# DESIGNING THE ENVELOPE: GUIDELINES FOR BUILDERS

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## ABSTRACT

Envelope design and construction variables affecting the energy performance of more than one-hundred Minnesota houses have been investigated. The houses were built as part of a 1981 energy efficient housing demonstration project. Field data gathered on 25 houses using an infrared camera showed common design and construction errors. Performance was evaluated from weekly and monthly energy use measurements.

The basis for several of the builder envelope design and construction guidelines is illustrated in side-by-side infrared and visible photographs. A common problem area to most houses is air infiltration into and through walls and ceilings, as shown by thermal scans of the envelope under pressurization and depressurization. Sometimes this air infiltration is the result of an overly complex design, which was originally intended to save energy. Heat loss due to below slab air-distribution systems was found to be significant, indicating that this design feature should receive increased attention.

## INTRODUCTION

The builder guidelines presented in this paper are general recommendations for the design and construction of energy-efficient houses. They are derived from an investigation of more than 100 Minnesota houses built under a 1981 energy efficient housing demonstration project by the Minnesota Housing Finance Agency. Data collected in this research project included total energy use, domestic hot water temperature and energy use, physical and operational characteristics of the houses, occupant characteristics, instrumented field observations, and indoor air quality measurements. The complete results of this investigation will be reported in the final project report.

Energy data were obtained from utility companies or from paid and volunteer homeowners who read the meters in one or more houses. For 47 houses monitored by paid meter readers, data were also collected on space temperature, hot water temperature, and supply water temperature. A self-reported homeowner questionnaire was the source of occupant and operational data.

The research also included the on-site inspection of 25 houses. The instrumented inspection technique used consisted of infrared observations of the house envelope with the envelope either pressurized or depressurized by a blower door. Such observations showed areas of excessive air leakage or thermal conduction and formed a qualitative basis for the proposed

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guidelines. Similar problems to those reported here have been documented before (Socolow 1978). However, it is noteworthy that even in a highly visible energy-efficient demonstration project, these practices still persisted. It is speculated that the home designer/builder community did not change its practice because they were not aware of the significance of these problems.

A major problem seems to be that quality control is frequently lacking so that energy-conserving designs do not perform as well as they should and in some cases are even counterproductive. It appears that quality control needs to be improved in the field to insure that energy-efficient housing is indeed energy efficient.

This paper will present three general guidelines derived from this research and will illustrate them by citing several specific problems observed in the energy-efficient house research project. It is expected that within the framework of these general guidelines, specific guidelines can be developed for different climatic regions and building practices. These specific guidelines could then be used to educate the residential building design and construction community on quality controlled energy-efficient construction.

## BUILDER GUIDELINES

### GUIDELINE # 1

Envelope design and construction should be more sensitive to the application and use of thermal insulation. Insulation should be installed to prevent air movement within insulated cavities.

The rationale for this guideline is based on several observations of insulation being in place but not performing effectively, because of areas of higher conductivity or because of convective air movement within the insulation cavity. The observation of three problems resulting from not following this guideline are cited.

The first was seen in batt-insulated walls with irregularities and gaps between the insulation and the wall cavity. Thermographic images of such walls showed irregular looking thermal transmission, apparently due either to compressed insulation or air movement within the wall cavity.

The second was wind-driven air currents moving under ceiling insulation batts adjacent to soffit vents. Here the edges of insulation batts were exposed to wind in this area, and cold air pushed under the batts on its way into the attic space, negating the effectiveness of the insulation at this location.

The third was convective looping seen as cold areas near the bottom of stud cavities. During the research, the bottoms of exterior walls were often found to be cold, apparently due to heavier cold air filtering through the batt insulation and warming as it circulated to the top of the wall along the warm side of the insulated cavity.

### GUIDELINE # 2

The design of exterior envelopes should specify details for air leakage reduction. During construction these details should be followed, and other possible sources of air leakage sealed.

Uncontrolled air leakage can seriously compromise an otherwise good design. In particular, if an extra investment in time and resources is made to provide an energy-efficient house, the relatively small additional investment to assure quality control to avoid air leakage is most cost-effective. In most of the 25 units inspected, the attics were the greatest source of air leaks. Three examples are discussed to illustrate this point.

Split-level houses have a common attic feature that results in a potential air leakage path through the wall separating the upper two levels of the house. This feature was examined in each split-level house in the research program, and in all cases a large air leakage site was found. The lower half of such a wall has heated space on both sides, while the upper half has heated space on one side and attic space on the other. Because normal practice is to use full length studs to frame these walls, a vertical air leakage path from the house to attic is readily created.

Photographs in the first two figures illustrate the above problem. They show each side of a wall that separates the second and third levels of a split-level home. The ceiling of the second level intersects this wall at about mid-height, so that there is an attic on the back side of the top half of the wall and heated space on the back side of the bottom. Figure 1 is a thermogram of the wall taken with the house depressurized. Note that the bottom part of the wall (with heated space on the back side) is the <u>cold</u> part. This is due to cold air being drawn into and down the wall from the attic. The photograph in Figure 2 was taken from the attic on the back side of the wall. The insulation at the bottom of the photo is above the ceiling of the second level. Some of the insulation for the ceiling of the second level has been removed for inspection, showing the polyethlyene vapor barrier. The open top of the heated wall cavity shows between the fiberglass batts. The interior wall cavity is also exposed just to the left of the black plumbing vent. Water staining was evident on the gypsum board above and to the left of the plumbing vent and on some of the wood in this area. This staining is at the level of the top of the blown fiberglass and was probably caused by condensation from warm, moist air leaking out of the house through the fiberglass insulation.

Unless the space between studs is carefully sealed where the ceiling of the lower level intersects this wall, the stud cavities form chaseways connecting heated space to the attic. Since these walls generally contain major plumbing, wiring, and duct runs, it is usually easy for heated air to get into the stud spaces of these walls.

The second example shows that air leaks were also found to be common where interior partition walls intersect the ceiling. The photograph in Figure 3 is a thermogram of the intersection of the wall and ceiling again while the house is being depressurized. The photograph in Figure 4 shows what this area looked like from the attic when the insulation was removed. The hole where the wiring goes through the top plate is a common source of air leakage. A pocket knife blade is seen sticking into a crack approximately 1/32-inch wide between the top plate and the gypsum board of the wall. The dark streak on the fiberglass batt that was covering up the leaks is indication of dirt that was filtered out of the air that leaked from the house.

The third example illustrating this guideline shows how complex design features might compromise energy conservation if quality control is omitted. In the house shown in the next two photographs, there is a closet on the other side of the walls that are built out over the stairway. The photograph in Figure 5 is a thermogram of the cathedral ceiling-closet wall intersection taken with the house depressurized. It shows a cold streak coming down from the cathedral ceiling into the partition between the closet and the room where the photos were taken. The photograph in Figure 6 was taken from the attic. A hand could be inserted into the dark area in the middle of the picture into the top of the cold wall cavity that showed up in the thermogram. Two walls, the flat closet ceiling, and the cathedral ceiling all meet at this location, creating some complicated framing details. The cathedral ceiling structure also changes from trusses to solid wood rafters at this point. The plans showed no details of how the air-vapor barrier was to be sealed here.

<u>GUIDELINE # 3</u>
Design and install the heat distribution system so as to insure effective operation.

Leakage of outdoor air into cold air returns or leakage of warm air from supply ducts into unheated spaces will reduce the effectiveness of the heating system. The potential for leakage is enhanced due to the fan-driven pressure differentials in the distribution system, and the potential for heat loss is increased because of the high temperature differences between the ducts and the surrounding space. Two examples that illustrate this guideline are given.

Air leakage and heat loss are increased when the return plenum for a furnace is open into an attic. The photograph in Figure 7 shows a top floor return air grille that connects to two stud spaces that serve as a return duct. The photograph in Figure 8 is a thermogram of this part of the wall, taken with the house depressurized and the furnace fan off. Cold air is apparently being drawn down the return from the attic, and a large amount of cold air was felt coming through the grille. This return plenum was designed to collect warm, solar-heated air from the ceiling of this room, to be blown through a rock-bed under the first level floor. From the above observation, this system appears not only to move warm air out of the living room but to pull cold air from the attic as well.

Eleven of the 25 field-inspected houses had forced air heating systems with warm air supply ducts beneath a concrete slab. The plans for these houses all called for some sort of insulation either around or below ducts located close to the exterior edge of a slab. However, thermal bridges may be causing high heat loss in these ducts, especially where there is thermal bridging between the slab and the footings. Two separate analyses showed that these duct systems were responsible for a significant portion of the total house heat loss.

Supply air temperature data on six houses were collected and data for one house is shown in Figure 9. This figure shows the differences between the cold air return temperature and the warm air supply temperatures measured at several locations for about one hour. After the furnace was on for more than an hour, the air coming out of the register farthest from the furnace had lost almost 65% of its energy to the ducts under the slab. Of course, not all of this heat is really lost, since the house will now lose less heat to a slab that is warmer. However, comparing the energy performance of houses with below-slab ducts to those without proves that much of this energy is lost into the ground. In two other units, measurements showed that about 25% was being lost after 25 minutes. In a fourth house, where all the supply air goes below the slab, about 50% of the heat was lost after 30 minutes.

The second method of analysis, which demonstrated that below slab duct losses were significant, was a statistical analysis of the energy performance of all houses in the project. A regression analysis for this variable showed that, on the average, houses of this type had below-slab distribution losses of 110 therms per year (3200 kWh per year). Depending on the annual heating energy required, this loss could amount to 20% to 25% of the total heat loss from the house.

There is general agreement of both field observations and statistical analysis that improperly insulated below-slab heat distribution systems increase energy use. Therefore, it is recommended that below-slab heat ducts be properly insulated or avoided.

## CONCLUSION

1. Energy efficiency of housing could be improved if designers and builders were more careful about the field variables over which they have control. These include the use of insulation, the reduction of air infiltration, and the proper design and installation of forced air distribution systems.

2. Many energy efficient designs are possible, but quality control, following the general guidelines presented here, is essential if any design is to deliver its maximum potential for energy savings.

3. Little progress seems to be occurring in quality control in construction. Even though an effort was made to educate builders on this matter in the energy-efficient housing demonstration project, the importance of this issue was not conveyed. Designers and builders need a more focused educational effort, involving them in the problem solving element.

## REFRENCES

Socolow, Robert M., ed. 1978. "Saving energy in the home, Princeton's experience in Twin Rivers."

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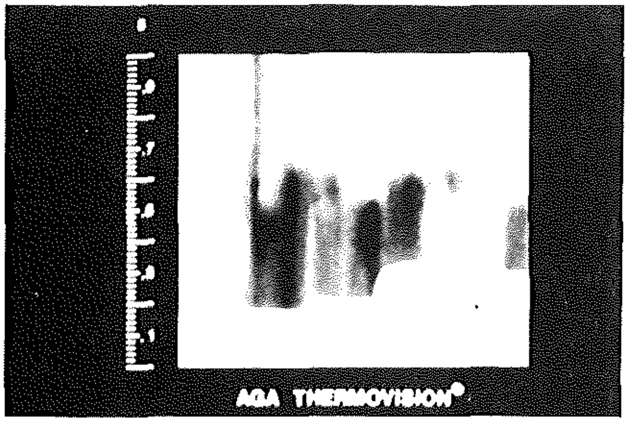


*Figure 1.* *Thermogram of wall taken with house depressurized*

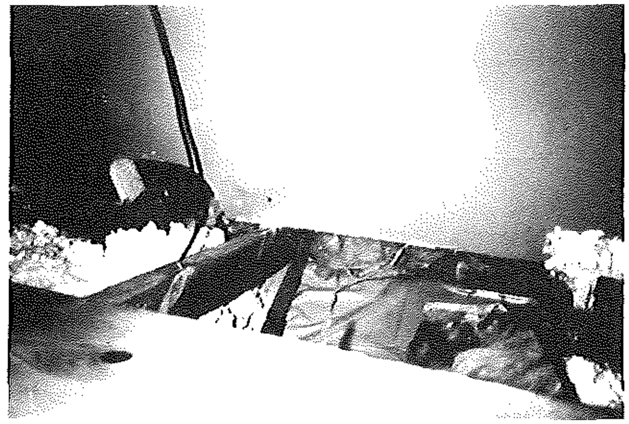

*Figure 2.* *View from attice of back side of wall*

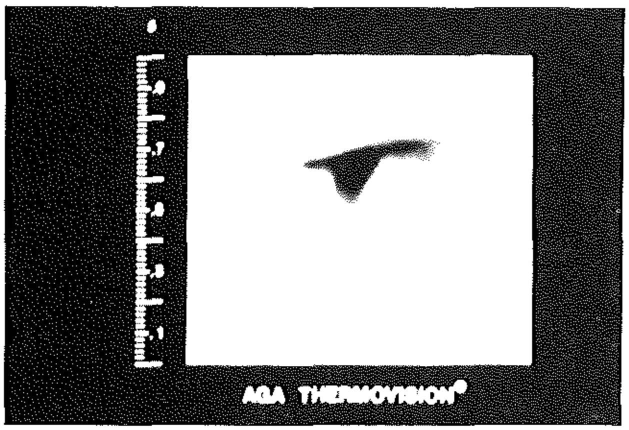


*Figure 3.* *Thermogram of intersection of wall and ceiling while house is being depressurized*

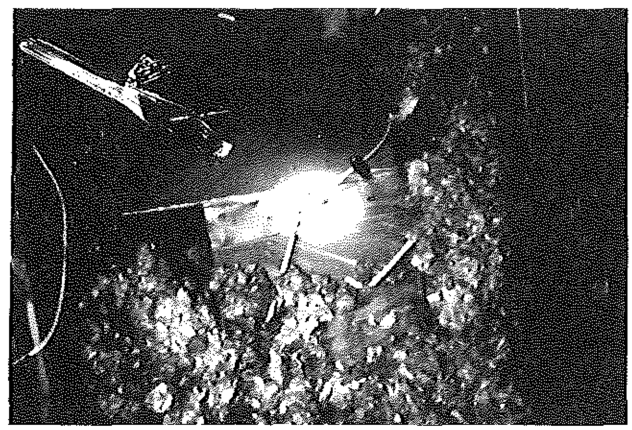

*Figure 4.* *View from attic of wall-ceiling intersection with insulation removed*


*Figure 5.* *Thermogram of cathedral ceiling-closet wall intersection taken with house depressurized*

*Figure 6.* *View from attic of cathedral ceiling-closet wall intersection. Dark area in middle of picture leads to top of cold wall cavity shown in Figure 5*

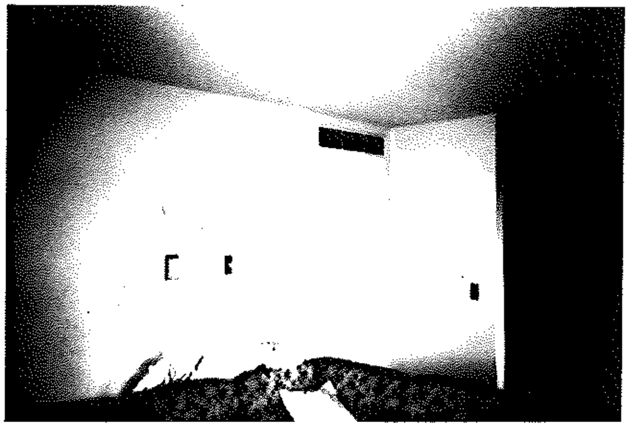

*Figure 7. Top-floor return air grille that connects two stud spaces that serve as a return duct*

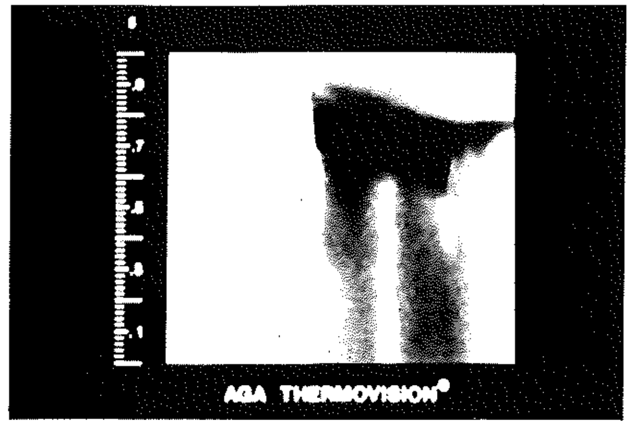


*Figure 8. Thermogram of return air grille with house depressurized and furnace fan off*

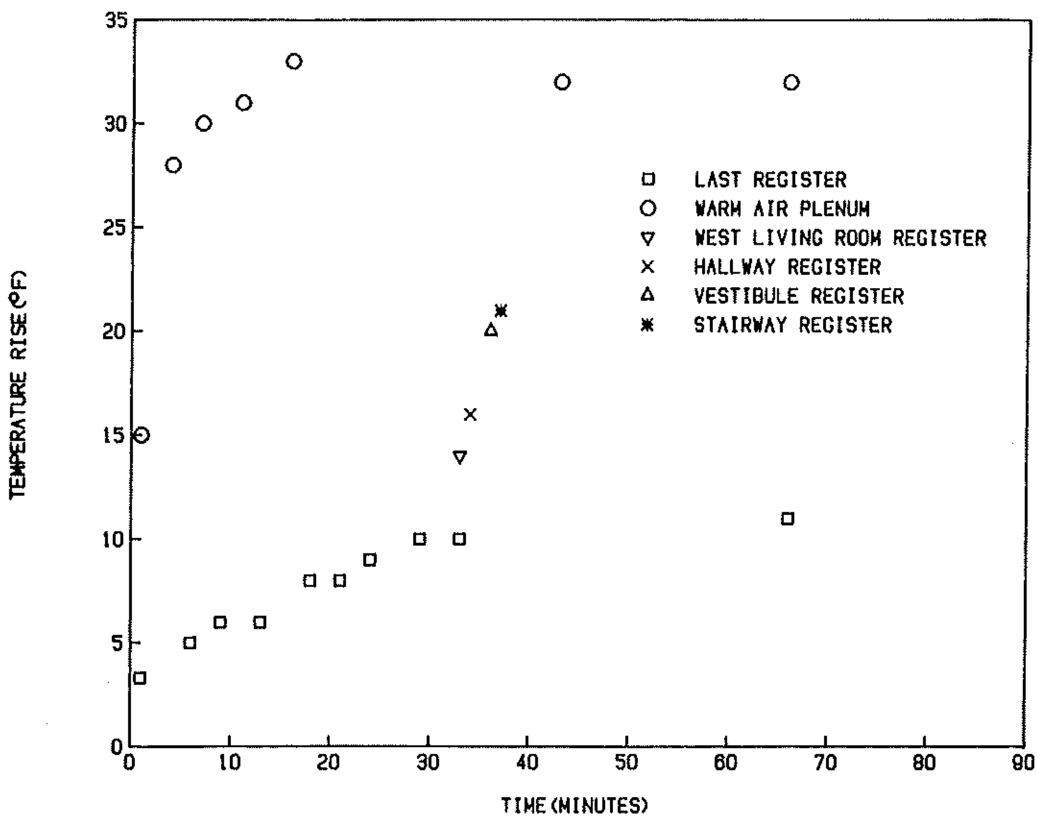


*Figure 9. Heat loss in below-slab air distribution systems*