. Refer to Report FESA-TS-2072.

APPENDIX A

THE TEST FACILITY AND INSTRUMENTATION

The test facility consisted of a "furnace room" 6 feet wide and 12 feet long by 8 feet high and an instrumentation room the same size located adjacent to the furnace room. The test rooms were located inside the hydro-machinery laboratory space at the Engineering Research Center at the Foothills Campus of Colorado State University. The laboratory has a large enclosed floor of 90 feet by 175 feet. This floor space is heated in the winter by radiant style heaters at the roof level with vent fans venting in the roof.

This facility was still intact from the Task Order No. 7 study of vent energy-saving devices and only minor changes and additions were made. As originally constructed, the furnace room was insulated from the attached instrumentation room and from the surrounding hydro-machinery lab. The concrete exterior wall of the furnace room was not insulated nor was the ceiling space.

No special attempt was made to seal the walls or doorway against air intrusion. Duct penetrations, holes for instrumentation leads, etc. into the furnace room were sealed to form a reasonably airtight penetration. This is assumed to be typical of how a retrofit for outdoor combustion air might be accomplished.

The "room air" for the test furnace was supplied from the laboratory space. Heated air was delivered to the lab space at 8 feet above the floor and directed in an opposite direction from the cold air intake. The air temperature near the floor of the laboratory varied between 65°F to 70°F which is representative of return air temperature in a heated building.

A regulated natural gas supply line already existed within the building and was easily extended to the test rooms for operation of the furnace. The combustion vent was run through an office balcony located immediately above the test rooms and vented into a space near the "roof" inside the building. A vent fan, operating whenever the furnace was operating, then pulled the combustion gases outside the lab building. This arrangement enabled tests to be independent of random wind effects on the vent. To simulate a wind induced draft through the vent, a two-speed vent fan was used. This allowed the effects of a wind induced draft to be duplicated consistently from run to run without being dependent on the actual wind. The vent fan was installed so that the flue gas flow would not be obstructed when the fan was not being used.

Combustion and dilution air for furnace operation was provided through one of two alternate sets of combustion air vents. For the baseline case, where combustion and dilution air are defined as tempered indoor air, two vents were placed in a wall common to the hydro-machinery lab space. These vents had a gross area of 144 in^2 each with one located with center 11 inches above the floor and the second with center located 16 inches below the ceiling.

The gross area was reduced to an effective free area of 100 in^2 each by installation of a metal grill over the openings.

The outside air source for combustion air was provided by drilling four 6 inch diameter holes through the concrete wall, two located with centers 17 inches above the floor and two with centers located 12 inches below the ceiling. This provided a gross area of 56.5 in^2 for both the low and high vent. This was reduced to an effective free area of about 35 in^2 for each of the high and low vents after a grill and screen cover was installed.

Each of the combustion air vents are fitted with a tight removable cover so that air vents were blocked appropriately for testing either for outdoor air or for indoor air. The outdoor air vents had direct access to the outside air along the main west wall of the hydro-machinery lab building.

The furnace used for the tests was a Lennox Model G1203-110 with a nameplate rating at 110,000 BtuH input. The furnace is a complete standard model just as shipped by the manufacturer. The unit included a four speed blower and a standing gas pilot light and all burner controls, fan switches and 24 volt control wiring. The furnace was purchased from a local distributor and delivered in the original factory carton. Figure A1 is an overall view of the furnace as installed with connecting duct work.

Furnace installation was accomplished by a local heating contractor. Blower fan settings were placed on the "medium high" speed, which in many cases accommodated air conditioning systems installed in conjunction with the furnace unit. Fan thermostat settings were adjusted so that the fan would turn off at around 80°F. This setting was made to assist in smoothing out blower operation time through the various tests.

Air ducts to the furnace from the laboratory space were stubbed through the instrumantation room and through the common wall of the furnace room. All connections on the duct were sealed with a silicone sealant to prevent air leakage from or air infiltration into the "room air" system. The ducts were wrapped with 3-1/2 inches of fiber glass insulation with an R value of 11. Two Cambridge Filter Corporation air flow monitors Model FMS-D-14 X 14, consisting of pitot rakes and static pressure probes were installed, one in the cool air return duct and one in the warm air delivery duct. The duct air flow monitors, were calibrated at the Solar Energy Applications Laboratory using an ASME flow nozzle as the calibration standard. Each monitor consisted of total and static pressure probe arrays which were separately manifolded to an outlet port. The differences between total and static pressures were measured with a Barocel electronic manometer. Average air velocity at the cross-section of the monitor, hence volumetric air flow rate and flow rate coefficients were determined from the calibrations. Figure A2 shows an air flow monitor as installed in the ductwork. Figure A3 is an overall plan view of the test rooms and furnace layout.

Instrumentation

The following data were taken for the analysis of each device on the vent stack:

1. Temperatures throughout the system.

2. Temperature differentials across the furnace.

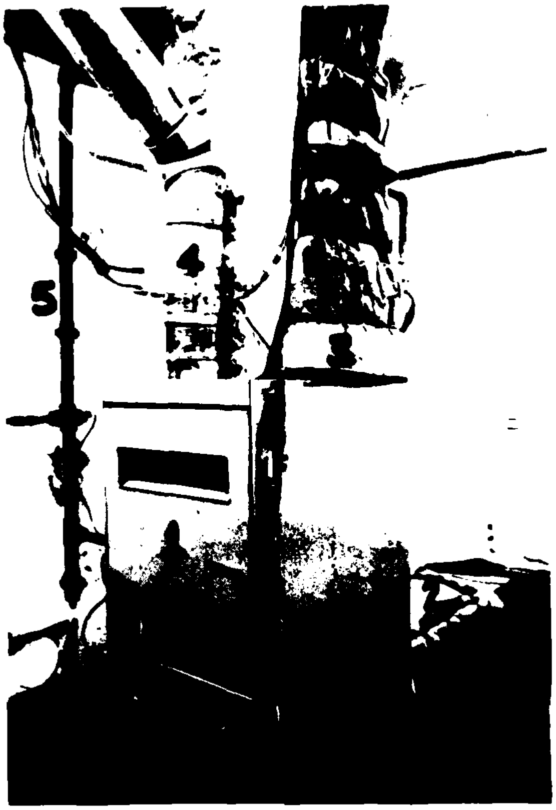


FIGURE A1. View of Furnace and Connecting Duct Work. In Order as Shown: (1) Furnace, (2) Air Return Duct, (3) Air Delivery Duct, (4) Gas Stack, (5) Gas Delivery Line.

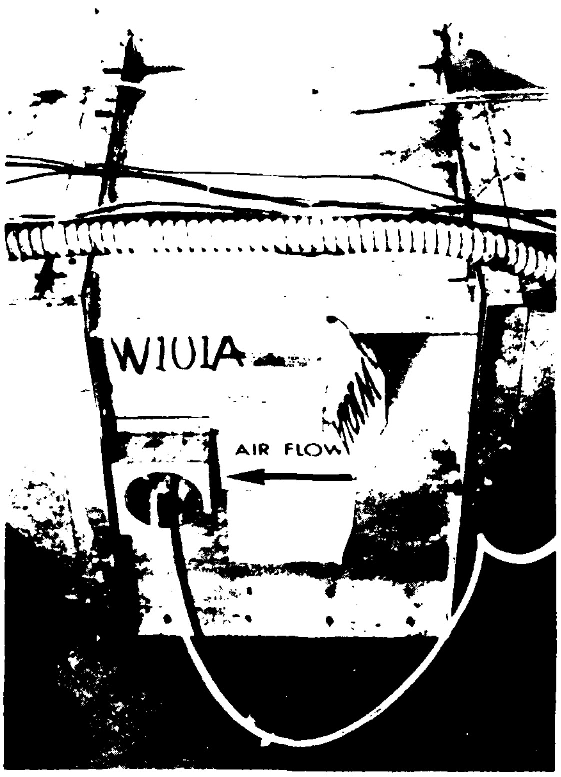


FIGURE A2. Air Flow Monitor as Mounted in Air Circuit Duct Work.

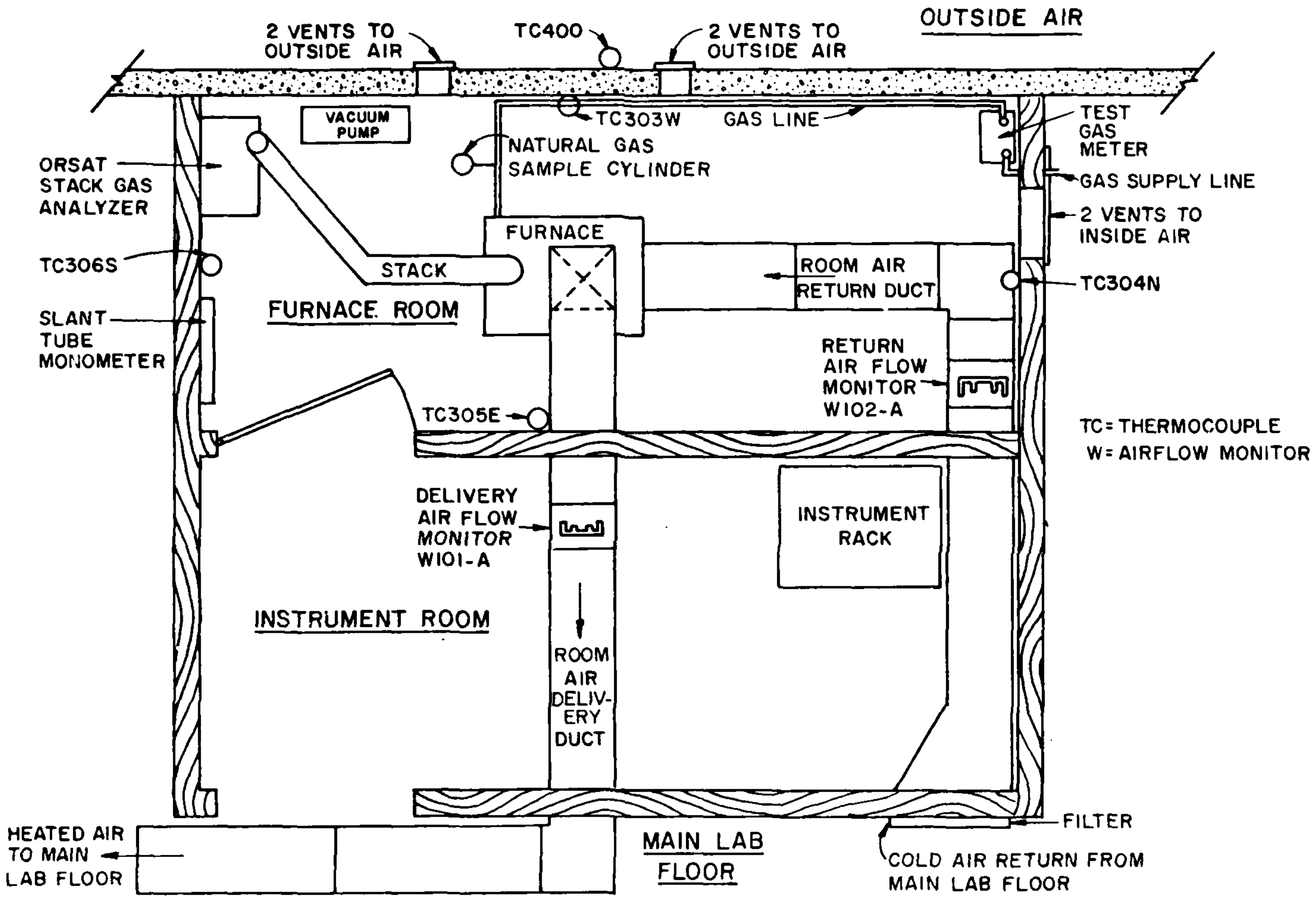


Figure A3. Floor Plan of Instrument and Furnace Rooms.

3. Air flow rates in the room air circuit.

4. Vent flow rates during and before burner operation.

5. Wet and dry bulb temperature in the lab.

6. Gas consumption during each run.

7. Stack gas samples for CO_2, O_2 and CO.

8. Natural gas samples for heating value analysis.

Temperatures

Copper-constantan (Type T) thermocouples were used to monitor temperatures throughout the system during testing. Figures A4 and A5 are system schematics giving relative positions of temperature sensors. Thermocouples, designated by TC on the figures were used to measure absolute temperatures.

The thermocouples were formed from type T thermocouple wire manufactured to special limits of purity. For the vent positions at a high temperature, teflon-insulated thermocouple wire was used and a ceramic thermal coating was applied over the exposed thermocouple to protect it from possible deterioration. The "special limits of error" (3/8 percent) wire used results in thermocouples of more uniform and predictable characteristics. Junctions were welded bead and measures were taken to insure a uniform and small size of the weld bead to reduce response time.

Thermopiles, which are made up of individual thermocouple pairs wired in series, were used to measure all temperature differences. The thermopile circuits do not measure absolute temperature relative to some reference but rather, provide a measurement of temperature increase or decrease (delta) across the circuit points relative to either end of the circuit. For example, a sixteen junction thermopile was used to measure differences in air temperature across the furnace, designated as TP-11 in Figure A2. This thermopile detects the increase in temperature across the furnace between the cool air in and the warm air delivery. Each of the sixteen thermocouples making up the thermopile was placed at the centroid of an equal area in the duct cross section. In this way, the thermopile provides an average of the air temperature through the duct cross-section. The thermopile junctions were mounted to an open wire grid in the duct section and carefully fitted along the grid to cover a minimum of pressure drop in the air flow. The thermocouple absolute temperature junction was also placed at the center of this grid.

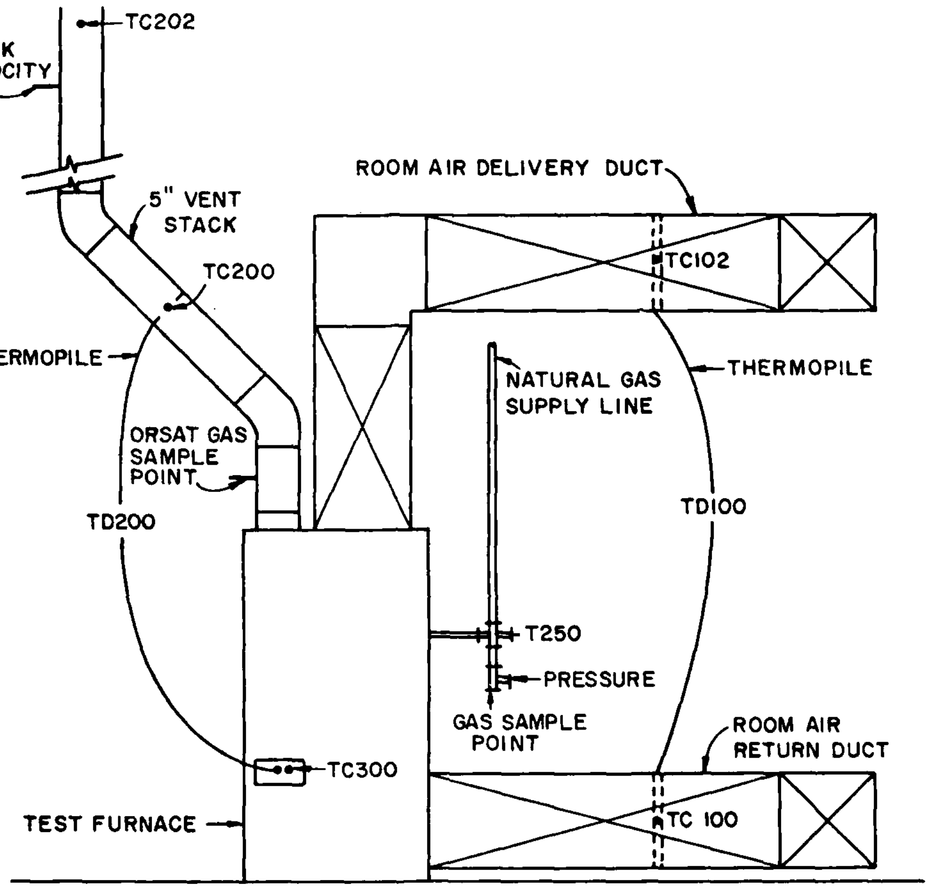


FIGURE A4. Schematic of Air Circuit and Stack Indicating Temperature Measuring Locations.

FIGURE A5. View of Instrumentation: (1) Doric Digital Acquisition System, (2) Kennedy Incremental Magnetic Tape Recorder, (3) Furnace as Seen Through the Observation Window.

Data Acquisition System

A digital data acquisition system with magnetic tape recorder was used to collect the data over the 30-minute duty cycle with enough data points to make significant energy flow calculations. The system used was a Doric Digitrend Model 220 linked with a Kennedy Incremental Model 1600 digital tape recorder. The Doric sampled all temperatures and thermopiles approximately every 1.8 seconds in a continuous scan mode and the data was recorded, via the Kennedy, on magnetic tape. The Doric system has temperature conservation circuits contained within the wire connection blocks so that thermocouple junctions can input directly and read out in absolute values relative to the ice point of water. This instrument was factory calibrated and then checked after receipt on site immediately prior to the testing program. Figure A6 is an overall view of the instrumentation roack containing the Doric and Kennedy data acquisition system.

Table A1 is a listing of the channels sampled on the Doric during test runs. The information consists of either a thermocouple temperature measurement or a voltage with the channel range approximately set to accommodate the maximum voltage expected to achieve the best resolution. Other T type thermocouples were read directly in temperature, the thermopiles produce a voltage and are read on a multivolt scale.

Several other channels of data are also a voltage relationship, including the air flow measurements throughout the system, a signal to indicate which airflow measurement is being sampled, the gas temperature and the blower and thermostat-on indicators.

TABLE A1

LIST OF DATA CHANNELS RECORDED ON THE DORIC DIGITAL AQUISITION SYSTEM

Doric Data Channel	Label	Units	Location
1	TC100	°C	Room Air Return
2	TC101	"	Room Air Delivery
3	TC102	"	Room Air Delivery
4	TC200	"	Stack
5	TC201	"	Stack
6	TC202	"	Upper Stack Air
7	TC300	"	Furnace Room Air
8	TC301	"	Low Interior Vent
9	TC302	"	High Interior Vent
10	TC303W	"	Furnace Room Air (West)
11	TC304N	"	Furnace Room Air (North)
12	TC305E	"	Furnace Room Air (East)
13	TC306W	"	Furnace Room Air (South)
14	TC400	"	Outside Air
15	TC401	"	Low Exterior Vent
16	TC402	"	High Exterior Vent
17	TD100	mV	Air Circuit Thermopile
18	TD101	"	Air Circuit Thermopile
19	TD200	"	Stack Circuit to Room Air
20	TD201	"	Stack Circuit to Room Air
21	TD202	"	Stack Circuit
22	DP101	"	Barocel Differential Pressure
23	T250	°F	Gas Temperature (Thermistor)
24	SP1		Scanivalve Position for
25	SP2		Barocel
26	SP3		(Binary Coded)
27	SP4		
28	THERM		Thermostat on Indicator
29	BLOW		Blower on Indicator
30	TC103	°C	Furnace Plenum

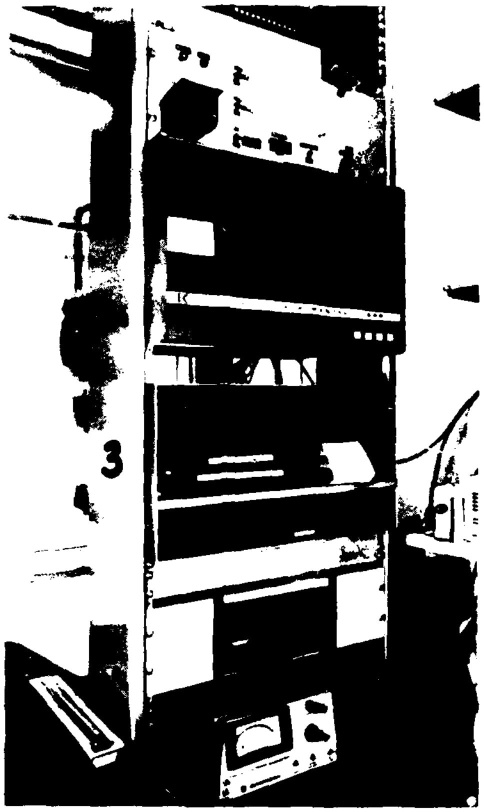


FIGURE A6. View of Instrumentation Rack. From the Top: (1) Thermostat Timer, (2) Kennedy Incremental Magnetic Tape Recorder, (3) Doric Digital Acquisition System (4) Barocel Differential Pressure Meter.

Air Flow Rates

The air flow rates in the room air duct system during blower operation and the stack flow rates are required to compute the energy flux from the furnace.

Two Cambridge Filter Corporation duct air flow monitors, Model FMS-D were used in the room air system: one in the return air duct and one in the air delivery duct. These flow monitors were located to have a long straight duct section at the upstream approach. Although care was taken to seal all duct connections with flexible silicone sealant, no special measures were taken with the furnace blower cabinet and the two flow minitors are needed to provide the air leakage rate into the system.

The flow monitors consist of a series of pitot tubes, known as a pitot rake, which are connected into a common averaging manifold. These individual pitot tubes are arranged into a pattern that samples velocity at equal area intervals through the flow monitor cross-section. Also contained within is a second set of static pressure parts brought out to a second averaging manifold. The two manifolds connect to ports on the side of the flow monitor and the pressure difference detected here is proportional to air flow. The pressure differential was detected by running tubing from the flow monitor to a "scanivalue" selection switch and then to a Datametrics Corp. Barocel, and Electronic Model 1173 Manometer which is a low-level differential pressure transducer. The Barocel converts the pressure to a voltage which is sensed by one of the Doric data channels. The scanivalue selector was manually stepped at regular intervals during test runs to sample all the air flow rates in the system.

Stack flow rates were measured with a pitot static tube at the centerline of the stack located in a straight section of stack passing through the balcony room above the test room. Pressure differentials on the pitot static tube were also read on the Barocel by stepping the scanivalue. Attempts to use a hot wire anemometer to measure stack flow rates proved unsuccessful despite the manufacturer's claim that the unit used should function in the stack environment.

Wet and Dry Bulb Temperatures

A Taylor Model 1328 sling psychrometer was used to measure dry bulb and wet bulb temperatures, both in laboratory space and in the furnace room. Readings were taken for each test run and manually recorded on the data sheets.

Blower Power

The electric energy to the blower was measured with a power watt meter. This value was manually entered in the data sheets for each run. While parasitic power should be subtracted from the heat supplied by the burner, blower energy consumed was not large enough to have a significant effect on the comparisons of the different testing conditions.

Gas Input

Volume of gas input to the test furnace was measured using a Sprague Corp Model 175 Test Meter Serial 3433436 specially factory-calibrated for testing purposes. The meter was located within the furnace room space close to where the gas temperature was monitored. The meter readings were taken manually and recorded on data sheets during the test runs.

Gas line pressure was monitored using a Dwyer slant tube manometer topped onto the gas line near the furnace.

Gas quality was obtained by gas chromatograph analysis at the CSU Chemistry Department. One liter sample bottles were connected to the gas line and a small quantity of gas was allowed to run through the bottle and outside. The bottles are double ended with vacuum tight valves at each end. After purging the bottle, a vacuum pump is used for several hours to pull remaining air and gas out of the bottle before a gas sample is allowed to enter the evacuated bottle.

The sample bottles were delivered to the Mass Spectroscopy Lab at the Colorado State University Chemistry Department for gas chr atograph analysis to determine the constituent makeup and ˀpare to a natural gas standard for determining ting value. These samples were taken an average of every two days when many test runs were being made.

Test Procedure

The proposed testing matrix for determining the effect outside combustion air has on furnace efficiency was as follows:

Outside Air Temperature Ranges °F	Vent Fan	Duty Cycle Percent
-10,0,10,25,40,55	OFF	10,20,30,50,75,100
	LOW	10,20,30,50,75,100
	HIGH	10,20,30,50,75,100
Indoor Tempered Air		
	OFF	10,20,30,50,75,100
	LOW	10,20,30,50,75,100
	HIGH	10,20,30,50,75,100

Testing was usually scheduled so that one complete set of duty cycles; i.e., 10 through 100 percent, for a given test situation could be completed in one day. This was in fact rarely possible because of the inability to control the outside air temperature over the length of this test run. The duty cycle was selected to be 30 minutes as previous tests had shown the furnace operation was well stabilized within this time period. The percent of duty cycle represents the actual time, as a percent of 30 minutes, that the burner was actually on. The duty cycle begins when the "thermostat" activates turning the burner solenoid on and allowing gas to flow to the burner. For the test series, a clock timer was used as the "thermostat" contacts so that the burner-on times could be easily controlled and adjusted.

Each 30-minute test sequence included two preconditioning sequences of the same burner-on time as the test sequence, run immediately prior to the test sequence. Testing usually proceeded beginning with the 10 percent duty cycle and working towards the 100 percent duty cycle. Again, because of the inability to control the outside vent air temperature, this was not always the case. With the two preconditioning cycles used, the test cycle would reach a uniform response regardless of the test cycle run previously. Attempts were made, however, to not run the shorter duty cycles such as 10 and 20 percent following a 100 percent duty cycle run.

During a test run, the Doric Data Acquisition System was set to scan the 30 data channels continuously at a rate of approximately one scxan every 2.25 seconds, resulting in approximately 800 individual data points for each data channel. At the same time, all manual readings were taken and the scanivalue stepping switch was manually stepped to sample all air flow channels several times during the test sequence. The test was concluded when the thermostat switch once again engaged signalling the beginning of the next 30-minute cycle. A known 30-minute span was recorded since the thermostat contact could not provide the end signal in the 100 percent case.

Baseline (Indoor Tempered Air)

The baseline test for comparing the effect of outdoor air on furnace efficiency was a complete series of the burner duty cycles run with inside or tempered air as the source of combustion and dilution air in the furnace room. The covers were placed over the outside air vents and the covers removed from the inside air vents to accomplish this. This allowed laboratory-tempered air to enter the furnace room -- the same air source as is used for the room air circuit. This series of tests included the two-stack fan-induced draft speeds to simulate moderate and heavy wind. One of the primary requirements for running this test was to define the furnace performance for the calculations to be used in arriving at comparisons of the annual fuel utilization for inside and outside combustion air.

Outside Combustion Air

The inside air vents were blocked and the outside air vents were opened to allow unheated outside air to provide all combustion and dilution air to the furnace. Table A-1 shows that the complete series of tests run for the baseline was to be duplicated for each indicated outdoor air temperature. This is the hoped for situation, but is is recognized that some portions of the matrix simply will not be filled in due to actual outdoor conditions. This is particularly true of the colder temperatures where there will be a limited time to get all data possible.

Simulation

Upon obtaining the furnace performance over as wide a range of conditions as possible, as described by Table A, a furnace and nouse model was formed for use in a computer simulation to determine annual fuel utilization numbers. Two house models were formed, one with outside combustion air to the furnace and the other with tempered indoor air to the furnace. A penalty is included in the house model that uses indoor combustion air that takes into account the additional air exfiltration from the house caused by furnace operation. Wind effects are included in this model as they have a significant bearing on the total stack flow rate, and flow rates for burner-on and burner-off are included.

A computer program known as TRNSYS has been selected to do the performance modeling based on prior experience with the program at CSU. This program was developed by the Solar Energy Laboratory at the University of Wisconsin, Madison. Although it was originally developed for, and is primarily used on solar heating and cooling simulations, there is nothing inherent within the program which would exclude its use for the furnace simulation. In fact, quite the opposite is true; it is ideally suited for obtaining the overall fuel utilization figures for the furnace models.

Actual meteorological data contained on "Typical Meteorological Year" ("TMY") tapes are used in the simulation to control the house and furnace model. Three cities from among the listing of those available were selected to provide a wide range of conditions under which the house/furnace model would operate. These cities are Boston, MA; Great Falls, MO; and Albuquerque, NM. These three cities represent a fairly wide range in both the minimum design temperature and the degree day load that the furnace must meet.

The house size and load factors were approximately matched to the furnace with a 50 percent oversizing of the furnace. This has been a fairly typical practice in the past since the cost of additional Btu input was small and natural gas was cheap. It is important that the load reflect some oversizing of the furnace since this results in the inefficiencies of short burn cycles.

The computer simulation was set up to run in 3-minute increments for the months of October through April. While some small load may occur outside these months in some of the locations, it was felt that the additional computer costs involved to process this relatively small part of the load did not justify running beyond the months selected.

APPENDIX B

OUTLINE OF KEY DATA FOR EACH CONDITION

TABLE B1

OUTLINE OF DATA-STILL AIR

		Gas Input BTU's	Room Delivery BTU's	Energy Loop Closure %	Total Losses BTU's	Thermal Efficiency %	Avg. Actual Outdoor Temp. °F	Avg. Furnace Room Temperature °F	Barometer, in. Hg	Wet Bulb/Dry Bulb °F	Maximum Stack Temperature °F	Gas Line Pressure, in. H_2O
10%	-10	--	--	--	--	--	--	--	--	--	--	--
	0	5700	2591	35.2	1102	45.5	-0.1	28.6	25.020	47/61	257.5	7.54
	10	6488	3140	30.1	1397	48.4	12.1	29.5	25.058	49/63	263.7	7.54
	25	5634	3432	11.7	1541	60.9	21.9	38.2	25.000	52/67	268.3	7.37
	40	5504	3158	36.5	1504	57.4	47.2	56.3	25.052	53/71	278.4	7.63
	55	5529	3192	25.2	942	57.7	53.6	59.8	25.188	49/69	265.8	7.97
Indoor Air		5525	2971	28.5	982	53.8	--	62.7	24.766	54/71	257.0	7.97
20%	-10	--	--	--	--	--	--	--	--	--	--	7.37
	0	11069	6245	18.9	2732	56.4	-1.3	26.4	25.019	45/61	279.1	7.37
	10	11599	6441	20.3	2808	55.5	11.7	30.2	25.060	49/64	281.3	7.39
	25	10860	6606	14.5	2683	60.8	24.0	42.4	25.057	52/67	284.0	7.88
	40	10713	6907	13.0	2419	64.5	45.3	62.3	25.045	54/72	291.7	--
	55	10626	6451	--	--	60.7	58.7	68.1	--	--	284.7	7.97
Indoor Air		10798	6717	16.4	2313	62.2	--	63.1	24.785	53/70	286.5	
30%	-10	16141	9881	9.6	4711	61.2	-4.2	17.9	25.150	45/59	283.6	7.20
	0	16216	10070	14.7	3764	62.1	-3.0	31.9	24.997	44/60	288.1	7.37
	10	15949	9756	12.1	4267	61.2	11.1	31.4	25.064	49/64	288.5	7.37
	25	15931	10715	6.1	4253	67.3	22.6	43.1	25.092	52/67	293.0	7.63
	40	16742	10707	11.1	4177	64.0	36.7	55.7	25.027	54/69	296.1	7.58
	55	15978	10548	--	--	66.0	57.3	67.8	--	--	293.0	--
Indoor Air		15717	10642	8.5	3744	67.7	--	62.9	24.805	52/69	295.3	7.97
50%	-10	27235	17763	5.0	8099	65.2	-4.6	19.0	25.450	--	289.2	7.20
	0	26631	17771	3.8	7842	66.7	-2.9	28.8	25.030	--	290.8	7.03
	10	26527	17793	3.4	7824	67.1	11.7	32.1	25.096	50/63	292.5	7.37
	25	26036	18103	1.1	7654	69.5	26.7	45.6	25.085	52/67	298.2	7.46
	40	26659	18355	3.8	7293	68.9	45.7	58.2	25.231	52/70	314.8	7.67
	55	26543	18384	15.4	4079	69.3	60.1	70.8	25.180	50/70	304.7	8.05
Indoor Air		25920	18163	5.3	6392	70.1	--	64.6	24.823	55/70	300.7	7.46
75%	-10	41887	28229	-1.3	14195	67.4	-6.8	21.2	25.810	44/58	290.5	7.29
	0	40992	28020	1.8	12247	68.4	-3.4	27.9	25.499	44/60	293.5	7.16
	10	39776	27667	0.5	11926	69.6	15.1	36.2	25.112	50/62	296.8	7.16
	25	39959	28941	-0.1	11055	72.4	26.7	48.8	25.072	51/67	299.7	7.46
	40	40013	29053	0.1	10910	72.6	4.15	60.0	25.241	52/72	319.8	8.05
	55	--	--	--	--	--	--	--	--	--	--	--
Indoor Air		--	28253	3.1	9447	72.6	--	67.7	24.865	56/71	303.4	7.50
100%	-10	58140	28713	3.6	17326	66.6	-6.9	23.9	25.975	45/61	292.6	7.33
	0	55669	38949	0.1	16687	70.0	0.3	28.5	25.850	46/61	293.0	7.20
	10	56504	37877	5.0	15829	67.0	18.7	40.1	25.128	50/63	301.8	7.16
	25	58384	40411	-2.0	19010	69.2	27.2	44.9	25.061	51/67	302.9	7.29
	40	--	--	--	--	--	--	--	--	--	--	--
	55	53935	38968	8.2	10538	72.2	55.8	67.9	25.103	53/72	319.3	7.68
Indoor Air		51457	37977	--	--	73.8	--	67.2	24.837	55/71	303.3	7.58

TABLE B2

[illegible] DATA MODERATE WIND

		Gas Input BTU's	Room Delivery BTU's	Energy Loop Closure	Total Losses BTU's	Thermal Efficiency %	Avg Acc. Outdoor Temperature °F	Avg. Furnace Room Temperature °F	Barometer, in. Hg	Wet Bulb/Dry Bulb °F	Maximum Stack Temp. °F	Gas Line Pressure, in. H_2O
10%	-10	--	--	--	--	--	--	--	--	--	--	--
	0	--	--	--	--	--	--	--	--	--	--	--
	10	--	--	--	--	--	--	--	--	--	--	--
	25	--	--	--	--	--	--	--	--	--	--	--
	40	6200	3699	14.3	1647	59.2	44.0	47.6	24.811	53/71	227.8	7.88
	55	4732	3026	33.8	768	52.8	56.7	69.1	25.148	52/72	223.7	7.92
Indoor Air		5484	2889	27.8	1068	52.7	--	58.3	24.857	60/72	220.1	8.22
20%	-10	--	--	--	--	--	--	--	--	--	--	--
	0	--	--	--	--	--	--	--	--	--	--	--
	10	--	--	--	--	--	--	--	--	--	--	--
	25	--	--	--	--	--	--	--	--	--	--	--
	40	10765	6937	15.7	2138	64.4	48.0	64.1	24.776	56/73	246.0	7.97
	55	10902	6822	12.9	2677	62.6	50.4	55.6	25.136	53/72	244.4	7.84
Indoor Air		11553	6559	21.9	2464	56.8	--	61.9	24.837	60/72	243.[illegible]	8.31
30%	-10	--	--	--	--	--	--	--	--	--	--	--
	0	15874	9490	10.1	4773	59.8	-4.0	17.2	24.983	--	239.2	7.20
	10	--	--	--	--	--	--	--	--	--	--	--
	25	--	--	--	--	--	--	--	--	--	--	--
	40	15866	10762	6.4	4085	67.8	48.0	54.4	25.180	51/69	249.1	8.05
	55	15784	10834	7.7	3738	68.6	51.0	64.8	24.948	49/69	250.3	7.92
Indoor Air		15959	10394	12.8	3526	65.1	--	68.4	24.811	52/70	251 8	7.54
50%	-10	--	--	--	--	--	--	--	--	--	--	--
	0	26484	17403	2.3	8463	65.7	1.0	18.9	24.989	45/60	246.4	7.03
	10	--	--	--	--	--	--	--	--	--	--	--
	25	26950	17755	10.7	6300	65.9	32.7	47.7	25.187	55/71	254.1	7.67
	40	26394	18575	3.4	6925	70.4	41.1	57.3	24.725	54/70	253.4	8.39
	55	26131	18578	3.3	6683	71.1	51.6	62.8	24.670	51/71	257.9	8.43
Indoor Air		26069	18569	6.2	5891	71.2	--	77.0	24.784	54/72	259.0	8.22
75%	-10	--	--	--	--	--	--	--	--	--	--	--
	0	40457	27643	0.4	12981	68.3	1.9	23.4	25.000	46/59	248.9	7.20
	10	--	--	--	--	--	--	--	--	--	--	--
	25	40407	28152	5.8	9892	69.7	31.4	49.4	25.188	55/72	258.6	7.58
	40	38820	28317	-0.1	10540	72.9	46.3	60.5	24.431	55/70	257.7	8.05
	55	--	--	--	--	--	--	--	--	--	--	--
Indoor Air		38008	28142	3.3	8610	74.0	--	81.7	24.769	55/73	261.0	7.92
100%	-10	--	--	--	--	--	--	--	--	--	--	--
	0	--	--	--	--	--	--	--	--	--	--	--
	10	54308	39510	--	--	72.7	6.8	29.8	25.050	46/59	251.8	7.20
	25	55455	39106	5.8	13142	70.5	32.5	52.2	25.189	55/72	260.0	7.42
	40	-	--	--	--	--	--	--	--	--	--	--
	55	55612	39460	-	--	71.0	53.3	69.4	25.156	46/68	256.5	8.47
Indoor Air		52260	38880	1.8	12447	74.4	--	80.2	24.766	51/74	262.8	8.22

TABLE B3

OUTLINE OF DATA HIGH WIND

		Gas Input BTU's	Room Delivery BTU's	Energy Loop Closure %	Total Losses BTU's	Thermal Efficiency %	Avg. Act. Outdoor Temperature °F	Avg. Furnace Room Temperature °F	Barometer, In. Hg	Wet Bulb/Dry Bulb °F	Maximum Stack Temperature °F	Gas Line Pressure, In. H_2O
10%	-10	--	--	--	--	--	--	--	--	--	--	--
	0	5361	2229	37.2	1139	41.6	4.8	23.2	25.855	46/59	196.9	--
	10	--	--	--	--	--	--	--	--	--	--	--
	25	6732	2815	38.9	1296	41.8	25.4	39.5	25.147	55/69	200.7	7.67
	40	5310	3116	19.0	1163	58.7	44.9	55.7	25.138	52/70	205.2	8.05
	55	--	--	--	--	--	--	--	--	--	--	--
Inside Air		5451	3256	18.4	1191	59.7	--	57.2	24.583	55/70	207.3	7.75
20%	-10	--	--	--	-	--	--	--	--	--	--	--
	0	--	--	--	--	--	--	--	--	--	--	--
	10	10890	6085	16.6	3002	55.9	6.0	24.9	25.450	--	218.7	7.20
	25	10854	6529	12.6	2962	60.1	23.4	39.6	25.073	54/69	226.8	7.63
	40	10756	6896	10.4	2787	64.1	41.3	54.3	25.149	52/70	229.3	7.71
	55	10762	6627	21.5	1817	61.6	61.8	66.8	24.940	--	234.1	8.09
Inside Air		10469	6837	10.2	2559	65.1	--	58.8	24.594	56/70	232.0	7.75
30%	-10	--	--	--	--	--	--	--	--	--	-	--
	0	--	--	--	--	--	--	--	--	--	-	--
	10	15777	9799	8.8	4584	62.1	9.2	28.2	25.010	48/62	228.5	7.33
	25	15674	9934	8.9	4346	63.4	19.4	41.1	25.244	53/69	233.4	7.58
	40	16230	10546	8.8	4257	65.0	39.8	53.6	25.149	53/70	236.8	6.05
	55	15911	10399	15.9	2988	65.4	57.7	62.6	24.993	41/69	241.5	8.31
Inside Air		15786	10885	5.7	4004	69.0	--	59.8	24.604	56/70	239.4	7.80
50%	-10	--	--	--	--	--	--	--	-	--	--	--
	0	--	--	--	--	--	--	--	--	--	--	--
	10	26790	17736	2.4	8407	66.2	6.3	28.3	24.854	47/62	232.0	7.25
	25	27319	18049	5.3	7826	66.1	23.0	41.3	25.241	51/68	239.4	7.56
	40	26474	18477	3.3	7125	69.8	42.3	59.0	24.725	54/70	245.3	7.84
	55	25811	18484	--	--	71.6	58.8	74.9	24.961	50/73	249.3	8.31
Inside Air		26209	18034	5.3	6782	68.8	--	61.6	24.614	51/71	244.8	7.50
75%	-10	41136	27451	0.7	13394	66.7	-6.8	21.3	25.507	45/61	231.4	7.29
	0	--	--	--	--	--	--	--	--	--	--	--
	10	40660	28103	0.9	12188	69.1	18.5	41.6	25.251	53/68	239.9	7.33
	25	--	--	--	--	--	--	--	--	--	--	--
	40	89143	27890	1.4	10716	71.3	40.4	58.3	24.713	54/71	242.4	7.63
	55	--	--	--	--	--	--	--	--	--	--	--
Inside Air		40098	29118	1.7	10286	72.6	--	68.6	24.847	56/72	248.9	7.54
100%	-10	56078	40888	--	--	72.9	-9.1	21.9	25.960	45/61	231.4	7.25
	0	--	--	--	--	--	--	--	--	--	--	-
	10	--	--	--	--	--	--	--	--	--	--	--
	25	58331	38546	5.9	16316	66.1	20.9	46.3	25.252	53/69	243.1	7.54
	40	53695	38286	1.5	14598	7.13	40.8	59.7	24.706	54/71	243.3	8.05
	55	53099	38843	0.1	14187	73.2	57.3	61.3	25.160	45/66	247.1	7.75
Inside Air		53445	38777	1.5	13842	72.6	--	68.5	24.862	56/72	249.4	7.50

APPENDIX C

EQUATIONS USED

Two different equations must be used to approximate the nonlinear behaviorism of thermocouples in the calculation of thermopile temperature differentials.

First, the reference thermocouple at one end of the thermopile must be known and the temperature read. This known temperature is then converted to an equivalent thermocouple EMF relative to 0°C by using an 8th order fit equation:

$$
\begin{aligned}
EMF_{REF\ T} = {} & (3.8740773840 \times 10 \times T + 3.3190198092 \times 10^{-2} \times T^2 \\
& + 2.0714183645 \times 10^{-4} \times T^3 - 2.1945834823 \times 10^{-6} \times T^4 \\
& + 1.1031900550 \times 10^{-8} \times T^5 - 3.0927581898 \times 10^{-11} \times T^6 \\
& + 4.5653337165 \times 10^{-14} \times T^7 - 2.7616878040 \times 10^{-17} \times T^8) \times 10^{-3}
\end{aligned}
$$

where EMF is in milivolts and T is degrees Celsius.

The recorded thermopile voltage is then divided by the known number of junction pairs making up the series thermopile. This results in an average thermocouple EMF difference between the reference thermocouple and the opposite and of the thermopile. Assuming that the reference thermocouple temperature is at the colder end of the thermopile (which is the way it was done in the computer) the reference EMF is added to the average thermopile EMF to obtain an overall EMF referenced to zero degrees C.

$$EMF_{overall} = EMF_{REF\ T} + EMF_{AVG\ T\text{-}PILE}$$

$$\text{where } EMF_{AVG\ T\text{-}PILE} = \frac{\text{T-PILE Milli-Volts}}{\text{N}^{\underline{o}}\text{ Junction Pairs}}$$

The $EMF_{overall}$ is now converted to a temperature relative to 0°C using a fourth order fit equation:

$$
\begin{aligned}
T_{overall} = {} & 2.5661297 \times 10 \times E - 6.1954869 \times 10^{-1} \times E^2 \\
& + 2.2181644 \times 10^{-2} \times E^3 - 3.55000 \times 10^{-4} \times E^4
\end{aligned}
$$

where $E = EMF_{overall}$

T = Temperature in degrees Celsius

The thermopile average ΔT is now the difference between $T_{overall}$ and the original reference temperature.

$$\Delta T_{T\text{-}PILE} = T_{overall} - T_{reference}$$

Flow rates within the system were measured with pitot static tubes for which a pressure differential recorded as a voltage. The voltage was converted to a pressure differential from the calibration performed on the Barocel. The voltage-pressure relationship is a straight line equation of the form

$$P = A(VOLTS) + B$$

where A and B are constants from the calibration.

Possible zero shift within the Barocel is allowed for by measuring one position in which a short circuit tubing is installed so that a known zero pressure exists across the pressure sensing unit. Any zero shift detected is then added or subtracted as appropriate.

The local velocity can be calculated when the pressure difference on the pitot static tubes is known.

$$V_L = K \sqrt{\frac{2\Delta P\ g}{\rho_L}}$$

and the local flow rate is then the velocity times the cross-section area of the flow:

$$\dot{V}_L = AK \sqrt{\frac{2\Delta P\ g}{\rho_L}}$$

where:

$\dot{V}_L$ = local volume flow rate FT^3/sec

A = cross-sectional area of flow measurement FT^2

K = flow monitor coefficient from calibration

ΔP = pitot static pressure differential lbf/ft^2

ρ_L = local density of the flow medium lbm/ft^3

g = gravity constant ft/sec^2

ρ_L is related to ρ_s, standard density, by the perfect gas law and knowing local barometric pressure and the temperature at the pitot static tube, T_L:

$$\rho_L = \frac{\rho_s P_L T_s}{T_L P_s}$$

where subscripts s refer to standard conditions and L refer to local conditions

T is absolute temperature

P is barometric pressure

therefore:

$$\dot{V}_L = \sqrt{\frac{2\ g\ P_s}{\rho_s T_s}}\ \sqrt{\frac{\Delta P\ T_L}{P_L}}$$

In order to directly add and subtract flow rates as measure by the two room air circuit monitors, the local flow rates are converted to standard conditions by:

$$\dot{V}_s = \dot{V}_L \frac{\rho_L}{\rho_s}$$

again using the relationship for P_L

$$\dot{V}_s = \dot{V}_L \frac{T_s \rho_L}{T_L \rho_s}$$

or

$$\dot{V}_s = AK \underbrace{\frac{2\ g\ T_s}{s\ s}}_{\text{knowns}} \cdot \underbrace{\frac{P_L}{T_L}}_{\text{data}}$$

The heat flow rate is calculated .· owing the temperature increase from the earlier T thermopile calculation.

$$\dot{Q} = \dot{M}C_p\Delta T$$

where:

$\dot{Q}$ = heat flow rate, Btu/sec

$\dot{M}$ = mass flow rate $\dot{V}_s P_s$, lb_m/sec

C_p = specific heat of flow medium, Btu/°F

ΔT = thermopile temperature difference, °F

The incremental heat flow is:

$$Q_{1-2} = MC_p\ T\ (t_2 - t_1)$$

where $t_2 - t_1$ is the incremental time of one data scan in seconds.

All the incremental heat flows are summed in the computer for the test resulting intotal heat flows for the test.

The heating value for natural gas obtained by gas chromatograph analysis is referred to standard conditions. To obtain the gas input Btu's for a test, this value must be converted to test conditions.

$$H_L = H_s \frac{P_L}{P_s} \frac{T_s}{T_L}$$

where:

H_s = is the standard heating value of the gas, Btu's/Ft^3

p = barometric pressure, standard and local

T_s = standard temperature

T_L = temperature of the gas delivered at the furnace

then:

GAS INPUT = $H_L \cdot M$

where M = meter reading, FT^3

Barometric pressure was provided by the Colorado Climatological Office at Colorado State University, which operates a weather station at CSU.

$$\text{Gas Input} = \Sigma \text{ all heat flows} + \text{losses}$$

The energy balance check was done in the computer using the above equations and recorded data to calculate all heat flows in the system.

Jacket and duct losses in the system were not measured but were only estimated to be 1 percent of the sum of all other heat flows. In steady state (100 percent burner cycle) the heat balance was within 1 or 2 percent for most test runs.

APPENDIX D

SIMULATION OF FURNACE PERFORMANCE

Simulation Program

The furnace simulations were performed using a program called "TRNSYS", a transient simulation program developed by the University of Wisconsin, Madison. This simulation program was originally developed for use in simulating solar energy systems, but with the provision of a full array of outside heat sources, it is ideally suited for simulation of heating systems of a nonsolar nature.

"TRNSYS" is a modular program with subroutines already developed for the various components in the heating system, such as the load model, which is a standard UA (house load) model with single mode capacities. Also available is a thermostat with optional setback and adjustable hysteresis. A model for the furnace was developed based on the actual measured performance of the furnace under test. This furnace model was then incorporated into the "TRNSYS" program.

Load Model

A standard UA load model was used to predict a load for each selected geographic location. The UA was chosen in each location so that the furnace was about 50 percent oversize for the load. This sizing is based on a minimum design temperature for the particular location, and the nameplate output of the furnace.

When heated room air is used as the combustion and dilution air source for the furnace, the air infiltration into the house increases, making the load greater than for outside combustion air. This additional load is calculated based on the temperature of the outside air, whether or not the furnace is operating and the outdoor wind speed causing induced draft. This additional load is added to the UA load already being used, as a penalty for additional air intrusion. Some internal heat generation is also added to the load model to simulate occupancy and electrical usage. A listing of the system parameters used to set up the model simulation are presented in Table D1.

The simulation program was set up to operate on three minute increments. That is, every three minutes, the entire system is examined to determine any changes in status or operation. This coincided with the minimum duty cycle measured on the test furnace and was one of the key reasons for selecting a three minute increment of time step.

The weather data used to drive the model is contained on TMY (Typical Meteorological Year) tapes developed by the National Oceanographic and Atmospheric Administration (NOAA).

TABLE D 1

SYSTEM PARAMETERS

Location	Minimum Design Temp. °F	Load UA BtuH/°F	Capacitance Btu/°F	Internal Heat Generation KWH/Day	Thermostat Setpoint °F*	Thermostat Hysteresis °F
Albuquerque	14.0	1050	5000	29.5	70*	2
Boston	6.0	920	5000	29.5	70*	2
Great Falls	-20.0	650	5000	29.5	70*	2

* One option included a setback thermostat reducing the setting to 60°F between the hours of 11 PM and 7 AM.

Results

Weekly summaries of minimum and maximum outdoor temperature, as well as overall furnace output, gas input and furnace efficiency are contained in Tables 2D through 13D. These tables cover the period 1 October through 30 April where Week 1 in the table refers to the first seven days in October.

Figures 1D through 12D are histogram plots of furnace run time for each simulation. The height of the column represents the number of times during the simulated heating season that the furnace operated for the specified time period. The furnace had slightly more operations of longer duration when inside combustion air was used. With a setback thermostat, the furnace shows some runs of 60 minute duration which do not occur when no setback thermostat is used. This is caused by changing the thermostat setting at 7 AM from 60oF to 70oF which requires the furnace to operate for a longer period to recover.

It is also interesting to note that the only time the furnace has any operating cycles of 3 or 6 minute durations is when a setback thermostat is used. These short duty cycles occur for all three locations with the setback thermostat in use.

Table 14D and 15D present the annual fuel data for the simulated furnace in each geographical location for both indoor and outdoor combustion air and a percent savings value. Also presented for interest are the results when a setback thermostat is used.

Annual gas savings can be realized for each of the three locations simulated when outside combustion air as opposed to inside combustion air is used in the furnace room. The savings are greatest for the most severe climate of Great Falls, MT, where a 6 percent annual fuel reduction occurs and the least for the more moderate climate of Albuquerque, NM, where the fuel savings are 3.8 percent.

Use of outside combustion air results in savings despite the fact that the furnace operates with slightly less thermal efficiency. Fortunately, the furnace does not normally operate for short 10 percent or 20 percent duty cycles (3 or 6 minute runs) as seen on Figures 1D through 6D, since these are the duty cycles where the most severe drop in furnace efficiency occurs as outdoor temperature decreases.

With the load as modeled, the furnace operates mostly on 12 to 15 minute duty cycles, regardless of the combustion air source or the use of a setback thermostat.

The major change introduced by the setback thermostat is the use of rather long duration duty cycles (60 minutes) and also the addition of a few fewer short duration duty cycles (3 and 6 minutes). The use of a setback thermostat still provides a savings over no setback thermostat. However, the savings are now greatest for the more moderate climate in Albuquerque and slightly less for the more severe climate at Great Falls.

TABLE D2

FURNACE PERFORMANCE SUMMARY

LOCATION : ALBUQUERQUE, NM　　　　INSIDE AIR

THERMOSTAT SETBACK : NO

WEEK	TMIN F	TMAX F	TAVE F	QFURN MMBTU	QGAS MMBTU	FURNACE EFFICIENCY
1	41.00	82.04	61.70	1.35	1.99	67.98
2	42.98	82.04	62.65	1.24	1.83	67.76
3	35.06	75.02	50.97	3.04	4.43	68.58
4	41.00	71.06	55.65	2.16	3.16	68.25
5	37.94	69.08	50.75	3.03	4.43	68.46
6	24.98	66.92	43.65	4.36	6.27	69.52
7	19.94	69.08	42.53	4.57	6.54	69.80
8	30.92	62.06	46.62	3.80	5.51	68.88
9	17.96	57.92	38.58	5.30	7.56	70.17
10	21.02	64.94	43.70	4.36	6.27	69.52
11	21.02	55.04	34.73	6.05	8.58	70.52
12	17.96	55.04	33.53	6.28	8.84	70.98
13	8.96	53.96	29.95	6.96	9.71	71.65
14	17.06	51.08	32.87	6.40	9.01	70.97
15	21.92	53.96	36.00	5.80	8.23	70.41
16	17.96	53.96	35.09	5.96	8.46	70.51
17	10.94	46.94	30.97	6.76	9.48	71.31
18	28.94	64.04	41.44	4.78	6.86	69.76
19	28.04	66.02	43.99	4.30	6.20	69.42
20	21.92	60.08	35.86	5.85	8.30	70.48
21	12.02	62.96	29.93	6.96	9.74	71.51
22	16.16	62.06	34.22	6.16	8.67	71.06
23	14.00	59.00	41.19	4.83	6.89	70.07
24	32.00	60.98	44.63	4.18	6.04	69.26
25	21.92	69.98	45.02	4.12	5.90	69.81
26	33.98	71.06	53.57	2.53	3.69	68.53
27	30.02	80.96	52.42	2.85	4.12	69.11
28	39.02	77.00	57.56	1.88	2.76	68.18
29	30.02	75.02	53.46	2.62	3.81	68.86
30	35.96	75.02	54.79	2.33	3.41	68.29
31	44.06	71.06	56.48	.58	.85	68.11
TOTAL	8.96	82.04	44.05	131.40	187.50	70.06

TABLE D3

FURNACE PERFORMANCE SUMMARY

LOCATION : ALBUQUERQUE, NM OUTSIDE AIR

THERMOSTAT SETBACK : NO

WEEK	TMIN F	TMAX F	TAVE F	QFURN MMBTU	QGAS MMBTU	FURNACE EFFICIENCY
1	41.00	82.04	61.70	1.30	1.93	67.30
2	42.98	82.04	62.65	1.15	1.71	67.06
3	35.06	75.02	50.97	2.88	4.25	67.81
4	41.00	71.06	55.65	2.06	3.05	67.57
5	37.94	69.98	50.75	2.88	4.24	67.81
6	24.98	66.92	43.65	4.13	6.03	68.45
7	19.94	69.08	42.53	4.32	6.30	68.57
8	30.92	62.06	46.62	3.61	5.31	68.01
9	17.96	57.92	38.58	5.02	7.29	68.89
10	21.02	64.94	43.70	4.12	6.01	68.46
11	21.02	55.04	34.73	5.70	8.25	69.06
12	17.96	55.04	33.53	5.91	8.53	69.33
13	8.96	53.96	29.95	6.54	9.39	69.68
14	17.06	51.08	32.87	6.04	8.71	69.30
15	21.92	53.96	36.00	5.47	7.93	69.07
16	17.96	53.96	35.09	5.64	8.16	69.10
17	10.94	46.94	30.97	6.37	9.16	69.52
18	28.94	64.04	41.44	4.51	6.57	68.61
19	28.04	66.02	43.99	4.07	5.94	68.44
20	21.92	60.08	35.86	5.51	7.98	69.01
21	12.02	62.96	29.93	6.55	9.41	69.62
22	16.16	62.06	34.22	5.78	8.34	69.34
23	14.00	59.00	41.19	4.56	6.63	68.77
24	32.00	60.99	44.63	3.96	5.79	68.34
25	21.92	69.98	45.02	3.89	5.67	68.57
26	33.98	71.06	53.57	2.40	3.54	67.80
27	30.02	80.96	52.42	2.67	3.92	68.20
28	39.02	77.00	57.56	1.78	2.63	67.59
29	30.02	75.02	53.46	2.46	3.62	68.02
30	35.96	75.02	54.79	2.19	3.25	67.56
31	44.06	71.06	56.48	.54	.80	67.38
TOTAL	8.96	82.04	44.05	124.00	180.30	68.76

TABLE D3

FURNACE PERFORMANCE SUMMARY

LOCATION : ALBUQUERQUE, NM OUTSIDE AIR

THERMOSTAT SETBACK : NO

WEEK	TMIN F	TMAX F	TAVE F	QFURN MMBTU	QGAS MMBTU	FURNACE EFFICIENCY
1	41.00	82.04	61.70	1.30	1.93	67.30
2	42.98	82.04	62.65	1.15	1.71	67.06
3	35.06	75.02	50.97	2.88	4.25	67.81
4	41.00	71.06	55.65	2.06	3.05	67.57
5	37.94	69.08	50.75	2.88	4.24	67.81
6	24.98	66.92	43.65	4.13	6.03	68.45
7	19.94	69.08	42.53	4.32	6.30	68.57
8	30.92	62.06	46.62	3.61	5.31	68.01
9	17.96	57.92	38.58	5.02	7.29	68.89
10	21.02	64.94	43.70	4.12	6.01	68.46
11	21.02	55.04	34.73	5.70	8.25	69.06
12	17.96	55.04	33.53	5.91	8.53	69.33
13	8.96	53.96	29.95	6.54	9.39	69.68
14	17.06	51.08	32.87	6.04	8.71	69.30
15	21.92	53.96	36.00	5.47	7.93	69.07
16	17.96	53.96	35.09	5.64	8.16	69.10
17	10.94	46.94	30.97	6.37	9.16	69.52
18	28.94	64.04	41.44	4.51	6.57	68.61
19	28.04	66.02	43.99	4.07	5.94	68.44
20	21.92	60.08	35.86	5.51	7.98	69.01
21	12.02	62.96	29.93	6.55	9.41	69.62
22	16.16	62.06	34.22	5.78	8.34	69.34
23	14.00	59.00	41.19	4.56	6.63	68.77
24	32.00	60.98	44.63	3.96	5.79	68.34
25	21.92	69.98	45.02	3.89	5.67	68.57
26	33.98	71.06	53.57	2.40	3.54	67.80
27	30.02	80.96	52.42	2.67	3.92	68.20
28	39.02	77.00	57.56	1.78	2.63	67.59
29	30.02	75.02	53.46	2.46	3.62	68.07
30	35.96	75.02	54.79	2.19	3.25	67.56
31	44.06	71.06	56.48	.54	.80	67.38
TOTAL	8.96	82.04	44.05	124.00	180.30	68.76

TABLE D4

FURNACE PERFORMANCE SUMMARY

LOCATION : ALBUQUERQUE, NM INSIDE AIR

THERMOSTAT SETBACK : YES

WEEK	TMIN F	TMAX F	TAVE F	QFURN MMBTU	QGAS MMBTU	FURNACE EFFICIENCY
1	41.00	82.04	61.70	.96	1.36	70.69
2	42.98	82.04	62.55	.86	1.20	71.11
3	35.06	75.02	50.97	2.48	3.57	69.57
4	41.00	71.06	55.55	1.57	2.39	69.72
5	37.94	69.08	50.75	2.46	3.54	69.56
6	24.98	66.92	43.55	3.77	5.38	70.06
7	19.94	69.08	42.53	3.96	5.65	70.31
8	30.92	62.06	46.52	3.25	4.65	69.75
9	17.96	57.92	38.58	4.70	6.67	70.53
10	21.02	64.94	43.70	3.77	5.38	70.08
11	21.02	55.04	34.73	5.42	7.66	70.71
12	17.96	55.04	33.53	5.56	7.95	71.13
13	8.96	53.96	29.95	6.30	8.79	71.73
14	17.06	51.08	32.87	5.79	8.14	71.08
15	21.92	53.96	36.00	5.16	7.31	70.58
16	17.96	53.96	35.09	5.35	7.56	70.78
17	10.94	46.94	30.97	6.13	8.60	71.31
18	28.94	64.04	41.44	4.20	5.98	70.21
19	25.04	56.02	43.99	3.70	5.29	70.02
20	21.92	60.08	35.36	5.25	7.43	70.64
21	12.02	62.96	29.33	6.31	8.82	71.59
22	15.16	62.06	34.22	5.54	7.78	71.16
23	14.00	59.00	41.19	4.26	6.06	70.32
24	32.00	60.98	44.53	3.60	5.16	69.74
25	21.92	69.98	45.02	3.53	5.03	70.22
26	33.98	71.06	53.57	2.00	2.87	69.74
27	30.02	80.96	52.42	2.29	3.28	69.83
28	39.02	77.00	57.56	1.35	1.93	69.85
29	30.02	75.02	53.46	2.06	2.95	69.93
30	35.96	75.02	54.79	1.80	2.59	69.41
31	44.06	71.06	55.46	.42	.61	69.27
TOTAL	8.96	82.04	44.05	114.00	161.60	70.56

TABLE D5

FURNACE PERFORMANCE SUMMARY

LOCATION : ALBUQUERQUE, NM OUTSIDE AIR

THERMOSTAT SETBACK : YES

WEEK	TMIN F	TMAX F	TAVE F	QFURN MMBTU	QGAS MMBTU	FURNACE EFFICIENCY
1	41.00	82.04	61.70	.94	1.34	70.25
2	42.98	82.04	62.55	.81	1.14	70.87
3	35.06	75.02	50.97	2.35	3.41	69.84
4	41.00	71.06	55.55	1.58	2.28	69.08
5	37.94	69.08	50.75	2.34	3.41	69.66
6	24.98	66.92	43.55	3.54	5.19	69.93
7	19.94	69.08	42.53	3.74	5.47	69.13
8	30.92	62.06	46.52	3.07	4.46	69.75
9	17.96	57.92	38.58	4.45	6.45	69.18
10	21.02	64.94	43.70	3.56	5.16	69.94
11	21.02	55.04	34.73	5.13	7.40	69.29
12	17.96	55.04	33.53	5.34	7.69	69.48
13	8.96	53.96	24.35	5.95	8.53	69.73
14	17.06	51.08	32.87	5.46	7.87	69.39
15	21.92	53.96	36.00	4.91	7.08	69.30
16	17.96	53.96	35.09	5.05	7.30	69.25
17	10.94	46.94	30.97	5.79	8.32	69.59
18	28.94	64.04	41.44	3.95	5.74	69.97
19	24.04	66.02	43.99	3.51	5.09	69.02
20	21.92	60.08	35.86	4.94	7.13	69.25
21	12.02	62.96	29.93	5.95	8.54	69.71
22	15.16	62.06	34.22	5.20	7.49	69.53
23	14.00	59.00	41.19	4.03	5.83	69.01
24	32.00	60.98	44.53	3.41	4.96	69.79
25	21.92	69.98	45.92	3.34	4.83	69.08
26	33.98	71.06	53.57	1.90	2.75	69.03
27	30.02	80.96	52.42	2.17	3.15	69.05
28	39.02	77.00	57.56	1.28	1.85	69.49
29	30.92	75.02	53.46	1.95	2.82	69.12
30	35.96	75.02	54.79	1.70	2.47	69.90
31	44.06	71.06	55.48	.40	.58	69.05
TOTAL	8.96	82.04	44.05	107.80	155.70	69.25

TABLE D6

FURNACE PERFORMANCE SUMMARY

LOCATION : BOSTON, MASS. INSIDE AIR

THERMOSTAT SETBACK : NO

WEEK	TMIN F	TMAX F	TAVE F	QFURN MMBTU	QGAS MMBTU	FURNACE EFFICIENCY
1	55.04	57.02	55.93	1.80	2.68	67.40
2	46.04	62.06	54.85	1.93	2.86	67.49
3	37.04	51.98	55.62	1.83	2.70	67.57
4	35.06	44.96	49.70	2.80	4.09	68.44
5	55.04	71.06	53.36	2.18	3.22	67.61
6	28.94	42.08	47.06	3.27	4.75	68.84
7	35.96	42.98	48.89	2.90	4.25	68.10
8	37.94	50.00	39.00	4.57	6.61	69.18
9	32.00	39.92	35.80	5.10	7.32	69.70
10	26.06	37.04	38.60	4.64	6.69	69.33
11	12.02	26.06	32.46	5.66	8.05	70.33
12	21.92	33.08	29.84	6.09	8.64	70.45
13	15.08	24.98	29.60	6.14	8.71	70.47
14	32.00	39.92	37.17	4.86	6.97	69.66
15	10.04	26.96	24.76	6.97	9.75	71.49
16	33.45	37.04	27.28	6.54	9.20	71.03
17	21.02	28.94	30.04	6.05	8.61	70.36
18	23.00	30.92	23.77	7.17	10.01	71.60
19	24.08	33.98	34.65	5.29	7.57	69.88
20	26.06	37.04	32.70	5.61	8.01	70.07
21	32.05	53.96	37.80	4.76	6.82	69.71
22	33.98	59.00	39.35	4.50	6.50	69.27
23	21.02	32.00	35.67	5.12	7.33	69.74
24	15.98	28.94	31.92	5.76	8.20	70.27
25	33.08	39.92	33.33	5.49	7.83	70.07
26	32.00	51.98	43.89	3.73	5.43	68.75
27	33.98	51.08	42.69	3.94	5.72	68.81
28	42.08	69.08	46.37	3.34	4.86	68.62
29	44.96	68.00	51.82	2.50	3.67	68.13
30	42.08	53.06	47.67	3.09	4.52	68.21
31	45.50	56.48	51.59	.70	1.04	67.44
TOTAL	6.08	77.00	39.83	134.30	192.62	69.72

TABLE D7

FURNACE PERFORMANCE SUMMARY

LOCATION : BOSTON, MASS.　　　　OUTSIDE AIR

THERMOSTAT SETBACK :　NO

WEEK	TMIN F	TMAX F	TAVE F	QFURN MMBTU	QGAS MMBTU	FURNACE EFFICIENCY
1	55.04	57.02	55.93	1.68	2.52	66.73
2	46.04	62.06	54.85	1.80	2.69	66.80
3	37.04	51.98	55.62	1.72	2.58	66.84
4	35.06	44.96	49.70	2.61	3.86	67.60
5	55.04	71.06	53.36	2.04	3.05	66.94
6	28.94	42.08	47.06	3.04	4.49	67.70
7	35.96	42.98	48.89	2.72	4.04	67.30
8	37.94	50.00	39.00	4.25	6.23	68.13
9	32.00	39.92	35.80	4.75	6.95	68.31
10	26.06	37.04	38.60	4.31	6.32	68.14
11	12.02	26.06	32.46	5.26	7.68	68.58
12	21.92	33.08	29.84	5.67	8.26	68.66
13	15.08	24.98	29.60	5.70	8.31	68.60
14	32.00	39.92	37.17	4.52	6.63	68.17
15	10.04	26.96	24.76	6.45	9.34	69.02
16	33.45	37.04	27.28	6.06	8.80	68.83
17	21.02	28.94	30.04	5.64	8.22	68.58
18	23.00	30.92	23.77	6.60	9.56	69.03
19	24.08	33.98	34.65	4.92	7.20	68.33
20	26.06	37.04	32.70	5.22	7.63	68.46
21	32.05	53.96	37.80	4.43	6.49	68.22
22	33.98	59.00	39.35	4.20	6.16	68.10
23	21.02	32.00	35.67	4.77	6.98	68.28
24	15.98	28.94	31.92	5.34	7.80	68.51
25	33.08	39.92	33.33	5.12	7.48	68.47
26	32.00	51.98	43.89	3.49	5.15	67.78
27	33.98	51.08	42.69	3.68	5.42	67.91
28	42.08	69.08	46.37	3.12	4.60	67.76
29	44.96	68.00	51.82	2.33	3.46	67.34
30	42.08	53.06	47.67	2.91	4.31	67.49
31	45.50	56.48	51.59	.66	.98	66.97
TOTAL	6.08	77.00	39.83	125.00	183.18	68.23

TABLE D8

FURNACE PERFORMANCE SUMMARY

LOCATION : BOSTON, MASS. INSIDE AIR

THERMOSTAT SETBACK : YES

WEEK	TMIN F	TMAX F	TAVE F	QFURN MMBTU	QGAS MMBTU	FURNACE EFFICIENCY
1	44.06	77.00	55.93	1.40	2.02	69.21
2	39.92	73.04	54.85	1.51	2.18	69.42
3	37.04	73.94	55.62	1.45	2.08	69.55
4	35.06	75.92	49.70	2.39	3.43	69.60
5	35.96	71.06	53.36	1.77	2.55	69.23
6	28.94	75.92	47.06	2.83	4.07	69.62
7	33.98	60.98	48.89	2.45	3.53	69.29
8	30.02	50.00	39.00	4.05	5.80	69.74
9	28.04	48.92	35.80	4.58	6.53	70.12
10	26.06	55.94	38.60	4.12	5.89	69.97
11	12.02	46.04	32.46	5.11	7.23	70.75
12	19.04	39.92	29.84	5.56	7.85	70.73
13	15.08	42.08	29.60	5.59	7.89	70.78
14	15.98	60.08	37.17	4.35	6.20	70.15
15	5.98	41.00	24.76	6.39	8.92	71.65
16	6.08	37.94	27.28	5.99	8.42	71.22
17	15.08	37.94	30.04	5.50	7.78	70.71
18	10.04	55.22	23.77	6.50	9.20	71.75
19	23.00	53.05	34.65	4.75	6.78	70.27
20	24.08	58.00	32.70	5.07	7.21	70.30
21	21.92	60.08	37.40	4.25	6.07	70.11
22	27.68	59.00	39.35	3.98	5.71	69.77
23	21.02	53.05	35.57	4.58	6.52	70.20
24	15.98	48.92	31.92	5.22	7.34	70.58
25	15.98	46.04	33.33	4.95	7.05	70.39
26	32.00	64.04	43.89	3.24	4.66	69.52
27	33.98	57.02	42.69	3.43	4.93	69.62
28	30.92	69.08	46.37	2.85	4.10	69.51
29	37.94	75.92	51.82	2.05	2.96	69.35
30	39.92	64.94	47.57	2.63	3.80	69.25
31	45.50	56.48	51.59	.57	.83	53.51
TOTAL	6.08	77.00	39.83	119.20	169.60	70.31

TABLE D9

FURNACE PERFORMANCE SUMMARY

LOCATION : BOSTON, MASS. OUTSIDE AIR

THERMOSTAT SETBACK : YES

WEEK	TMIN F	TMAX F	TAVE F	QFURN MMBTU	QGAS MMBTU	FURNACE EFFICIENCY
1	41.06	77.00	55.93	1.31	1.90	53.86
2	39.92	73.04	54.85	1.43	2.08	53.58
3	37.04	73.94	55.52	1.35	1.96	53.03
4	35.06	75.92	49.70	2.22	3.23	53.85
5	35.96	71.06	53.36	1.54	2.38	53.67
6	28.94	75.92	47.06	2.55	3.87	53.54
7	33.98	60.98	48.89	2.28	3.33	53.53
8	30.02	50.00	39.00	3.78	5.50	53.58
9	28.04	48.92	35.80	4.25	6.18	53.84
10	26.06	55.94	38.50	3.83	5.57	53.80
11	12.02	46.04	32.46	4.77	6.91	53.95
12	19.04	39.92	29.84	5.18	7.50	53.02
13	15.08	42.08	29.50	5.19	7.54	53.83
14	15.98	60.08	37.17	4.05	5.91	53.72
15	5.98	41.00	24.76	5.94	8.58	53.24
16	6.08	37.94	27.28	5.57	8.06	53.05
17	15.08	37.94	30.04	5.12	7.44	53.85
18	10.04	55.22	23.77	6.10	8.81	53.22
19	23.00	53.06	34.55	4.44	6.46	53.70
20	24.08	50.00	32.70	4.73	6.88	53.80
21	21.92	60.08	37.80	3.95	5.76	53.73
22	27.68	59.00	39.35	3.72	5.41	53.72
23	21.02	53.06	35.57	4.27	6.20	53.74
24	15.98	48.92	31.92	4.85	7.03	53.92
25	15.98	46.04	33.33	4.64	6.75	53.81
26	32.00	64.04	43.89	3.03	4.42	53.59
27	33.98	57.02	42.59	3.22	4.69	53.74
28	30.92	69.08	45.37	2.55	3.86	53.82
29	37.94	75.92	51.52	1.93	2.80	53.76
30	39.92	64.94	47.57	2.48	3.61	53.52
31	45.50	56.48	51.59	.54	.79	57.91
TOTAL	5.08	77.00	39.83	111.10	161.40	53.84

TABLE D10

FURNACE PERFORMANCE SUMMARY

LOCATION : GREAT FALLS, MONTANA   INSIDE AIR

THERMOSTAT SETBACK :   NO

WEEK	TMIN F	TMAX F	TAVE F	QFURN MMBTU	QGAS MMBTU	FURNACE EFFICIENCY
1	30.92	80.06	54.68	1.32	1.95	67.59
2	32.90	82.04	55.61	1.20	1.78	67.48
3	26.96	57.92	39.21	3.05	4.47	68.22
4	-.04	62.96	37.56	3.26	4.71	69.24
5	5.00	53.06	32.43	3.89	5.65	68.89
6	-13.00	66.02	34.55	3.62	5.17	69.95
7	19.04	62.96	37.40	3.26	4.76	68.52
8	23.00	60.98	41.97	2.74	4.03	67.98
9	19.04	46.04	33.87	3.68	5.36	68.59
10	26.06	60.08	45.56	2.26	3.35	67.52
11	3.02	42.98	23.80	4.86	6.99	69.54
12	10.94	48.02	33.30	3.77	5.48	68.75
13	-14.98	48.02	11.70	6.37	8.91	71.49
14	-16.96	37.04	5.74	7.13	9.94	71.75
15	-9.94	42.08	19.44	5.48	7.78	70.46
16	26.06	53.06	39.94	2.99	4.40	68.00
17	-9.04	60.98	29.30	4.27	6.06	70.34
18	-13.00	33.98	9.03	6.67	9.35	71.29
19	8.96	51.98	30.99	4.06	5.86	69.24
20	8.06	48.92	28.83	4.32	6.23	69.27
21	-9.04	57.92	24.43	4.86	6.91	70.32
22	-2.02	53.96	31.06	4.06	5.84	69.45
23	10.04	48.02	32.68	3.85	5.59	68.88
24	21.02	48.92	34.47	3.63	5.29	68.60
25	5.00	51.98	26.63	4.56	6.55	69.66
26	23.00	59.00	38.03	3.20	4.68	68.37
27	19.04	57.92	39.06	3.07	4.48	68.40
28	28.04	78.98	46.32	2.28	3.34	68.07
29	24.08	62.06	36.14	3.41	4.97	68.54
30	23.00	71.96	46.17	2.22	3.26	67.85
31	39.92	71.96	52.84	.43	.64	67.53
TOTAL	-16.96	82.04	33.51	113.70	163.80	69.44

TABLE D11

FURNACE PERFORMANCE SUMMARY

LOCATION : GREAT FALLS, MONTANA   OUTSIDE AIR

THERMOSTAT SETBACK :   NO

WEEK	TMIN F	TMAX F	TAVE F	QFURN MMBTU	QGAS MMBTU	FURNACE EFFICIENCY
1	30.92	80.06	54.68	1.20	1.80	66.55
2	32.90	82.04	55.61	1.08	1.63	66.44
3	26.96	57.92	39.21	2.76	4.13	66.92
4	-.04	62.96	37.56	2.95	4.42	66.80
5	5.00	53.06	32.43	3.51	5.24	66.99
6	-13.00	66.02	34.55	3.28	4.89	67.00
7	19.04	62.96	37.40	2.98	4.44	67.05
8	23.00	60.98	41.97	2.46	3.69	66.62
9	19.04	45.04	33.87	3.35	5.01	66.90
10	26.06	60.08	45.56	2.08	3.13	66.47
11	3.02	42.98	23.80	4.45	6.63	67.06
12	10.94	48.02	33.30	3.42	5.13	66.69
13	-14.98	48.02	11.70	5.77	8.59	67.21
14	-16.96	37.04	5.74	6.43	9.56	67.31
15	-9.94	42.08	19.44	4.93	7.35	67.05
16	26.06	53.06	39.94	2.70	4.04	66.74
17	-9.04	60.98	29.30	3.85	5.74	66.98
18	-13.00	33.98	9.03	6.08	9.05	67.22
19	8.96	51.98	30.99	3.67	5.47	66.99
20	8.06	48.92	28.83	3.90	5.84	66.91
21	-9.04	57.92	24.43	4.39	6.54	67.04
22	-2.02	53.96	31.06	3.66	5.46	66.95
23	10.04	48.02	32.68	3.48	5.19	67.11
24	21.02	48.92	34.47	3.29	4.91	66.95
25	5.00	51.98	26.63	4.15	6.19	67.03
26	23.00	59.00	38.03	2.90	4.35	66.84
27	19.04	57.92	39.06	2.78	4.17	66.77
28	28.04	78.98	46.32	2.09	3.12	66.82
29	24.08	62.06	36.14	3.09	4.61	67.03
30	23.00	71.96	46.17	2.03	3.03	66.81
31	39.92	71.96	52.84	.38	.58	66.27
TOTAL	-16.96	82.04	33.51	103.10	153.90	66.97

TABLE D12

FURNACE PERFORMANCE SUMMARY

LOCATION : GREAT FALLS, MONTANA INSIDE AIR

THERMOSTAT SETBACK : YES

WEEK	TMIN F	TMAX F	TAVE F	QFURN MMBTU	QGAS MMBTU	FURNACE EFFICIENCY
1	30.92	80.06	54.58	1.06	1.52	70.10
2	32.90	82.04	55.51	.95	1.37	69.95
3	26.96	57.92	39.21	2.71	3.91	69.25
4	-.04	62.96	37.56	2.90	4.13	70.25
5	5.00	53.06	32.43	3.54	5.08	69.67
6	13.00	66.02	34.55	3.29	4.64	70.98
7	19.04	52.96	37.40	2.89	4.16	69.46
8	23.00	60.98	41.97	2.39	3.45	69.16
9	19.04	46.04	33.87	3.33	4.80	69.39
10	26.06	60.06	45.56	1.95	2.82	69.00
11	3.02	42.98	23.80	4.46	6.36	70.11
12	10.94	48.02	33.30	3.41	4.91	69.51
13	-14.98	48.02	11.70	5.97	8.30	71.90
14	-16.96	37.04	5.74	6.71	9.32	72.05
15	-9.94	42.08	14.44	5.11	7.22	70.86
16	26.06	53.06	39.94	2.65	3.84	69.93
17	-9.04	50.98	29.30	3.88	5.45	71.18
18	-13.00	33.98	9.03	6.30	8.78	71.67
19	8.96	51.98	30.99	3.57	5.24	69.94
20	8.06	48.92	28.83	3.48	5.09	69.92
21	-9.04	57.92	24.43	4.47	6.30	70.97
22	-2.02	53.46	31.06	3.70	5.27	70.13
23	10.04	48.02	32.58	3.48	5.00	69.59
24	21.02	48.92	34.47	3.26	4.69	69.45
25	5.00	51.98	25.53	4.19	5.95	70.33
26	23.00	59.00	38.03	2.84	4.10	69.40
27	19.04	57.92	39.06	2.72	3.93	69.35
28	28.04	74.98	46.32	1.95	2.82	69.39
29	24.06	62.96	35.14	3.05	4.39	69.51
30	23.00	71.96	45.17	1.90	2.74	69.19
31	39.92	71.96	52.84	.33	.48	69.67
TOTAL	-16.96	82.04	33.51	103.00	146.60	70.25

TABLE D13

FURNACE PERFORMANCE SUMMARY

LOCATION : GREAT FALLS, MONTANA   OUTSIDE AIR

THERMOSTAT SETBACK : YES

WEEK	TMIN F	TMAX F	TAVE F	QFURN MMBTU	QGAS MMBTU	FURNACE EFFICIENCY
1	30.92	80.06	54.58	.98	1.41	59.26
2	32.90	82.04	55.51	.87	1.25	59.15
3	25.96	57.92	39.21	2.45	3.62	57.99
4	-.04	62.96	37.56	2.63	3.86	58.01
5	5.00	53.95	32.43	3.19	4.70	57.79
6	-13.00	66.02	34.55	2.99	4.42	57.79
7	19.04	62.96	37.40	2.65	3.89	58.08
8	23.00	60.98	41.97	2.15	3.17	57.98
9	19.04	46.04	33.87	3.04	4.46	57.85
10	25.06	60.08	45.56	1.79	2.63	58.00
11	3.02	42.98	23.80	4.11	6.07	57.59
12	10.94	48.02	33.30	3.10	4.57	57.72
13	-11.98	48.02	11.70	5.42	8.02	57.54
14	-15.96	37.04	5.74	6.07	8.99	57.56
15	-9.94	42.08	19.44	4.51	6.93	57.49
16	25.06	53.05	39.94	2.38	3.50	57.88
17	-9.04	60.98	29.30	3.51	5.18	57.65
18	-13.00	33.98	9.03	5.74	8.49	57.54
19	8.96	51.98	30.99	3.33	4.92	57.73
20	8.06	49.92	24.83	3.58	5.30	57.63
21	-9.04	57.92	24.43	4.06	5.99	57.72
22	-2.02	53.96	31.05	3.33	4.92	57.72
23	10.04	48.02	32.58	3.15	4.66	57.76
24	21.02	48.92	34.47	2.95	4.35	57.83
25	5.00	51.98	25.63	3.81	5.63	57.58
26	23.00	59.00	38.03	2.58	3.81	57.89
27	19.04	57.92	39.06	2.47	3.64	57.95
28	29.04	78.98	46.32	1.80	2.62	58.51
29	24.08	62.05	35.14	2.78	4.08	58.13
30	23.00	71.95	45.17	1.72	2.52	58.37
31	39.92	71.95	52.84	.29	.42	59.59
TOTAL	-15.96	82.04	33.51	93.53	137.90	57.81

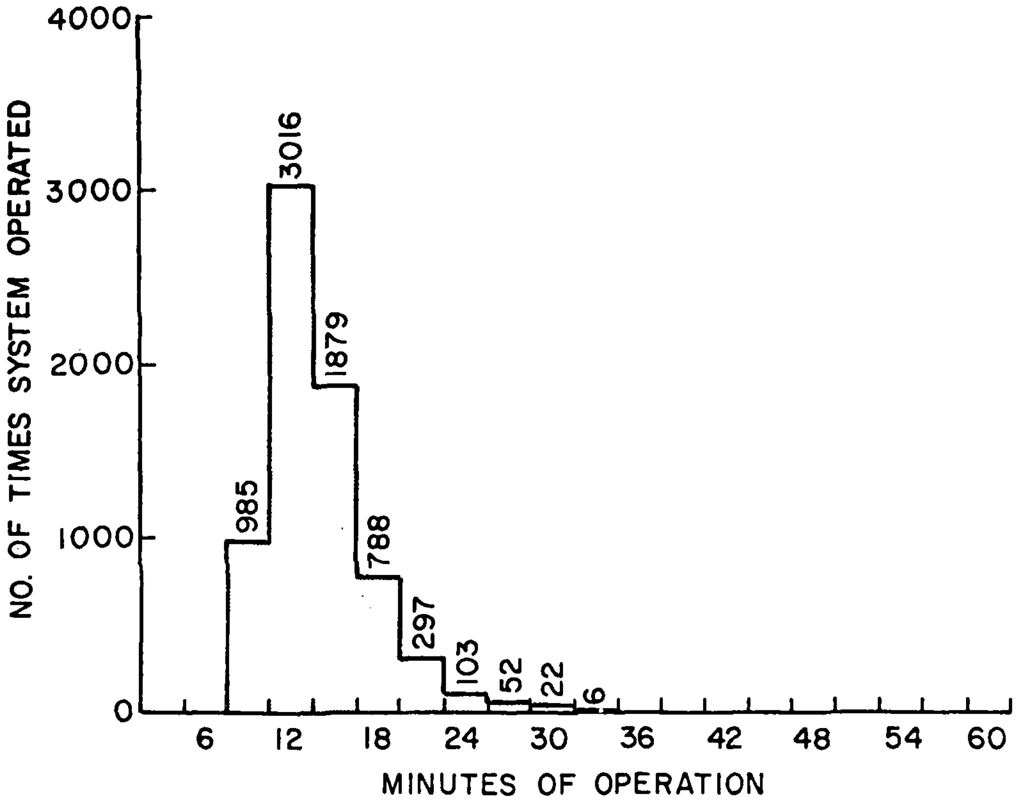


FIGURE D1. Seasonal Histogram of Furnace Operating Cycles for Albuquerque, NM Using Outside Combustion and Dilution Air With No Furnace Setback.

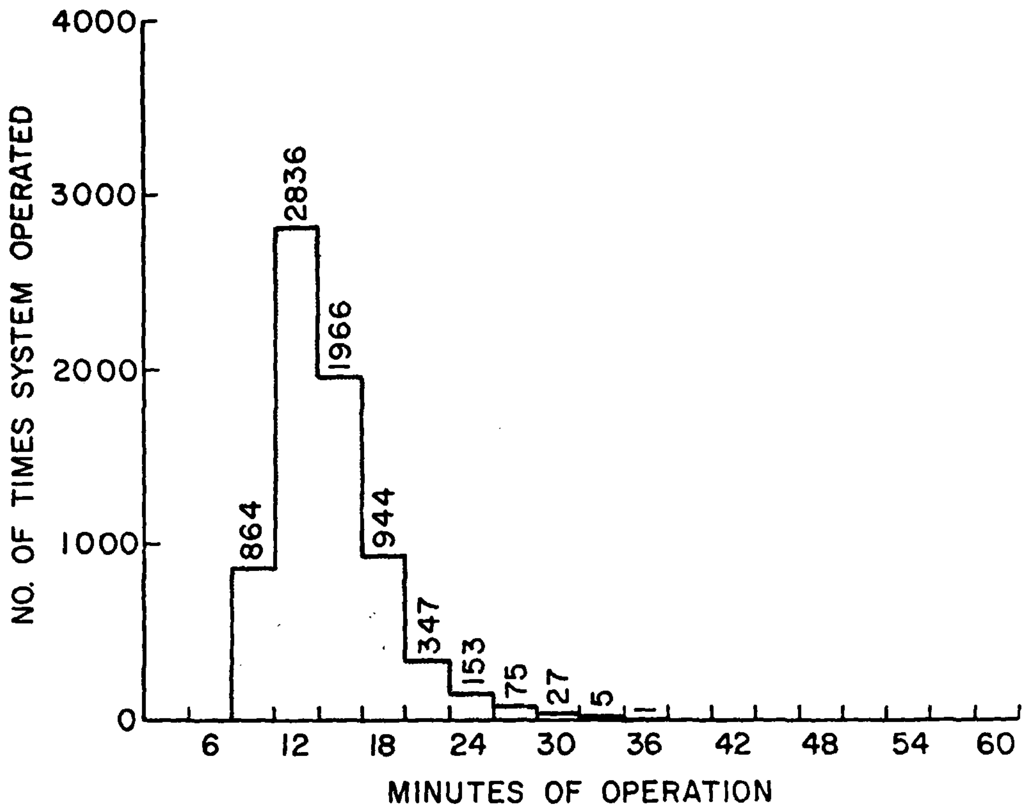


FIGURE D2. Seasonal Histogram of Furnace Operating Cycles for Albuquerque, NM Using Inside Combustion and Dilution Air With No Furnace Setback.

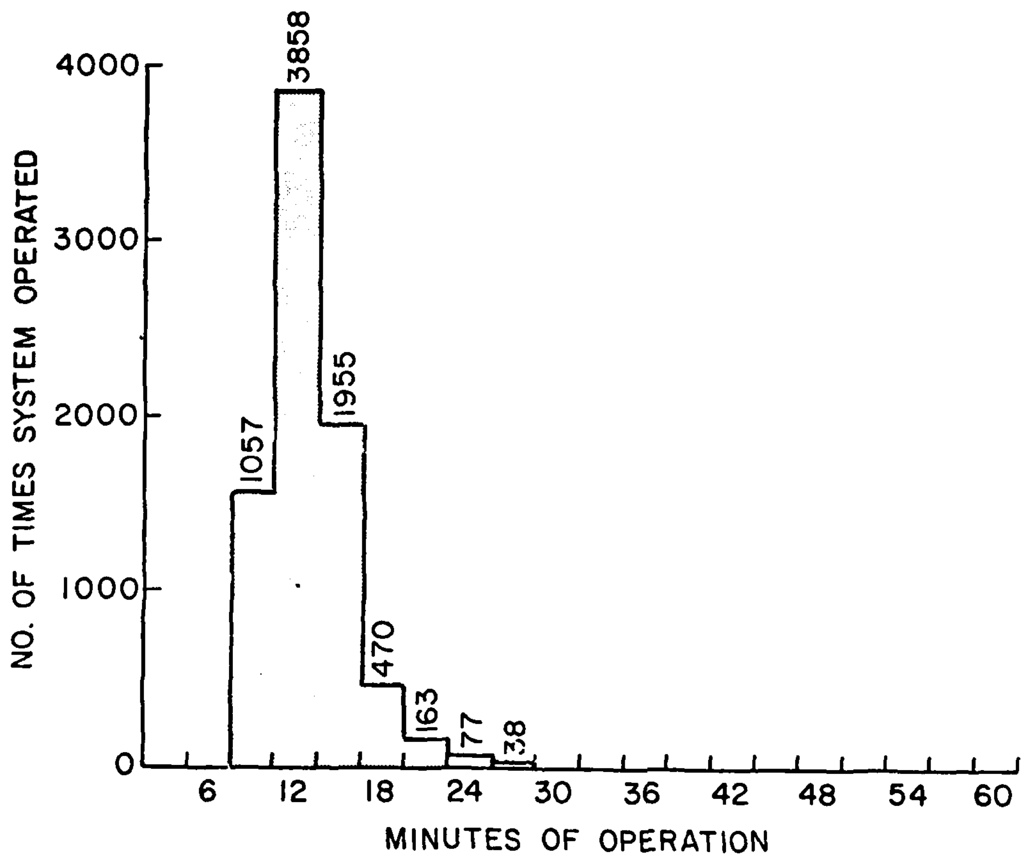


FIGURE D3. Seasonal Histogram of Furnace Operating Cycles for Boston, MA Using Outside Combustion and Dilution Air With No Furnace Setback.

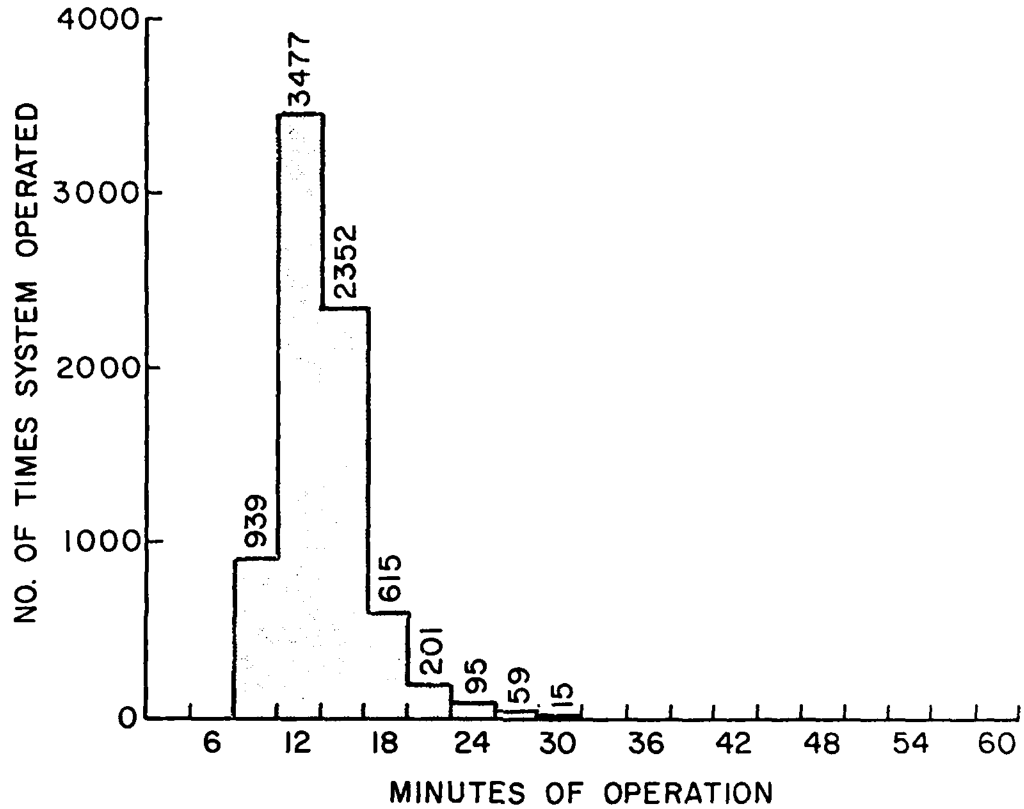
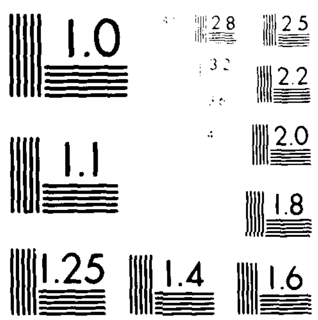


FIGURE D4. Seasonal Histogram of Furnace Operating Cycles for Boston, MA Using Inside Combustion and Dilution Air With No Furnace Setback.

AD-A113 484 JOHNS-MANVILLE SALES CORP DENVER CO RESEARCH AND DEV--ETC F/G 13/1
EFFECT OF OUTSIDE COMBUSTION AIR ON GAS FURNACE EFFICIENCY.(U)
OCT 81 T E BRISBANE, K L HANCOCK DAAK70-78-D-0002
UNCLASSIFIED USAFESA-TS-2104 NL

2 OF 2
AD A
113484

END
DATE
FILMED
05-82
DTIC


1.0
2.8
2.5
3.2
2.2
2.0
1.1
1.8
1.25
1.4
1.6

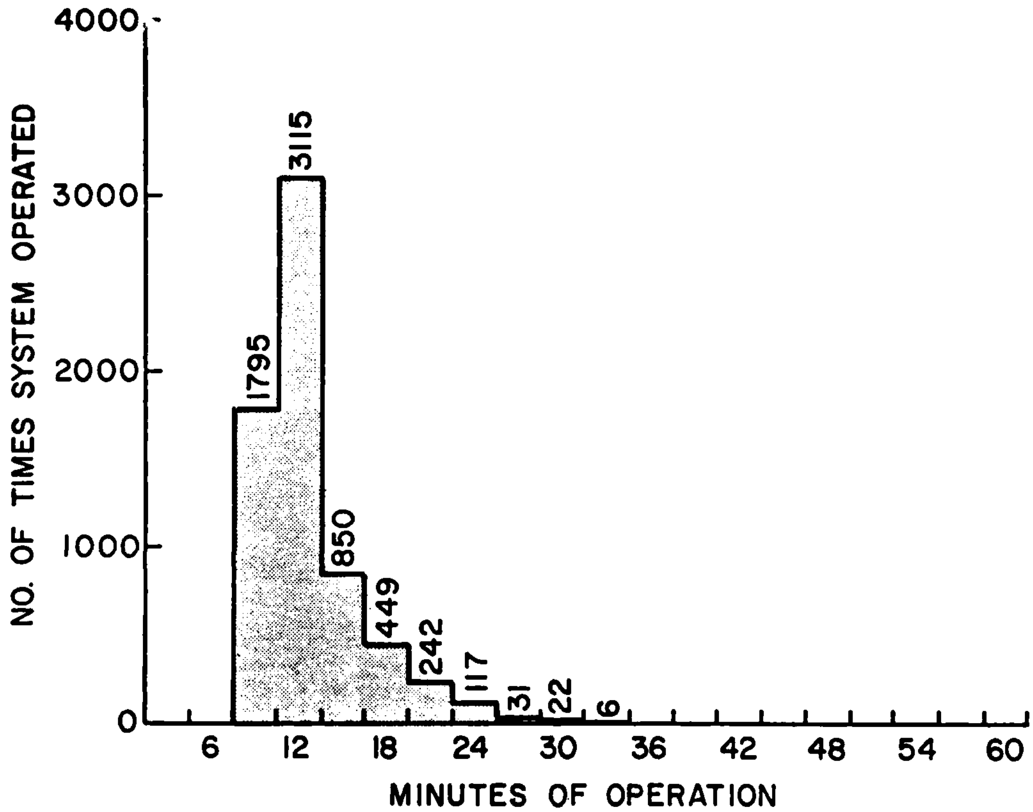


FIGURE D5. Seasonal Histogram of Furnace Operating Cycles for Great Falls, MT Using Outside Combustion and Dilution Air With No Furnace Setback.

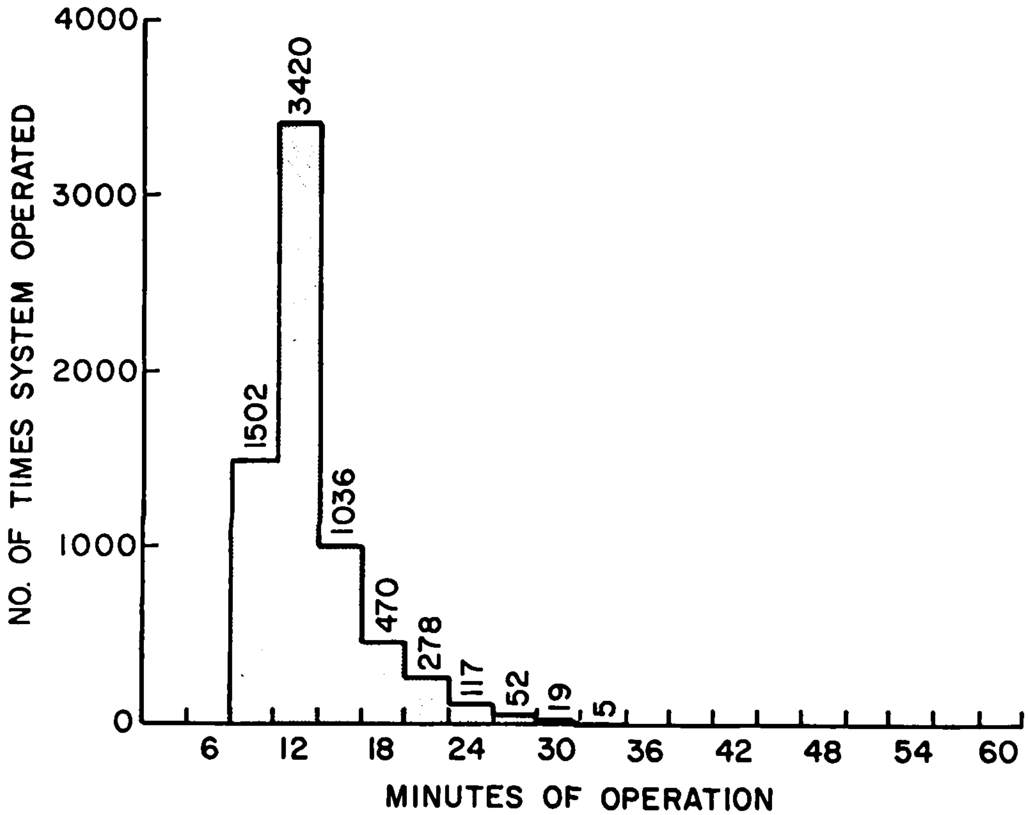


FIGURE D6. Seasonal Histogram of Furnace Operating Cycles for Great Falls, MT Using Inside Combustion and Dilution Air With No Furnace Setback.

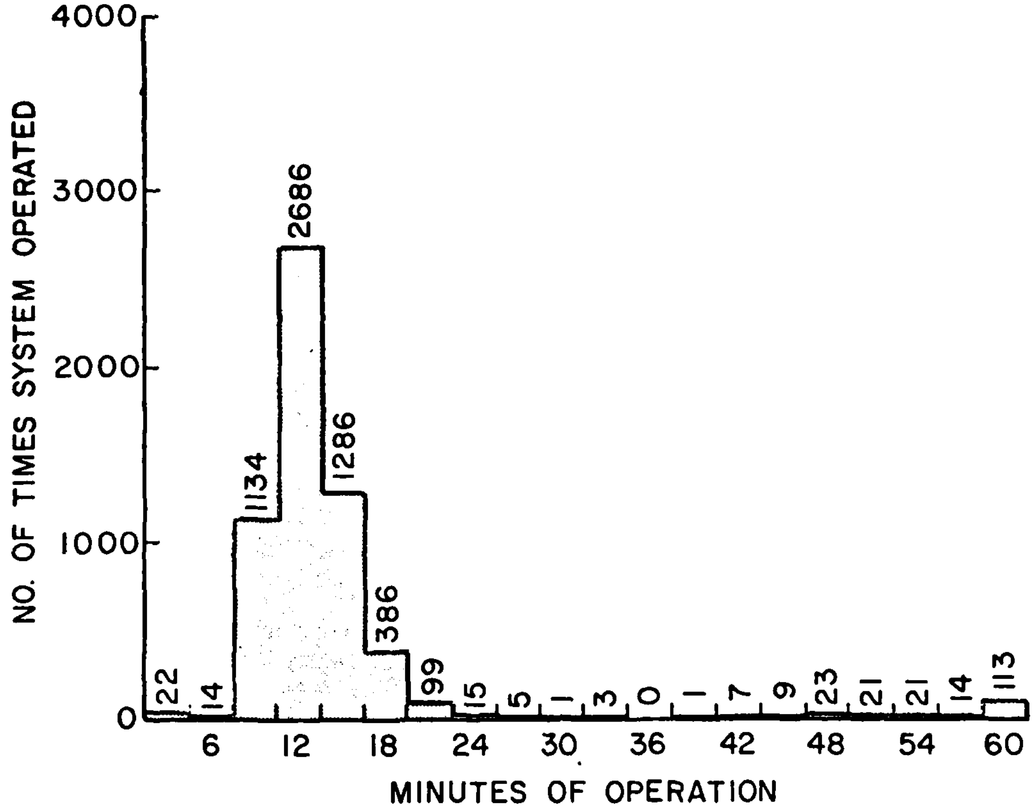


FIGURE D7. Seasonal Histogram of Furnace Operating Cycles for Albuquerque, NM Using Outside Combustion and Dilution Air With A Furnace Setback.

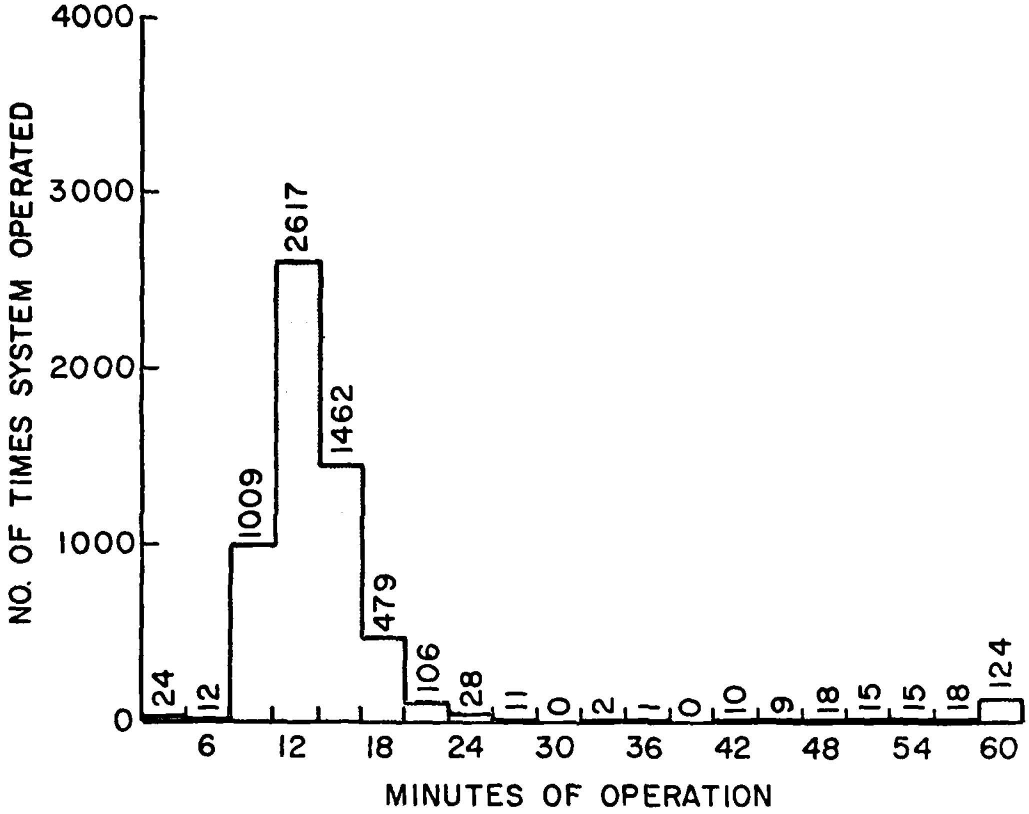


FIGURE D8. Seasonal Histogram of Furnace Operating Cycles for Albuquerque, NM Using Inside Combustion and Dilution Air With A Furnace Setback.

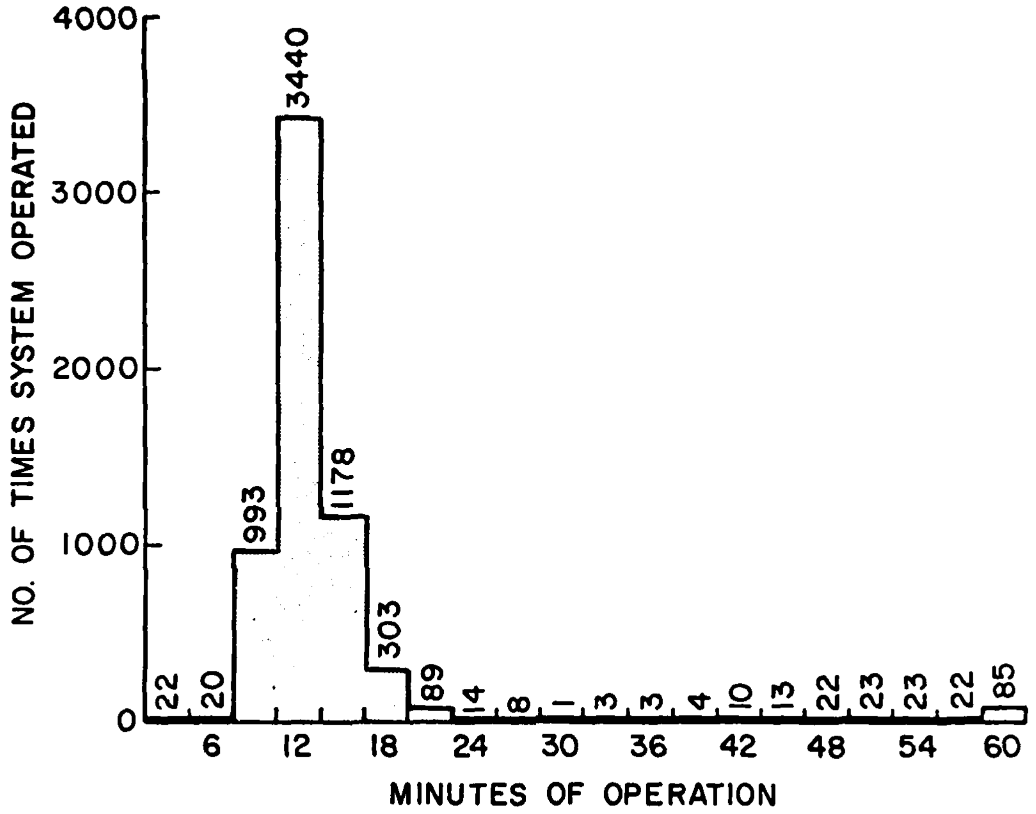


FIGURE D9. Seasonal Histogram of Furnace Operating Cycles for Boston, MA Using Outside Combustion and Dilution Air With A Furnace Setback.

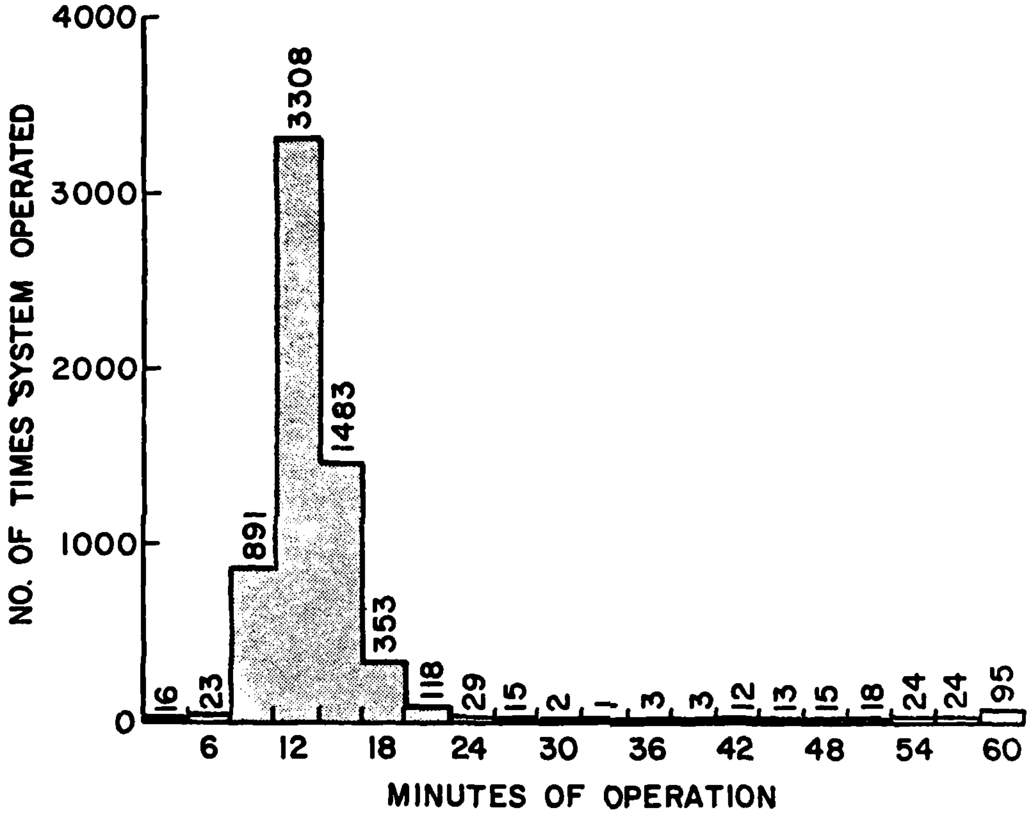


FIGURE D10. Seasonal Histogram of Furnace Operating Cycles for Boston, MA Using Inside Combustion and Dilution Air With A Furnace Setback.

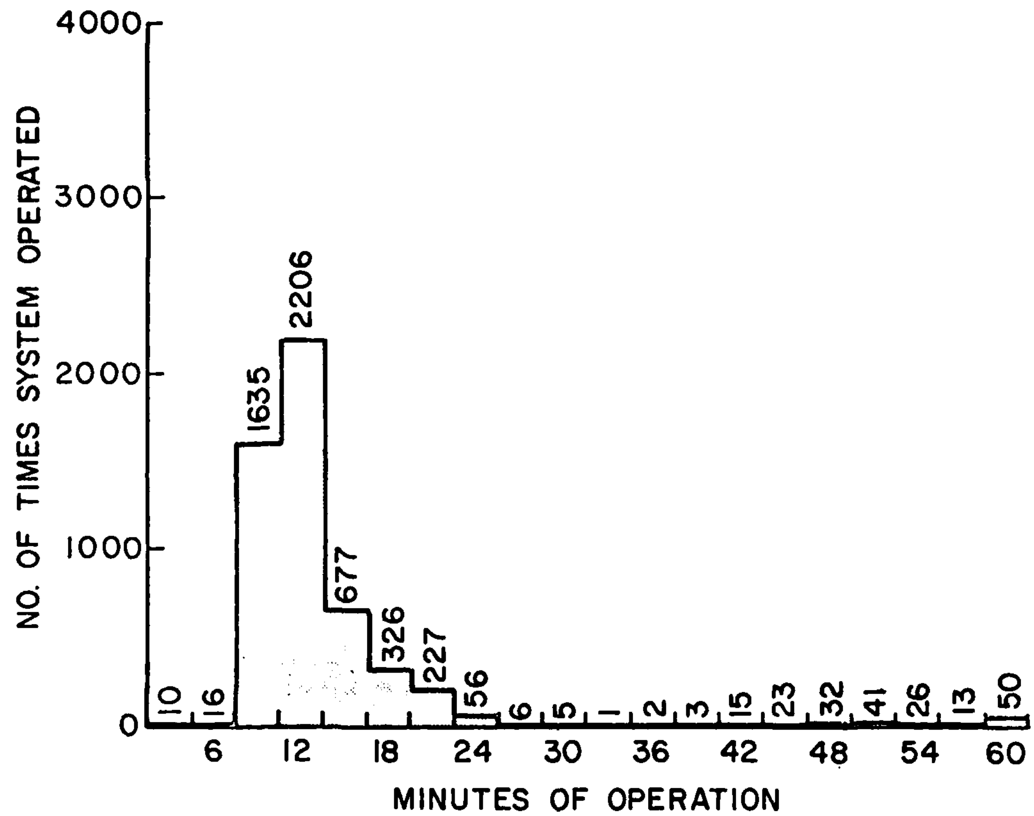


FIGURE D11. Seasonal Histogram of Furnace Operating Cycles for Great Falls, MT Using Outside Combustion and Dilution Air With A Furnace Setback.

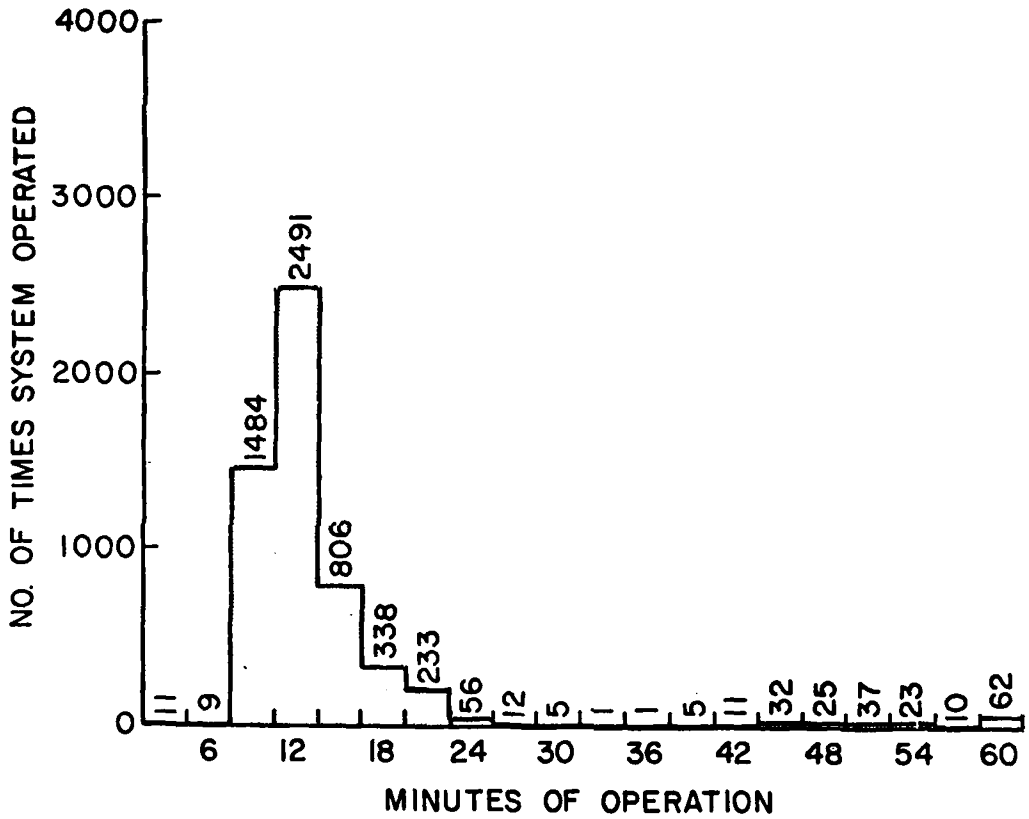


FIGURE D12. Seasonal Histogram of Furnace Operating Cycles for Great Falls, MT Using Inside Combustion and Dilution Air With A Furnace Setback.

TABLE D14

ANNUAL FUEL USAGE AND EFFICIENCY

		Inside Combustion Air			Outside Combustion Air		
Location	Thermostat Type	Gas Input $BTU\times10^{-6}$	Room Air Delivery $BTU\times10^{-6}$	Efficiency %	Gas Input $BTU\times10^{-6}$	Room Air Delivery $BTU\times10^{-6}$	Efficiency %
Albuquerque, NM	No Night Setback	187.5	131.4	70.1	180.3	124.0	68.8
	Night Setback	161.6	114.0	70.5	155.7	107.8	69.2
Boston, MA	No Night Setback	192.6	134.3	69.7	183.2	125.0	68.2
	Night Setback	169.6	119.2	70.3	161.4	111.1	68.8
Great Falls, MT	No Night Setback	163.8	113.7	69.4	153.9	103.1	67.0
	Night Setback	146.6	103.0	70.3	137.9	93.5	67.8

TABLE D15

COMPUTED SAVINGS FOR THE VARIOUS TEST CASES

	Savings %				Load Design Parameters		
Location	A	B	C	D	Design Temperature °F	Actual T Min °F	Load UA BTUH/°F
Albuquerque	3.84	3.65	13.81	13.64	14.0	8.9	1050
Boston	4.88	4.83	11.94	11.90	6.0	6.0	920
Great Falls	6.04	5.93	10.50	10.40	-20.0	-17.0	650

A. Inside vs. outside combustion air-no setback thermostat $\left(\frac{\text{Inside-Outside}}{\text{Inside}}\right)$

B. Inside vs. outside combustion air-with setback thermostat (")

C. Setback vs. no setback thermostat-inside air $\left(\frac{\text{No Setback-Setback}}{\text{No Setback}}\right)$

D. Setback vs. no setback thermostat-outside air (")

US Military Academy
ATTN: Dept of Mechanics
West Point, NY 10996

US Military Academy
ATTN: Library
West Point, NY 10996

HQDA (DALO-TSE-F)
WASH DC 20314

HQDA (DAEN-ASI-L) (2)
WASH DC 20314

HQDA (DAEN-MPO-B)
WASH DC 20314

HQDA (DAEN-MPR-A)
WASH DC 20314

HQDA (DAEN-MPO-U)
WASH DC 20314

HQDA (DAEN-MPZ-A)
WASH DC 20314

HQDA (DAEN-MPZ-E)
WASH DC 20314

HQDA (DAEN-MPZ-G)
WASH DC 20314

HQDA (DAEN-RDM)
WASH DC 20314

HQDA (DAEN-RDL)
WASH DC 20314

Director, USA-WES
ATTN: Library
P.O. Box 631
Vicksburg, MS 39181

Commander, TRADOC
Office of the Engineer
ATTN: ATEN
Ft. Monroe, VA 23651

Commander, TRADOC
Office of the Engineer
ATTN: ATEN-FE-U
Ft Monroe, VA 23651

AF Civil Engr Center/XRL
Tyndall AFB, FL 32401

Naval Facilities Engr Command
ATTN: Code 04
200 Stovall St.
Alexandria, VA 22332

Defense Documentation Center
ATTN: TCA (12)
Cameron Station
Alexandria, VA 22314

Commander and Director
USA Cold Regions Research Engineering Laboratory
Hanover, NH 03755

FORSCOM
ATTN: AFEN
Ft McPherson, GA 30330

FORSCOM
ATTN: AFEN-FE
Ft McPherson, GA 30330

Officer-in-Charge
Civil Engineering Laboratory
Naval Construction Battalion Center
ATTN: Library (Code L08A)
Port Hueneme, CA 93043

Commander and Director
USA Construction Engineering Research Laboratory
P.O. Box 4005
Champaign, IL 61820

Commanding General, 3d USA
ATTN: Engineer
Ft. McPherson, GA 30330

Commanding General, 5th USA
ATTN: Engineer
Ft Sam Houston, TX 78234

AFCE Center
Tyndall AFB, FL 32403

Commander, DARCOM
Director, Installation
and Services
5001 Eisenhower Ave.
Alexandria, VA 22333

Commander, DARCOM
ATTN: Chief, Engineering Div.
5001 Eisenhower Ave
Alexandria, VA 22333

Air Force Weapons Lab/AFWL/DE
Chief, Civil Engineering
Research Division
Kirtland AFB, NM 87117

Strategic Air Command
ATTN: DSC/CE (DEEE)
Offutt AFB, NE 68112

Headquarters USAF
Directorate of Civil Engineering
AF/PREES
Bolling AFB, Washington, DC 20333

Strategic Air Command
Engineering
ATTN: Ed Morgan
Offutt AFB, NE 68113

USAF Institute of Technology
AFIT/DED
Wright Patterson AFB, OH 45433

Air Force Weapons Lab
Technical Library (DOUL)
Kirtland AFB, NM 87117

Chief, Naval Facilities
Engineer Command
ATTN: Chief Engineer
Department of the Navy
Washington, DC 20350

Commander
Naval Facilities Engineering Cmd
200 Stovall St
Alexandria, VA 22332

Commander
Naval Facilities Engr Cmd
Western Division
Box 727
San Bruno, CA 94066

Civil Engineering Center
ATTN: Moreell Library
Port Hueneme, CA 93043

Commandant of the Marine Corps
HQ, US Marine Corps
Washington, DC 20380

National Bureau of Standards (4)
Materials & Composites Section
Center for Building Technology
Washington, DC 20234

Assistant Chief of Engineer
Rm 1E 668, Pentagon
Washington, DC 20310

The Army Library (ANRAL-R)
ATTN: Army Studies Section
Room 1A 518, The Pentagon
Washington, DC 20310

Commander-in-Chief
USA, Europe
ATTN: AEAEN
APO New York, NY 09403

Commander
USA Foreign Science and
Technology Center
220 8th St. N.E.
Charlottesville, VA 22901

Commander
USA Science & Technology
Information Team, Europe
APO New York, NY 09710

Commander
USA Science & Technology
Center - Far East Office
APO San Francisco, CA 96328

Commanding General
USA Engineer Command, Europe
APO New York, NY 09403

Deputy Chief of Staff
for Logistics
US Army, The Pentagon
Washington, DC 20310

Commander, TRADOC
Office of the Engineer
ATTN: Chief, Facilities
Engineering Division
Ft Monroe, VA 23651

Commanding General
USA Forces Command
Office of the Engineer
(AFEN-FES)
Ft McPherson, GA 30330

Commanding General
USA Forces Command
ATTN: Chief, Facilities
Engineering Division
Ft McPherson, GA 30330

Commanding General, 1st USA
ATTN: Engineer
Ft George G. Meade, MD 20755

Commander
USA Support Command, Hawaii
Fort Shafter, HI 96858

Commander
Eighth US Army
APO San Francisco 96301

Commander
US Army Facility Engineer
Activity - Korea
APO San Francisco 96301

Commander
US Army, Japan
APO San Francisco, CA 96343

Facilities Engineer
Fort Belvoir
Fort Belvoir, VA 22060

Facilities Engineer
Fort Benning
Fort Benning, GA 31905

Facilities Engineer
Fort Bliss
Fort Bliss, TX 79916

Facilities Engineer
Carlisle Barracks
Carlisle Barracks, PA 17013

Facilities Engineer
Fort Chaffee
Fort Chaffee, AR 72902

Facilities Engineer
Fort Dix
Fort Dix, NJ 08640

Facilities Engineer
Fort Eustis
Fort Eustis, VA 23604

Facilities Engineer
Fort Gordon
Fort Gordon, GA 30905

Facilities Engineer
Fort Hamilton
Fort Hamilton, NY 11252

Facilities Engineer
Fort A P Hill
Bowling Green, VA 22427

Facilities Engineer
Fort Jackson
Fort Jackson, SC 29207

Facilities Engineer
Fort Knox
Fort Knox, KY 40121

Facilities Engineer
Fort Lee
Fort Lee, VA 23801

Facilities Engineer
Fort McClellan
Fort McClellan, AL 36201

Facilities Engineer
Fort Monroe
Fort Monroe, VA 23651

Facilities Engineer
Presidio of Monterey
Presidio of Monterey, CA 93940

Facilities Engineer
Fort Pickett
Blackstone, VA 23824

Facilities Engineer
Fort Rucker
Fort Rucker, AL 36362

Facilities Engineer
Fort Sill
Fort Sill, OK 73503

Facilities Engineer
Fort Story
Fort Story, VA 23459

Facilities Engineer
Kansas Army Ammunition Plant
Parsons, KS 67357

Facilities Engineer
Lone Star Army Ammunition Plant
Texarkana, TX 75501

Facilities Engineer
Picatinny Arsenal
Dover, NJ 07801

Facilities Engineer
Louisiana Army Ammunition Plant
Shreveport, LA 71130

Facilities Engineer
Milan Army Ammunition Plant
Milan, TN 38358

Facilities Engineer
Pine Bluff Arsenal
Pine Bluff, AR 71601

Facilities Engineer
Radford Army Ammunition Plant
Radford, VA 24141

Facilities Engineer
Rock Island Arsenal
Rock Island, IL 61201

Facilities Engineer
Rocky Mountain Arsenal
Denver, CO 80340

Facilities Engineer
Scranton Army Ammunition Plant
156 Cedar Avenue
Scranton, PA 18503

Facilities Engineer
Tobyhanna Army Depot
Tobyhanna, PA 18466

Facilities Engineer
Tooele Army Depot
Tooele, UT 84074

Facilities Engineer
Arlington Hall Station
400 Arlington Blvd
Arlington, VA 22212

Facilities Engineer
Cameron Station, Bldg 17
5010 Duke Street
Alexandria, VA 22314

Facilities Engineer
Sunny Point Military Ocean Terminal
Southport, NC 28461

Facilities Engineer
US Military Academy
West Point Reservation
West Point, NY 10996

Facilities Engineer
Fort Ritchie
Fort Ritchie, MD 21719

Facilities Engineer
Army Materials & Mechanics
Research Center
Watertown, MA 02172

Facilities Engineer
Ballistics Missile Advanced
Technology Center
P.O. Box 1500
Huntsville, AL 35807

Facilities Engineer
Fort Wainwright
172d Infantry Brigade
Fort Wainwright, AK 99703

Facilities Engineer
Fort Greely
Fort Greely, AK 98733

Facilities Engineer
Fort Richardson
Fort Richardson, AK 99505

Facilities Engineer
Harry Diamond Laboratories
2800 Powder Mill Rd
Adelphi, MD 20783

Facilities Engineer
Fort Missoula
Missoula, MT 59801

Facilities Engineer
New Cumberland Army Depot
New Cumberland, PA 17070

Facilities Engineer
Oakland Army Base
Oakland, CA 94626

Facilities Engineer
Vint Hill Farms Station
Warrentown, VA 22186

Facilities Engineer
Twin Cities Army Ammunition Plant
New Brighton, MN 55112

Facilities Engineer
Volunteer Army Ammunition Plant
Chattanooga, TN 37401

Facilities Engineer
Watervliet Arsenal
Watervliet, NY 12189

Facilities Engineer
St Louis Area Support Center
Granite City, IL 62040

Facilities Engineer
Fort Monmouth
Fort Monmouth, NJ 07703

Facilities Engineer
Redstone Arsenal
Redstone Arsenal, AL 35809

Facilities Engineer
Detroit Arsenal
Warren, MI 48039

Facilities Engineer
Aberdeen Proving Ground
Aberdeen Proving Ground, MD 21005

Facilities Engineer
Jefferson Proving Ground
Madison, IN 47250

Facilities Engineer
Dugway Proving Ground
Dugway, UT 84022

Facilities Engineer
Fort McCoy
Sparta, WI 54656

Facilities Engineer
White Sands Missile Range
White Sands Missile Range, NM 88002

Facilities Engineer
Yuma Proving Ground
Yuma, AZ 85364

Facilities Engineer
Natick Research & Dev Ctr
Kansas St.
Natick, MA 01760

Facilities Engineer
Fort Bragg
Fort Bragg, NC 28307

Facilities Engineer
Fort Campbell
Fort Campbell, KY 42223

Facilities Engineer
Fort Carson
Fort Carson, CO 80913

Facilities Engineer
Fort Drum
Watertown, NY 13601

Facilities Engineer
Fort Hood
Fort Hood, TX 76544

Facilities Engineer
Fort Indiantown Gap
Annville, PA 17003

Facilities Engineer
Fort Lewis
Fort Lewis, WA 98433

Facilities Engineer
Fort MacArthur
Fort MacArthur, CA 90731

Facilities Engineer
Fort McPherson
Fort McPherson, GA 30330

Facilities Engineer
Fort George G. Meade
Fort George G. Meade, MD 20755

Facilities Engineer
Fort Polk
Fort Polk, LA 71459

Facilities Engineer
Fort Riley
Fort Riley, KS 66442

Facilities Engineer
Fort Stewart
Fort Stewart, GA 31312

Facilities Engineer
Indiana Army Ammunition Plant
Charlestown, IN 47111

Facilities Engineer
Joliet Army Ammunition Plant
Joliet, IL 60436

Facilities Engineer
Anniston Army Depot
Anniston, AL 36201

Facilities Engineer
Corpus Christi Army Depot
Corpus Christi, TX 78419

Facilities Engineer
Red River Army Depot
Texarkana, TX 75501

Facilities Engineer
Sacramento Army Depot
Sacramento, CA 95813

Facilities Engineer
Sharpe Army Depot
Lathrop, CA 95330

Facilities Engineer
Seneca Army Depot
Romulus, NY 14541

Facilities Engineer
Fort Ord
Fort Ord, CA 93941

Facilities Engineer
Presidio of San Francisco
Presidio of San Francisco, CA 94129

Facilities Engineer
Fort Sheridan
Fort Sheridan, IL 60037

Facilities Engineer
Holston Army Ammunition Plant
Kingsport, TN 37662

Facilities Engineer
Baltimore Output
Baltimore, MD 21222

Facilities Engineer
Bayonne Military Ocean Terminal
Bayonne, NJ 07002

Facilities Engineer
Bay Area Military Ocean Terminal
Oakland, CA 94626

Facilities Engineer
Gulf Output
New Orleans, LA 70146

Facilities Engineer
Fort Huachuca
Fort Huachuca, AZ 86513

Facilities Engineer
Letterkenny Army Depot
Chambersburg, PA 17201

Facilities Engineer
Michigan Army Missile Plant
Warren, MI 48089

COL E.C. Lussier
Fitzsimons Army Med Center
ATTN: HSF-DFE
Denver, CO 80240

US Army Engr Dist, New York
ATTN: NANEN-E
26 Federal Plaza
New York, NY 10007

USA Engr Dist, Baltimore
ATTN: Chief, Engr Div
P.O. Box 1715
Baltimore, MD 21203

USA Engr Dist, Charleston
ATTN: Chief, Engr Div
P.O. Box 919
Charleston, SC 29402

USA Engr Dist, Detroit
P.O. Box 1027
Detroit, MI 48231

USA Engr Dist, Kansas City
ATTN: Chief, Engr Div
700 Federal Office Bldg.
601 E. 12th St
Kansas City, MO 64106

USA Engr Dist, Omaha
ATTN: Chief, Engr Div
7410 USOP and Courthouse
215 N. 17th St
Omaha, NE 68102

USA Engr Dist, Fort Worth
ATTN: Chief, SWFED-D
P.O. Box 17300
Fort Worth, TX 76102

USA Engr Dist, Sacramento
ATTN: Chief, SPKED-D
650 Capitol Mall
Sacramento, CA 95814

USA Engr Dist, Far East
ATTN: Chief, Engr Div
APO San Francisco, CA 96301

USA Engr Dist, Japan
APO San Francisco, CA 96343

USA Engr Div, Europe
European Div, Corps of Engineers
APO New York, NY 09757

USA Engr Div, North Atlantic
ATTN: Chief, NADEN-T
90 Church St.
New York, NY 10007

USA Engr Div, South Atlantic
ATTN: Chief, SAEN-TE
510 Title Bldg
30 Pryor St, SW
Atlanta, GA 30303

USA Engr Dist, Mobile
ATTN: Chief, SAMEN-C
P.O. Box 2288
Mobile, AL 36601

USA Engr Dist, Louisville
ATTN: Chief, Engr Div
P.O. Box 59
Louisville, KY 40201

USA Engr Div, Norfolk
ATTN: Chief, NAOEN-D
803 Front Street
Norfolk, VA 23510

USA Engr Div, Missouri River
ATTN: Chief, Engr Div
P.O. Box 103 Downtown Station
Omaha, NE 68101

USA Engr Div, South Pacific
ATTN: Chief, SPDED-TG
630 Sansome St, Rm 1216
San Francisco, CA 94111

USA Engr Div, Huntsville
ATTN: Chief, HNDED-ME
P.O. Box 1600 West Station
Huntsville, AL 35807

USA Engr Div, Ohio River
ATTN: Chief, Engr Div
P.O. Box 1159
Cincinnati, Ohio 45201

USA Engr Div, North Central
ATTN: Chief, Engr Div
536 S. Clark St.
Chicago, IL 60605

USA Engr Div, Southwestern
ATTN: Chief, SWDED-TM
Main Tower Bldg, 1200 Main St
Dallas, TX 75202

USA Engr Dist, Savannah
ATTN: Chief, SASAS-L
P.O. Box 889
Savannah, GA 31402

Commander
US Army Facilities Engineering
Support Agency
Support Detachment II
Fort Gillem, GA 30050

Commander
US Army Facilities Engr Spt Agency
ATTN: MAJ Brisbine
Support Detachment III
P.O. Box 6550
Fort Bliss, TX 79916

NCOIC
US Army Facilities Engr Spt Agency
Support Detachment III
ATTN: FESA-III-SI
P.O. Box 3031
Fort Sill, OK 73503

NCOIC
US Army Facilities Engr Spt Agency
Support Detachment III
ATTN: FESA-III-PR
P.O. Box 29704
Presidio of San Francisco, CA 94129

NCOIC
US Army Facilities Engr Spt Agency
ATTN: FESA-III-CA
Post Locator
Fort Carson, CO 80913

Commander/CPT Ryan
US Army Facilities Engr Spt Agency
Support Detachment IV
P.O. Box 300
Fort Monmouth, NJ 07703

NCOIC
US Army Facilities Engr Spt Agency
ATTN: FESA-IV-MU
P.O. Box 300
Fort Monmouth, NJ 07703

NCOIC
US Army Facilities Engr Spt Agency
Support Detachment IV
ATTN: FESA-IV-ST
Stewart Army Subpost
Newburgh, New York 12250

NCOIC
US Army Facilities Engineering
Support Agency
Support Detachment II
ATTN: FESA-II-JA
Fort Jackson, SC 29207

NCOIC
US Army Facilities Engr Spt Agency
Support Detachment II
ATTN: FESA-II-BE
P.O. Box 2207
Fort Benning GA 31905

NCOIC
US Army Facilities Engr Spt Agency
Support Detachment II
ATTN: FESA-II-KN
Fort Knox, KY 40121

Naval Facilities Engineering Cmd
Energy Programs Branch, Code 1023
Hoffmann Bldg. 2, (Mr. John Hughes)
Stovall Street
Alexandria, VA 22332

Commander
US Army Facilities Engineering
Support Agency
FE Support Detachment I
APO New York, NY 09081

Navy Energy Office
ATTN: W.R. Mitchum
Washington DC 20350

David C. Hall
Energy Projects Officer
Dept. of the Air Force
Sacramento Air Logistics Center (AFLC)
2852 ABG/DEE
McClellan, CA 95652

USA Engineer District, Chicago
219 S. Dearborn Street
ATTN: District Engineer
Chicago, IL 60604

Directorate of Facilities Engineer
Energy Environmental & Self Help Center
Fort Campbell, KY 42223

Commander and Director
Construction Engineering Research
Laboratory
ATTN: COL Circeo
P.O. Box 4005
Champaign, IL 61820

Mr. Ray Heller
Engineering Services Branch
DFAE, Bldg. 1950
Fort Sill, OK 73503

Commander-in-Chief
HQ, USAEUR
ATTN: AEAEN-EH-U
APO New York 09403

HQ AFESC/RDVA
ATTN: Mr. Hathaway
Tyndall AFB, FL 32403

Commander and Director
Construction Engineering Research Lab
ATTN: Library
P.O. Box 4005
Champaign, IL 61820

HQ, 5th Signal Command
Office of the Engineer
APO New York 09056

HQ, Us Military Community Activity, Heilbronn
Director of Engineering & Housing
ATTN: Rodger D. Romans
APO New York 09176

Commanding General
HQ USATC and Fort Leonard Wood
ATTN: Facility Engineer
Fort Leonard Wood, MO 65473

SSG Ruiz Burgos Andres
D.F.E., HHC HQ Cmd 193d Inf BDE
Ft. Clayton, C/Z

Energy/Environmental Office
ATTN: David R. Nichols
USMCA-NBG (DEH)
APO New York 09696

Commander
535th Engineer Detachment
P.O. Box 300
Fort Monmouth, NJ 07703

NCOIC
535th Engineer Detachment, Team A
ATTN: SFC Prenger
P.O. Box 224
Fort Knox, KY 40121

NCOIC
535th Engineer Detachment, Team B
ATTN: SP6 Cathers
P.O. Box 300
Fort Monmouth, NJ 07703

NCOIC
535th Engineer Detachment, Team C
ATTN: SFC Jackson
P.O. Box 4301
Fort Eustis, VA 23604

NCOIC
535th Engineer Detachment, Team D
ATTN: SFC Hughes
Stewart Army Subpost
Newburg, New York 12550

Commander
Persidio of San Francisco, California
ATTN: AFZM-DI/Mr. Prugh
San Francisco, CA 94129

Facilities Engineer
Corpus Christi Army Depot
ATTN: Mr. Joseph Canpu/Stop 24
Corpus Christi, TX 78419

Walter Reed Army Medical Center
ATTN: KHSWS-E/James Prince
6825 16th St., NW
Washington, DC 20012

Commanding Officer
Installations and Services Activity
ATTN: DRCIS-RI-IB
Rock Island Arsenal
Rock Island, IL 61299

Commanding Officer
Northern Division Naval
Facilities Engineering Command
Code 102 (Mr. E.F. Humm)
Naval Base
Philadelphia, PA 19112

Commander, US Army Facilities Engineering
Support Agency
Support Detachment I
APO New York 09081

HQ, USA Health Services Cmd
Bldg. 2792
ATTN: HSLO-F
Fort Sam Houston, TX 78234

HQDA
(DAEN-MPE-E)
WASH DC 20314

Commanding Officer
Northern Division Naval
Facilities Engineering Command
Code 10
Naval Base, Building 77
Philadelphia, PA 19112

Facilities Engineer
Fort Leavenworth
Fort Leavenworth, KS 66027

Facilities Engineer
Fort Benjamin Harrison
Fort Benjamin Harrison, IN 46216

Office of the A&E
ATTN: MAJ Johnson
Camp Ripley
Little Falls, MN 56345

Commander
US Army Garrison
ATTN: HSD-FE
Fort Detrick, MD 21701

AFESC/DEB
ATTN: Mr. Fred Beason
Tyndall AFB, FL 32403

Mr. David White
Defense Audit Service
888 North Sepulveda Blvd.
Suite 610
El Sequndo, CA 90245

Facilities Engineer
Bldg. 308
Fort Myer, VA 22211

NAVFAC
ATTN: John Zekan
Code 0833 Hoffmann Building
200 Stovall Street
Alexandria, VA 22332

HQ, USASCH
Director Engineering & Housing
Fort Shafter, HI 96858

HQ, WESTCOM
ATTN: APEN-CE
Fort Shafter, HI 96858

Headquarters US Army Materiel Development
& Readiness Command
ATTN: Energy Office, DRCIS-C
Alexandria, VA 22333

One Stop Coordinator
Army Corps of Engineers
ATTN: ORNED-D (Connie Flatt)
P.O. Box 1070
Nashville, TN 37202

Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

American Telephone & Telegraph Co.
ATTN: Kenneth T. Risberg
222 Mt. Airy Road, Rm 1928S
Basking Ridge, NJ 07920

LCDR D. J. Clark
Navy Material Command
COde 08E
Washington, DC 20360

Office of Secretary of Defense
Installations & Housing
ATTN: Mr. Millard Carr
WASH DC 20301

Commandant (G-ECV-2/65)
ATTN: LTC Peck
US Coast Guard HQTRS
2100 2nd St. SW
WASH DC 20593

HQ AFESC/DEB
ATTN: COL. William R. Gaddie
Tyndall AFB, FL 32403

U.S. GOVERMENT PRINTING OFFICE 1982-0- 368-063/657

FILMED

5-8