RESULTS OF CONSTRUCTION QUALITY INSPECTIONS OF 25 LOW-ENERGY MINNESOTA HOMES

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INTRODUCTION

This paper summarizes a more detailed presentation given at the Santa Cruz Summer Study, August 1986. The many photographs, thermograms, graphs, and tables presented there are omitted here for brevity. However, this and other material will soon be available from NTIS (ORNL/SUB/83-47980/1) in an Oak Ridge National Laboratory report titled Energy Efficient House Research Project Final Report. That report focuses on 144 energy efficient houses built in 1980 and includes a detailed analysis of the submetered fuel usage as well as results of indoor air quality testing. Details of the Minnesota Housing Financy Agency program, thru which these houses were built, and a comparison between predicted and measured energy performance were given at Santa Cruz in 1982 (Hutchinson,1982).

For this study we performed detailed, 2 person-day, highly-instrumented inspections of 25 of the original 144 houses. Instrumentation included a blower door, infrared scanner, wood moisture meter, sling psychrometer, flue gas testing equipment, and digital thermometers. We completed all inspections during the heating season. The purpose was to document constuction quality problems that would affect the energy performance of energy efficient houses.

AIR LEAKAGE

Field inspections for air tightness were conducted using an infrared scanner and precision blower door. As in conventional housing the largest source of air leakage was found between the top floor and the attic. Attic leakage sites were similar as well: chaseways for plumbing vents and chimneys, partition walls in split-level houses, wiring penetrations in the upper plates of partition walls, the joint between the sheetrock and top plates of exterior and partition walls, kitchen and bathroom soffits, ceiling light fixtures, duct work, and attic access hatches. Other leakage sites commonly found included floor/wall intersections (especially where floors cantilevered out over exterior walls), vent and utility wall penetrations, and exterior wall electrical boxes.

The average air tightness was 4.2 AC/H at 50 pascals, with the houses depressurized and intentional leaks sealed. For comparison, a Minnesota Department of Energy and Economic Development study of 68 typical houses built in 1983 reported an average of 3.8 AC/H (Fagerson, 1986). Although additional air tightening measures and air to air heat exchangers were included in 11 of the 25 houses, we did not find them to be statistically different from the others. Prescriptive standards set for the program were not followed by the builders and the program did not specifiy performance standards for air tightness.

INSULATION DEFFECTS

Infrared scans revealed numerous wall insulation defects in all houses. Defects fell into three categories, two of the three involved batt insulation, used in the walls of all houses. The first involved improperly fitted insulation. When scanned, many walls appeared non-uniform in temperature with studs barely visible in places. By comparison, scanned wall cavities properly filled with blown insulation appear uniform in temperature with studs visible as distinct straight lines. Non-uniform temperature readings suggest cavities in which insulation was compressed during installation, leaving gaps between the insulation and the sheetrock.

The second category is suspected to be caused by convective looping within wall cavities. Scanned studs appeared colder and wider at the bottom, believed to be caused by convection cells within the wall cavities. Cold air may be flowing down between the insulation and the exterior sheathing, passing through the insulation at the base of the wall cavity (or through gaps due to poor installation) and then flowing up between the sheetrock and the insulation.

The third category involved thermal bridging. In several cases, masonry foundation walls with exterior insulation were in direct contact with retaining walls or exterior concrete garage floors, which acted like fins to carry heat away from the foundation.

Another insulation defect was found in two houses with cathedral ceilings, that were built with ventilated air spaces above the insulation. The entire ceiling of rooms inspected showed cold streaks beginning at the bottom and extending various distances up the ceiling (the coldest portion of each streak appeared at the bottom). This appearance did not change with pressurization. Apparently these cold steaks are caused by outside air entering the lower soffit vents, moving under the insulation batts, and flowing upward between the sheetrock and insulation.

MECHANICAL SYSTEMS

The steady-state efficiency testing of gas furnaces found many to be below manufacturer's specifications. Several were found to have efficiencies between 69 and 75 percent. The condensing furnaces in one group of eight houses were all replaced due to corroded heat exchangers. Eleven of the 25 houses had forced air heating systems with warm air supply ducts beneath a concrete slab. Although housing plans called for insulation either around or below ducts near the slab's exterior edge, temperature measurments of air entering and exiting this ductwork indicated that 25 to 50 percent of the heat entering the ducts was lost before the air left the registers. A large percentage of this heat is probably lost to the ground. A statistical analysis of one year's energy consumption showed that, on the average, heating systems of this type have below slab distribution losses of about 11 million Btus per year.

Air-to-air heat exchangers were present in 13 houses. Of those 13, 10 were central, ducted units; all of these were poorly installed and none had provisions for air flow balancing. In most cases, the sizes and lengths of connected ductwork were such that the units, as installed, were probably poorly balanced. Only two of the units had filters and each of these had only one filter located in the outgoing air duct just before the heat exchange core. Control systems were complicated, operated improperly, or misunderstood by homeowners. None of the ducted systems came with an owners manual, and none of the owners knew to clean the heat exchanger. Many owners reported using their heat exchangers infrequently.

Four houses had rockbed storage systems below the floor; two of these filled with water every spring. The systems in place to move air in and out of the rockbed storage were poorly designed. In two houses, air was drawn through the rockbed storage whenever the furnace was in operation even if the rockbed was below room temperature. In addition to drawing warm solar heated air from the living room ceiling, these systems also drew cold attic air through leaks in the ductwork. In the other two houses, numerous leaks were found between the rockbed and the outside causing cold air to be drawn into the rockbed whenever circulation fans were in operation.

CONCLUSION

In spite of long lists of air-tightening measures for builders to follow, including the installation of air-vapor barriers, the houses examined here are not significantly tighter than conventional new Minnesota housing. Thermal defects reduced the advantages of higher levels of insulation and were probably due to improper installation. We repeatedly asked ourselves two questions during this study: "What would it have cost to build these houses right, and how much better would they have performed?" There is clearly much more work to be done before these questions can be answered.

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