EFFECT OF FURNACE OUTPUT AND OPERATION ON TEMPERATURE UNIFORMITY IN A PROTOTYPE RESEARCH HOUSE

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ABSTRACT

Tests were conducted in a prototype research house to determine if temperature distribution resulting from the use of a furnace and perimeter-duct system would be more uniform with the furnace operating at a low flame equal to house heat loss with continuous blower operation or at a flame output greater than house heat loss. Thermocouples were installed at 4 inches, 4 and 8 feet, and at ceiling height (8 to 10 feet) in each of three rooms in the concrete-block house to detect temperatures, and a strip-chart recorder was used to record these temperatures. The recorder scanned the thermocouples 10 times each hour, providing a complete set of data every 6 minutes. There was no appreciable difference in temperature distribution or stratification when the blower operated at high speed rather than low speed, but the temperature distribution was more uniform when the blower operated continuously at either speed. When the blower operated automatically, temperatures near the ceiling remained high, even when the furnace was in the off cycle. At full burner flame with continuous blower operation, fuel consumption at low blower speed was about 28 percent less than consumption at high blower speed.

KEYWORDS: automatic blower operation, blower speed, continuous blower operation, furnace output, heating efficiency, perimeter-duct system, temperature uniformity.

INTRODUCTION

The most common complaints about heating systems concern stratification drafts and non-uniform temperatures. These problems are not restricted to low-cost systems but are common to almost all heating systems. Newman showed that a high volume of air moving at low velocities through the living area was an effective method of maintaining uniform temperatures. Newman and Hurst showed that, in existing houses, uniform temperatures could be maintained by using a large-volume, low-velocity system that operated continuously.


On the basis of these studies, it was hypothesized that temperature distribution resulting from the use of a furnace and perimeter-duct system would be more uniform if the furnace were operated either at a low-flame output equal to house heat loss with continuous blower operation or at a low-flame output slightly greater than house heat loss, which would result in a longer heating cycle than the output customarily provided and a reduction in blower off-time. To prove this hypothesis, a series of tests was conducted in a prototype research house located at Kersey, Colo. (fig. 1).

This bulletin describes the equipment and instrumentation used in these tests; and it presents the test procedures, a brief discussion of the results, and conclusions based on the results.

**EQUIPMENT AND INSTRUMENTATION**

The concrete-block walls of the three-bedroom prototype house (26 by 38 feet) were built by the surface-bonding method. The cathedral ceiling had a slope of 2½ to 12 feet and a 10-foot height at the ridge of the house. The sloping roof created a high air pocket at the center of the house, which, together with the sloping ceiling, created good conditions for stratification when there was no forced circulation. The perimeter-duct system was laid out as shown in figure 2. The returns from all registers (located under each window) fed a duct mounted just above the down-draft furnace in the central hallway.

The house was instrumented with copper-constantan thermocouples located at heights of 4 inches, 4 feet and 8 feet, and at ceiling height (8 to 10 feet) in each of three rooms. The thermocouples were mounted on portable poles placed 1 foot from the exterior wall and at least 2 feet from the edge of a window and were shielded from radiant energy by ½- by 2-inch aluminum cylinders. A strip-chart recorder was used to record temperatures detected by the thermocouples. This instrument scanned the 12 thermocouples 10 times each hour, providing a complete set of data every 6 minutes.

**TEST PROCEDURES AND RESULTS**

The house remained unheated through the early winter months until 2:30 p.m. on January 8, when the furnace was first operated. Meter readings taken during furnace operation showed that the burner was consuming 1.47 ft³/min, or 88.13 ft³/h, of natural gas; at a heat value of 1,013 Btu/ft³, the burner was consuming 89,270 Btu/h. Since the output of the furnace was rated at 55,400 Btu/h, its efficiency was about 62 percent at this rate of consumption.

Figure 3 is a record of furnace-burner operation for a period of 9 hours when the outside temperature was decreasing from +12° to -6° F. This graph reveals several features of the furnace operation and shows that the on-off cycles were rather severe, with temperatures at a single point changing as much as

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FIGURE 3.—Temperatures outside and at different heights in house during normal furnace operation with continuous low-speed blower.

9°F between the time the burner was on and when it was off. At an outside temperature of 12°F the furnace was operating about 41 percent of the time. Assuming an efficiency of 62 percent and an outside temperature of 12°F, the furnace was producing 55,400 × 0.41 or 22,714 Btu/h. At -6°F the furnace was operating approximately 49 percent of the time, which increased the heat produced to 55,400 × 0.49 or 27,146 Btu/h. The greatest variation in temperature was near the ceiling, but at the living level 4 feet above the floor a 6°F variation was common, and an 8°F variation was not uncommon.

Figure 4 shows the temperature distribution at low blower speed during continuous versus automatic blower operation, with the blower cycling on and off automatically in sequence, as controlled by the furnace temperature. At 8:45 a.m. on January 11 the blower was switched from continuous to automatic operation, and there was an immediate change in the plotting pattern. Continuous blower operation between burner cycles continued to pull hot air off the ceiling. When the burner stopped at approximately 8:05 a.m., the ceiling temperature was 74°F, and 20 minutes later, just before the burner started again (at 8:25 a.m.), the ceiling temperature dropped to 68°F. At 8:45 a.m., just before the burner stopped, the temperature at the ceiling was again 74°F. At 8:45 a.m. the blower was switched to automatic so that it would operate by signal from a thermostat in the furnace bonnet. The blower stopped at about 8:48 a.m., and the ceiling temperature rose from 74°F to 76°F by 9:00 a.m. At 9:00 a.m. the blower started, and the ceiling temperature quickly dropped to 70°F. During the next cycle, when the blower was off, the ceiling temperature increased to 78°F by 9:45 a.m., just before the blower started again. Thus, the ceiling temperatures between burner cycles remained several degrees warmer.
when the blower did not operate continuously. At the 4-inch and 4-foot heights temperatures decreased in a similar pattern, regardless of the mode of blower operation, but continuous blower operation seemed to have less effect on the temperatures at these heights than on the temperatures near the ceiling.

Figure 5 gives the temperature distribution during continuous blower operation at high speed versus low speed. At 11:50 a.m. the blower was switched from high to low speed. The length of the heating cycle (burner on-time plus burner off-time) was immediately lengthened from approximately 40 minutes at high speed to approximately 50 minutes at low speed, and the percentage of burner operation time decreased from 40 to 29 percent. Though outside temperatures were 2 to 4 degrees higher during the low-speed operation than during the high-speed operation and outside radiation was nearing its peak value, the effect of these factors was delayed because of the heat-transfer resistance of the structure. Thus, it appears that continuous low-speed operation decreased the total time for burner operation (at full flame), which in turn decreased the amount of fuel burned to about 72 percent of that consumed when the blower was operating at high speed 1 hour earlier. The major temperature difference in the operational cycle was evident when the burner was off and the house was cooling. The house cooled off faster with the blower operating at high speed than at low speed. This seems logical, since most of the warm air discharged into the living area flowed directly onto windows or outside walls. At the higher velocities across these surfaces the heat loss was greater, resulting in faster cooling.

Figure 6 shows the temperature distribution for furnace operation at full flame (using 1.47 ft³/min of gas) versus reduced flame (using 0.41 ft³/min of gas). At 2:15 p.m., after several cycles of normal furnace operation with the burner consuming gas at the rate of 1.47 ft³/min and with the blower operating continuously at low speed, the burner was adjusted to consume 0.41 ft³/min. After 18 minutes without heat, the furnace ignited and began
FIGURE 7.—Temperature distribution during furnace operation at 28, 62, and 100 percent of full flame.

its heating cycle. During the next 67 minutes the furnace continued to operate at the reduced level. During this period the temperatures at all levels were 1° to 2° F lower than those at the beginning of this heating cycle. Before 2:15 p.m. the furnace burner was on for 11 minutes at full flame and was off for 30 minutes, operating 27 percent of the time and consuming 14,958 Btu/h. When the flame was reduced to 0.41 ft³/min of gas (assuming that the efficiency remained constant), the furnace output dropped to 28 percent of full capacity. Since the burner was operating 100 percent of the time, the output equaled 15,512 Btu/h. Thus, with low-speed blower operation, the total fuel consumption was about the same with a full-flame (on-off) cycle or with a continuous low flame.

Figure 7 shows the temperature distribution for the furnace at three different rates of fuel consumption. Because temperatures continued to drop at the fuel consumption rate of 0.41 ft³/min, the flame was increased at 3:37 p.m. to consume 0.91 ft³/min. At this consumption rate the temperatures began to rise at all measurement heights and at all locations in the house. The furnace continued to burn for the next 48 minutes until the desired room temperature was reached. The off cycle lasted 20 minutes and the high-to-low temperature range was reduced from 12° F to about 9° F. Thus, with the rate of 1.47 ft³/min the furnace operated 28 percent of the time. At 0.41 ft³/min the furnace operated continuously and temperatures dropped slowly. At 0.91 ft³/min the furnace operated 71 percent of the time. Because the house had cooled off more than a normal amount at the rate of 0.41 ft³/min, the 48-minute initial burn was longer than normal.

Work by Newman and Hurst (see footnote 5) showed that effective temperature distribution could be achieved in ductless heat distribution systems by operating the blower continuously and by injecting heat into the airflow pattern at any point within a house. Based upon this thesis, the furnace burner was shut off at 6:30 p.m., and the blower was allowed to continue operating at low speed. The oven of the cooking stove was lighted and adjusted to burn natural gas at the rate of 0.056 ft³/min. Figure 8 is a plot of the temperature distribution under these conditions. The temperatures were maintained at a uniform level throughout the living area for the next 15 hours.

DISCUSSION

The furnace for this house was oversized when operating at full capacity with outside temperatures as low as −6° F (fig. 3). Continuous blower operation at low speed resulted in lower temperatures near the ceiling than those resulting from automatic on-off operation (fig. 4). Thus, continuous blower operation resulted in some reduction of fuel consumption. At full burner flame with continuous blower operation the fuel consumption at low speed was about 72 percent of the consumption at high speed (fig. 5).

When the gas consumption was reduced to 0.41 ft³/min (28 percent of full burner capacity), the burner operated continuously, and
FIGURE 8.—Temperature distribution in house when heated by cooking stove and with continuous furnace-blower operation.

Temperatures at each level remained relatively uniform (fig. 6). In figure 8 the temperature at each height was maintained uniformly when the blower and the cooking stove oven were operated continuously at a predetermined rate, in this case at 38 percent of full-flame furnace capacity.

There was no appreciable difference in temperature distribution or stratification when the blower was operated at high speed rather than low speed, but the temperature distribution was more uniform when the blower operated continuously at either speed. When the blower operation was cycled automatically, temperatures near the ceiling remained high, even when the furnace was not operating. High temperatures at the ceiling will result in greater heat loss through the roof. However, a warmer ceiling may provide slightly more radiant heat to the occupants and provide some increased comfort at lower room temperatures.

No effort was made to compare the furnace's efficiency to that of the cooking stove, which used 38 percent as much fuel as the furnace when operating 100 percent of the time. When the furnace's fuel consumption was in excess of 38 percent of full capacity, a portion of the excess was probably due to the less efficient furnace operation.

It should be noted that only Underwriters'-approved heating units should be used in occupied houses and that many automatic furnaces are not designed for burner-flame adjustment. Turning the flame too low could prevent burner ignition, especially if the pilot light is not properly adjusted. Homeowners or prospective buyers should ascertain that the furnace burner can be adjusted and, if not, purchase a smaller furnace for more uniform operations.

CONCLUSIONS

1. Oversized heating units, thermostatically controlled, will cause frequent cycling, resulting in uneven temperatures and thus, uncomfortable houses.

2. More uniform temperature distribution can be maintained with continuous blower operation than with on-off operation controlled by furnace demand. High-speed blower operation provides no improvement in temperature uniformity over low-speed operation.

3. Reduction in temperatures near the ceiling with continuous blower operation results in some fuel saving.

4. The most uniform temperatures may be achieved by maintaining a continuous heat input equal to heat loss, which can be accomplished by controlling fuel supply, by flame size, or by using primary and auxiliary heating units.