Design and Experimental Analysis of Ventilated Walls and "Ice House" Roofs Applications in Warm Climates

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ABSTRACT

This paper contains the findings of experimental research conducted to determine the effectiveness of ventilated walls and "ice house" roof applications in hot-humid climates. Ventilated wall and "ice house" roof is the type of construction which consists of interposing an additional wall or roof skin between the standard building envelope and the exterior environment. The new skin is separated from the building envelope by an air space, which is usually vented to the ambient environment. The primary objective of such construction is to eliminate or drastically reduce the effects of solar loading on the building envelope. The information presented in this paper can enable the designer to have a better understanding of how buildings might function at various times of the day and the season. Recommendations on applications of new buildings and retrofit of existing structures are presented here as well.

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INTRODUCTION

To understand what measures can be taken to conserve energy through passive solar building design, the underlying causes of heat gain and loss must be examined. In warm climates, the primary problem in designing the building shell is how to reduce summer heat gain. Further north the primary problem is how to reduce winter heat loss.

The way heat transfers is distinctly different during the winter and summer seasons. For this reason the insulation strategy must be fine-tuned to take advantage of the correct mix of summer/winter severity. What works in the north to reduce energy costs does not necessarily work well in hot humid climates.

Heat flow in buildings is a complex subject that is best described with three physical laws of heat transfer from a warm to a cool area: conduction, convection and radiation. A basic group of these three principles helps in the understanding of requirements to reduce energy consumption.

Conduction and convection occur only through such mediums as air, glass, foam, etc. Radiation, however, can transfer without medium. Bodies need only 'see' each other for thermal transfer by radiation.

Typically, insulation design strategies attach the problem of summer heat gain by reducing convection and conduction. Walls, ceilings and windows only are traditionally protected from conduction and convection, ignoring radiant heat flow, which contributes most significantly to heat gain. Part of the reason radiation has been ignored until now is that only a small research base was available and because of the complexity of the calculations to adequately model a structure.

The Office of Building Research at LSU and Florida Solar Energy Center under a contract conducted a series of tests to determine the effectiveness of radiant barriers in reducing heat gain in typical roof and wall configurations.

METHODS OF TESTING

The basic experimental tool employed for this project was Passive Cooling Laboratory (PCL) of Florida Solar Energy Center (FSEC), which provides for controlled side-by-side building component experiments. Results were additionally compared with field monitoring results from three lived in residences in Orlando, Florida. Side-by-side testing is designed to indicate the relative performance of a particular alternative with respect to a given base case. The base case or control strategy is held constant throughout the experimental process and is used as the "yardstick" for the performance of alternative strategies. Both roof strategies and wall strategies were tested. For roofs, a standard frame roof with 6 in of fiberglass batt insulation was used as the base case. For wall system experiments, standard 2 x 4 in. frame wall construction with R-11 (thermal resistance value is 11 hr. sq. ft. °F/BTU) batt insulation functioned as the standard against which other wall types were compared.

FIELD TESTS

Three residences in Orlando, Florida have been retrofitted using foil radiation barrier techniques. One residence (Alas house) has employed a multiple layer foil radiation barrier product in the attic. It is manufactured in various widths to be installed between normal building framing members. This product was installed between the top chords of the roof trusses of the Alas house and stapled in placed. A continuous ridge vent was added to the roof peak of the residence to increase ventilation between the roof decking and the foil radiation barrier.

A second residence (Schoonmaker house) was retrofitted using a concept known as the vent-skin or "ice-house" roof. This technique consists of adding an additional roof above an existing roof plane. The two roof planes are separated by an air space, which is vented at the soffit and at the roof peak. As part of the retrofit project the Schoonmakers added additional space to their existing house. The new roof framing was sheathed with dennyboard. On top of the dennyboard, 2 x 2 in. vertical battens were applied to act as spacers between the dennyboard and a standard 1/2 in. plywood and shingle roof. A continuous ridge vent was employed at the roof peak.

The third residence (Castles house) was retrofitted with a similar roof. The old shingles were stripped off and a single layer of builder's foil was laid on top of the existing plywood roof deck. After application of the builder's foil, 2 x 2 in. vertical battens and a 1/2 in. plywood and shingle roof were applied as in the Schoonmaker house. Again a continuous ridge vent was used to ventilate the air space.

In addition to the roof of the Castles house, a radiation barrier vent-skin was employed in the retrofit of the west-facing wall of the residence. In a similar manner as in PCL tests, the uninsulated concrete block wall was covered on the exterior with a single layer of double-sided builder's foil.

Two 2x 2 in. vertical batten strips were then attached through the foil to the block wall. A reinforced 5/8 in. stucco finish backed with 30 lb. felt was then applied to the battens as the exterior finish. The wall was vented at the top and bottom with continuous vents.

TESTING RESULTS AND CONCLUSIONS

The results of the analytical studies performed with computer simulations sometimes showed a significant divergence form the experimental data. The most notable example of this occurred in the modeling of radiation barriers. Temperature distributions resulting from TNODE ventilated-skin radiant barrier roof systems often diverged from experimental data by a factor of two. The computer simulations showed temperature depressions on the order of 25 °F for these roof systems while monitoring results often indicated depressions of up to 60 °F.

No attempt was made to adjust the model to the measured data for two reasons:

1. It is still somewhat unclear exactly how the radiative heat transfer process is affected by the convective heat transfer process and vice versa, and

2. The model does not currently allow for the non-linear modelling of temperature dependent heat transfer coefficients.

The second constraint is especially critical to roof/attic modelling where temperature differences can be quite high and can have extensive diurnal swing patterns 100 °F. Modeling of radiant and convective fields in attics is even further complicated by the fact that convective transfer in such spaces is not only temperature dependent, but also directionally dependent (i.e., there are different non-linear functions for heat transfer upward and heat transfer downward).

WALL CONFIGURATIONS

The four wall configurations, which were studied include:

1. An uninsulated concrete block wall (R-2.5)*.
2. A concrete block wall with exterior insulation (R.8)*.
3. An uninsulated vent-skin concrete block wall with radiant barrier (R.5)*.
4. A reference frame wall (R-ll)*.

For convenience, these walls are referred to as concrete block wall, exterior insulated wall, vent-skin wall, and frame wall, respectively.

Representative test data in Table I for the wall configurations under summer sunlit conditions are shown. The following preliminary conclusions were reached.

1. The uninsulated concrete block wall was significantly less effective than the other configurations including the frame wall.

2. The vent-skin and exterior insulated concrete wall performed equally well under free-float test conditions (i.e., with unconditioned interior spaces).

3. The effectiveness of the vent-skin wall is primarily due to the radiant due to the radiant barrier, rather than airflow through the vent. Consequently, the use of a dead airspace with a radiant barrier is only slightly less effective than the vented configuration.

4. No clear alternative (between the frame, vent-skin and exterior insulated block walls) stands out yet as the best wall configuration for year round energy savings.

ROOF/ATTIC CONFIGURATIONS

The three roof configurations, which were studied, included:

1. An unventilated reference standard (R-19) roof with 6" fiberglass ceiling insulation.
2. The same roof with the addition of single-sided builders foil as a radiant barrier, and
3. A ventilated-skin (double) roof with a radiant barrier and ridge vent.

For convenience they will be referred to in the following discussions as:
Standard roof, radiant barrier roof, and vent-skin roof, respectively.

Resulting test data for the three roof configurations under summer sunlight conditions are shown. In addition, a much more detailed description of radiant barrier performance is presented in Reference 3. Preliminary conclusions are as follows:

1. Normal ceiling insulation products (e.g., fiberglass, mineral fiber, etc.) absorb significant amounts of radiant energy emitted by the underside of roof decks.

2. Attic heat transfer down is driven primarily by radiant heat transfer. Less than 10% convection is involved.

3. One single-sided aluminum foil radiant barrier can reduce the heat gain into an unconditioned building by over 40% under bright sunlight conditions compared to the standard roof.

4. Both the radiant barrier roof and vent-skin roof significantly reduce heat gain to the building compared to the standard roof.

5. Single foil radiant barriers will theoretically work almost as well as double or triple foil barriers in roofs. However, the winter season performance of these barriers has not been experimentally examined.

6. The use of aluminum foil radiant barriers appears to be one of the most simplest and cheapest energy improvements to a home.

The results of full-scale experiments are very well supported by the hotbox test results. Table 2 indicates the relative effectiveness of various attic/roof insulation strategies based on hotbox tests. The table is expressed in terms of relative effectiveness. Each ratio is expressed in terms of the effectiveness of R-19 plain fiberglass batt. In other words, the measured heat flux through the plain fiberglass batt is divided by the measured heat flux through each alternative giving a relative effectiveness for each. If the true resistance of the plain fiberglass batt (with foiled vapor barrier facing down toward ceiling) is known the other resistances can be determined by multiplying that resistance by the given effectiveness ratio.

DESIGN/CONSTRUCTION CONSIDERATIONS IN WARM CLIMATES

It is now well accepted that good building design is climate dependent. Designers and builders of structures must keep this fact uppermost in their minds. It is important that the information contained in this paper not be taken out of context climatically.

Armed with a knowledge of the climate, many of the "trends" indicated by the data presented here can enable the designer to have a better understanding of how his building might function at various times of the day and the season.

Applications of radiant barriers do not require any radical change in existing design practices. They are simply installed between the roofing and interior of any residential or commercial structure. This gives the designer a wide latitude in deciding where to place the product. The best location in most buildings will be either on the top or the bottom of the rafters with at least a 3/4 in. air space adjacent to the highly reflective (low emissivity) surface, which can face either, up or down with the same effect. Radiant barriers offer simple and cost effective solutions to existing energy problems in hot-humid climates.

TABLE 1 Effective Resistances of Walls

WALL TYPE	MEASUREMENTS FROM	TO	MEAN TEMP. °F	MEAN TEMP. DIFF. °F	TOTAL HRS. OF DATA COLLECTED	LAG TIME Hr.	EFFECTIVE RESISTANCE Hr.Sq.Ft.°F/BTU
Uninsulated Block	Exterior Surface	Interior Surface	83.5	5.2	55	4	5.0
Insulated Block	Exterior Surface	Interior Surface	83.2	9.1	44	4	12.7
Vent-skin Block	Exterior Surface	Interior Surface	82.9	6.9	67	4	13.5
Frame Wall	Exterior Surface	Interior Surface	87.9	16.0	44	2	*5.7

* Resistance values for this frame wall are quite low. We are unsure of the cause of this but believe that moisture levels in the exterior environment may be a contributing factor since the vapor barrier is on the interior. Calculated steady-resistance values around 10. Little confidence should be placed on this value unit its origin is determined.

TABLE 2 Effectiveness Ratios of Three Attic/Roof Insulation Strategies

Strategy	Effectiveness Ratio
Plain fiberglass batt (R-19)* (raw fiberglass facing radiating surface)	1.00
Single foil layer (double sided foil with air space on both sides of foil)[Ice house roof]	1.42
Foil faced fiberglass batt (R-19)* (with foil and air space facing radiating surfaces)	1.82

*R-19 means the thermal resistance value is 19 hr.sq.ft. F/BTU

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Many of the concepts incorporated in vent-skin walls are covered by U.S. Patent #4,286,420 held by Panayiotis D. Pharmakidis, 7623 Bonniebrook, Sylvania, Ohio 43560.

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