Hoffman Controls
Engineering Bulletin

706-FFS (TB) Series

VariFlow™ Furnace Fan Speed Controller

Patent Pending

Introduction

Development of a single phase variable motor speed controller for accomplishing Variable Flow in Residential and Light Commercial central air conditioning systems has been under development at Hoffman Controls, Dallas, Texas. Findings concerning this study have been extracted from the data files and are comments of AGA Research, or the manufacturer of the controls.

An original prototype was introduced to the HVAC industry at the ASHRAE International Exposition in Atlanta in 1996. The expanded series was introduced and displayed at ASHRAE in Philadelphia in 1997.

The original products introduced to the industry were designed for Variable Flow for Heating only applications; but later expanded to include Air Conditioning applications.

Various series are differentiated and identified by model suffixes that basically describe the application specific product.

Series	Suffix	Application Specific	"Time Based" (TB)	"Temp. Sensed" (TS)
706	FFS	Warm Air Furnaces/dx Coil	Heating/Cooling	Heating only
706	VFS	Heat Pump, with Electric Heat	Heating/Cooling	Heating only
706	VFS	Chill water/Hot water Fan Coils	Heating/Cooling	Heating only

In keeping with Hoffman's efforts to quantify the claims, the features, and benefits of the product series, products were tested and evaluated by an independent testing facility.

AGA Research recently conducted a series of tests with two of these auxiliary fan controls in a typical heating application in their research facility. The two controls used in this testing were (1) VariFlow™ Time Based Controller and (2) VariFlow™ Temperature Sensed Controller. In addition, the standard controls supplied with a manufacturer's furnace was tested for base line comparison. Cooling functions of the product were not tested.

Although both VariFlow™ controls were tested with and without DX cooling coils installed, all data and comments in this report are indicative of those tests with the DX cooling coil installed.

The findings of this case study are abbreviated and condensed by Hoffman Controls Corp. and only represent a portion of the actual study and data provided by AGA Research. Further information concerning these tests may be obtained by contacting Hoffman Controls Corp., Dallas, Texas.

The purpose of the testing was twofold:

1) Quantify the energy usage of the furnace under a variety of cycling conditions with particular attention to possible off cycle residual energy reclamation due to modulated fan operation.

2) Quantify the comfort level within the house due to temperature stratification of the air and the effect on stratification due to modulated fan speed (flow) operation.

Testing Performed

A total of twenty–six (26) tests were performed with the furnace. All test cycles were run with a standard 8 min. burner on cycle time. This on cycle time was chosen during an initial dry run as sufficient to insure that the furnace was operating at thermal equilibrium at the end of the on cycle. The off cycle times were in accordance with the following test matrix.

Type of Control	Furnace Setup	Burner Off Cycle Time (min.)
Standard	With A/C Coil Without A/C Coil	8 8
Time Based (TB)	With A/C Coil Without A/C Coil	8, 12, 16, 20, 24, 28 8, 12, 16, 20, 24, 28
Temperature Sensed (TS)	With A/C Coil Without A/C Coil	8, 12, 16, 20, 24, 28 8, 12, 16, 20, 24, 28

Instrument and Data Acquisition

All data was collected by computer data acquisition. Two system were used for testing. The first data system was connected to the furnace and was used to collect data for temperature, pressure, gas flow, electrical usage, circulating air flow, circulating blower motor speed, and CO2 concentration in the flue products. The second data system was connected to thermocouple "trees" installed in the great room and master bedroom of the house.

Furnace

Temperatures of combustion air, air inlet (RA), Supply Air furnace and AC Coil outlet, Flue temperature were obtained. Flow rate of circulated air was collected, CO2 concentration for flue loss, electrical energy consumption were recorded. Voltmeter gas flow was noted.

Conditioned Space

Two rooms; Great Room (high ceiling) and Master Bedroom (typical ceiling); were temperature recorded at 13 and 10 measuring points respectively on a thermocouple tree placed in each room.

Energy Balance on the Furnace

The total energy balance on the furnace was determined by calculating the total energy input to the furnace (gas and electric) and comparing to the total energy output (circulating air and flue loss).

The data acquisition system was set up to take an integrated average of all data every 5 seconds and record the average in a data file. Energy input and output were calculated for each 5 second interval over the entire operating cycle.

$$QIN = QGAS + QELECTRIC$$
$$QOUT = QAIR + QFLUE$$

Comfort Level

The temperature stratification in each room was recorded at 5 second intervals in order to determine the time at which maximum and minimum stratification occurred.

Test Results

Energy Balance

The objective with the energy balance experiment was to

- Account for all energy input to the system
- Determine the amount of energy extracted during the off cycle
- Determine the effect, if any, on energy efficiency due to blower operation during the off cycle

$$EBR = \frac{QOUT}{QIN}$$

The EBR was used as a quantified indicator of the accuracy of the experimental measurements.

Also defined is a Furnace Operating Efficiency (FOE) as the total energy output to the circulating air integrated over the entire operating cycle divided by total integrated energy input:

$$FOE = \frac{QAIR}{QIN}$$

Standard Control

The furnace was tested with the factory standard control with the A/C coil in place and with it removed. The standard control used selectable timings for the circulating air blower. The control was set to turn on the blower 30 sec after the main burner ignition (blower on delay). The blower off delay (operating time after burners shut off) was set for 140 sec.

VariFlow™ Time Based Control: Blower programmed "Off" after minimum flow obtained. For testing with the time based control, the factory control settings were set for a 60 sec blower on delay (longest available) and a 60 sec blower off delay (shortest available). This was done to optimize as much as possible the function of the auxiliary control.

The following observations are made concerning the Time Based controller operation:

Summary

- The FOE for the furnace with the A/C coil was about 2% greater than with the standard control.
- The FOE for the furnace without the A/C coil was about the same as the standard control case.
- The excess output energy extracted during the off cycle falls to zero at about 6 minutes into the off cycle. This indicates that all residual energy within the system was extracted and operation of the blower beyond this point did not have an effect on the operating efficiency.

  Note: Extended blower operation by VariFlow™ however greatly improved the comfort level by reducing stratification, see Comfort Level findings.

VariFlow™ Temperature Sensed Control: Blower programmed "Continuous" minimum flow until next cycle. Factory control settings were the same as the Time Based control. The following observations are made concerning the Temperature Sensed controller operation:

Summary

- The FOE for operation with the A/C coil is up to 3% greater than the furnace standard control system.
- The FOE for the furnace without the A/C coil was about the same as the standard control case.
- All residual energy within the system was extracted in about 6 minutes and operation of the blower beyond this point did not have an effect on the operating efficiency.

  Note: Extended blower operation by VariFlow™ however greatly improved the comfort level by reducing stratification, see Comfort Level findings.
- The residual energy delivered to the space for the Temperature Sensed control is slightly higher than the results shown for the Time Based control.

Overall Energy Summary for all Three Systems

Standard Furnace (Base Line) Qair in BTU

8 minute Burner on cycle Qair BTU delivered *8355 BTU
140 Sec. standard off cycle Qair BTU delivered 1589 BTU

$\frac{1589 \text{ BTU}}{8355 \text{ BTU}}$ = 19.02% of on cycle recovered air residual energy

VariFlow™ (Time Based) Qair in BTU

8 minute Burner (TB) Qair BTU delivered *8601 BTU
20 minute off cycle Qair BTU delivered 2321 BTU

$\frac{2321 \text{ BTU}}{8601 \text{ BTU}}$ = 26.98% of on cycle residual energy recovered

$\frac{7.96\%}{19.02\%}$ = 41.85% more residual energy recovered than standard control system residual energy

VariFlow™ (Temperature Sensed) Qair in BTU

8 minute Burner (TS) Qair BTU delivered *8473 BTU
20 minute off cycle Qair BTU delivered 2367 BTU

$\frac{2367 \text{ BTU}}{8473 \text{ BTU}}$ = 27.94% of on cycle residual energy recovered

$\frac{8.92\%}{19.02\%}$ = 46.90% more residual energy recovered than standard control system residual energy

Note: *Actual fuel flow varied during the 8 minute burner cycle period due to natural gas pressure variations, causing the actual BTU to vary for each 8 minute burner cycle. Percent (ratio) of values therefore must be used, rather than actual Qair BTUs for comparison.

Consensus: VariFlow™ improves system efficiency by delivering more useable energy to the space, precluding an earlier requirement for a call for heating and start of the next cycle.

Comfort Level

Master Bedroom – A/C Coil installed on Furnace

- ΔT measured at the end of the 8 minute burner on cycle ranged between a minimum of 6.5 to 10.3°F on the thermocouple tree.
- The maximum ΔT ranged of 7.6 and 10.8°F occurred at 1 to 2 minutes after the burner shut off (this would represent a typical bedroom °F stratification).
- The ΔT measured at the end of the off cycle showed a definite trend for minimizing stratified air as longer blower times at a reduced flow rate were observed.
- The optimum 20 minutes of off cycle of variable flow rate measured a decrease from over 6.0°F to 3.1°F floor to ceiling; a significant improvement in ΔT.
- For the Temperature Sensed control the ΔT decrease from 5.6°F to 1.3°F as the off time increased from 8 to 28 minutes; a significant improvement in ΔT.

Summary

The reduction in ΔT in the space indicates that a higher mean effective temperature at the occupant level was observed. This higher effective mean temperature would preclude the early initiation of a call for heating by the thermostat.

Since the residual energy was delivered to the space after 6 minutes of variable flow, the continuation in the reduction in flow for the next 9 minutes provided the optimum flow and velocity for obtaining a minimum ΔT stratification of 3.1°F (floor to ceiling).

Comfort Level

Great Room – A/C Coil installed on Furnace

- ΔT measured at the end of the 8 minute burner on cycle ranged between a minimum of 4.0 and 9.4°F on the thermocouple tree.
- The maximum ΔT ranged of 5.2 to 10.1°F occurred at 1 to 2 minutes after burner shut off (this would represent a typical living or family area with 16 foot high vaulted ceiling).
- The ΔT measured at the off cycle showed a definite trend for minimizing stratified air as longer blower time at a reduced flow rate were observed.
- The optimum off cycle of variable flow rate reduced to 3.1°F from 6.5°F floor to ceiling; a significant improvement in ΔT.
- The Temperature Sensed control decreased from 4.0°F to .9°F as the off time increased to 8 to 28 minutes.

Summary

The reduction in ΔT in the space indicates that a higher mean effective temperature at the occupant level was observed. This higher effective mean temperature would preclude the early initiation of a call for heating by the thermostat.

Since the residual energy was delivered to the space after 6 minutes of variable flow, the continuation of the reduction in flow for the next 9 minutes provided the same performance of 3.1°F ΔT stratification for the Great room and; decreased the ΔT stratification to 0.9°F after 28 minutes of continuous minimum flow.

Installation Option

Note: VariFlow™ Time Based or Temperature Sensed Controllers may optionally be programmed by the installer, or remotely controlled by the user, as follows:

a) "Off"… blower operation once minimum flow is obtained. (As was tested for Time Based model.)

b) "Continuous"… blower operation at minimum flow until the next heating cycle occurs. (As was tested for Temperature Sensed model).

Consensus: VariFlow™ improves operating efficiency and increases the comfort level of the occupied space. Residual energy when mixed with warm stratified air and delivered to the space at a decreasing flow rate provides a higher mean effective temperature. This precludes an earlier requirement for energy to heat the space while providing a more uniform temperature floor to ceiling.