Measured outdoor performance of radiant barriers in tropical climate

T. Soubdhan*, J.L. Bernard, P.H. Nguyen, M. Dupont

Groupe de Recherches sur les Énergies Renouvelables, Université Antilles Guyane, 97159 Pointe à Pitre, Guadeloupe, France

ABSTRACT

The motivation for this investigation was to evaluate the outdoor performance of radiant barriers in comparison with insulation material based on conductive heat transfer. For this study, four identical small-scale test cells were used. Their roofs were equipped with the respective insulation material to be tested. Temperature was measured at different levels in the cells and meteorological data were also measured. Time lag and decrement factor are used to compare the material efficiency.

The aim of this paper is to present the experimental apparatus and to show which insulation material and process gives best result in reducing heat gain through the roof. With a white corrugated iron roof top, all the insulation materials gave the same results. With a black one, polystyrene provided a better insulation level. However, when the roof air space was ventilated, the radiant barrier gave best results.

INDEX TERMS

Radiant barriers; Insulation; Outdoor performance; Time lag; Decrement factor

INTRODUCTION

In tropical climate, reducing solar loads on a building envelope is of major interest (Abdessalam *et al.*, 1998). In such a climate, high solar radiation throughout the year gives support to the use of mechanical cooling system, resulting in higher electrical consumption. In a building, 60% of the thermal transfer occurs in the roof. Thermal insulation of this component is of utmost importance (Garde, 1997).

Roof insulation materials are chosen with regard to their ability in reducing thermal transfer into the building. Most of them, like polystyrene, fibre glass, rock wool, have low conduction coefficient, which helps in minimizing heat transfer by conduction through the wall.

Materials having high reflectivity coefficient are also used. They are made of aluminium foil combined with different layers of thin materials. They are called 'radiant barriers' because of their ability in reflecting the infrared radiation; they have received increased attention during the past years (Moujaes, 1998). They are commonly used in attics to reduce the radiant heat transfer occurring between the roof deck and attic floor of a residence or a commercial building (Winiarski and O'Neal, 1996). In an attic, the radiant barriers can be located on top of ceiling insulation or underneath rafters. These products, placed in an attic, are well-documented means to reduce heat transfer through the ceiling (Hall, 1988; Al Hasmar *et al.*, 1999; Medina, 2000).

In Guadeloupean building, the insulation material is placed in the roof airspace, between the corrugated iron, roof top and the roof deck. Polystyrene and fibre glass are mostly used. Radiant barriers are being used for a few years in the configuration mentioned above. However, their efficiency in reducing the heat flow through the ceiling has not been shown in

*Corresponding author. E-mail: ted.soubdhan@univ-ag.fr

such a configuration. The roof airspace is only 4.5 cm large and dust accumulation may be important, particularly in tropical humid climate.

In this study, two points had to be cleared:

- Considering heat flow reduction through the ceiling, are the radiant barriers efficient in the way they are used in Guadeloupe?
- Which is the most valuable insulation material to be used in tropical humid climate—polystyrene, fibre glass or radiant barrier?

METHODS

Four identical small-scale test cells were used. Their roofs was equipped with the respective insulation material to be tested: the first with polystyrene called CP, the second with a radiant barrier called CRB, the third with fibre glass called CF and the last one with no insulation material, considered as the reference cell, was called C0. (Figure 2 shows the different roofs.)

Only the heat transfer through the roof system had to be taken into account. To avoid any heat transfer through the walls, they were insulated with 4 cm of polystyrene and the outside surfaces were painted white to minimize the outside absorbance. The cells are made of wood. Their dimensions and components are shown in Figures 1 and 2.

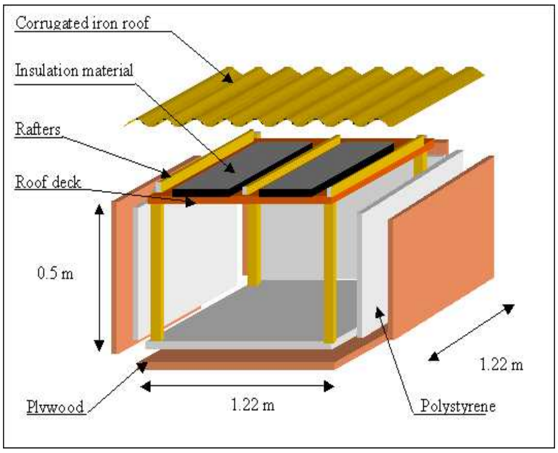

Figure 1 The different components of a test cell.

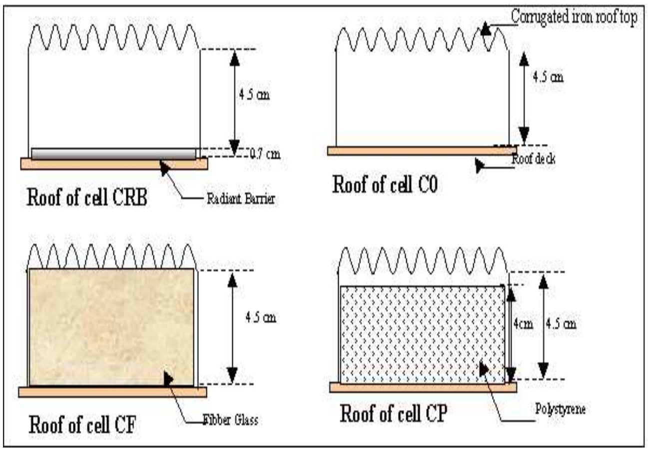

Figure 2 The different roof systems.

Instrumentation

Temperatures were measured at different level in the cells. For each cell, 15 data points were monitored simultaneously. These consisted of: roof top temperature, insulation temperature, roof airspace temperature (when this one exists), roof deck temperature, inside air temperature, black globe temperature and the temperature of the five walls.

Meteorological data were also measured: solar radiation (global and diffuse radiation), 'sky temperature', wind speed and direction.

All these data were recorded by a data logger connected to a personal computer. The measurements were done every 10 s and averaged on 1 min.

Time Lag and Decrement Factor

Time lag and decrement factor are the two characteristics of heat propagation in a material. The time taken for heat wave to propagate from outer surface to the inner surface is called 'time lag (Φ)' and the decreasing ratio of its amplitude during this process is the 'decrement factor (δ)'. A schematic explanation of time lag and decrement factor is shown in Figure 3.

$$\delta = \frac{A_0}{A_e} = \frac{T_{0\max} - T_{0\min}}{T_{e\max} - T_{e\min}} \tag{1}$$

A_0 and A_e are the amplitudes of the wave in the inner and outer surfaces of the building envelope, respectively. More details on time lag and decrement factor are given in Duffin (1984), Hassan (1998) and Ulgen (2001).

As per our study, a good insulation material is the one that leads to the smallest decrement factor and time lag. In tropical climate, there is a need for reducing solar heat gain through a building envelope, and also for avoiding thermal storage in the material. When heat is stored in the material, it is transferred into the building during the night (according to time lag), resulting in thermal discomfort.

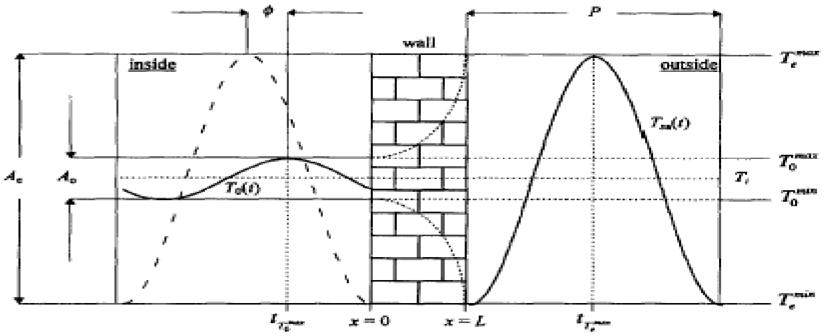

Figure 3 Schematic representation of time lag and decrement factor.

RESULTS

Four test sets were conducted. The first one allows comparison between the different insulation materials when they are combined with a roof having an albedo coefficient estimated to be 0.3 (a white corrugated iron roof top was used). In the second test set, the roof albedo was increased to a value estimated to be 0.9 (a black corrugated iron roof top was used) (Modest, 1993). The third test set was dedicated to the study of the roof air space ventilation.

For each test, with the measured roof surface temperature, time lag and decrement factor are calculated daily for the different roofs. The average over the test period and standard deviation are also calculated. Table 1 summarizes the results for each test and for each cell.

Considering the low roof albedo test, it appears that the decrement factor is quite the same for the radiant barrier, polystyrene and fibre glass ($\delta \approx 0.6$). For the reference cell, the decrement factor is 0.72.

The time lag observed varies from 93 to 180 min for different materials. Fibre glass and radiant barrier have the same averaged time response.

In this configuration, polystyrene, fibre glass and the radiant barrier are more efficient in reducing heat transfer through the roof than an air layer. The differences observed between these three insulation materials are not significant.

In the second test set, the same materials are compared when the roof albedo is estimated to be 0.9. To have such a value, the corrugated iron roof top was painted in black. Changing the roof albedo increases the heat flux going through the roof thus making the temperature level higher.

Radiant barrier can reduce from 50% the amplitude of the heat wave, polystyrene and fibre glass provide a 55% reduction. In the reference cell, the decrement factor is 0.7. Compared to the previous test (low roof albedo), it appears that time lag and decrement factor are smallest with a high roof albedo.

Table 1 Time lag and decrement factor for the different tests and cells

	Low roof albedo (0.3)							
	Radiant Barrier		Polystyrène		Fibber glass		Reference cell	
day	*δ*	*Φ (min)*	*δ*	*Φ (min)*	*δ*	*Φ (min)*	*δ*	*Φ (min)*
1	0.64	141	0.61	188	0.65	170	0.76	106
2	0.61	161	0.74	168	0.65	140	0.71	106
3	0.51	162	0.67	178	0.59	160	0.75	95
4	0.58	131	0.71	168	0.61	140	0.73	74
5	0.66	132	0.62	188	0.66	129	0.76	106
6	0.53	111	0.47	160	0.47	150	0.65	84
7	0.50	150	0.48	188	0.46	169	0.69	85
8	0.69	140	0.59	178	0.60	140	0.70	106
9	0.62	151	0.59	169	0.61	119	0.74	85
10	0.46	131	0.44	178	0.44	150	0.66	96
11	0.65	141	0.62	198	0.63	150	0.76	85
12	0.66	132	0.61	198	0.62	159	0.75	84
Average	**0.59**	**140.25**	**0.60**	**179.92**	**0.58**	**148**	**0.72**	**93**
Std deviation	**0.08**	**14.39**	**0.09**	**12.29**	**0.08**	**15.36**	**0.04**	**11.29**

	Hight roof albedo (0.9)							
	Radiant Barrier		Polystyrène		Fibber glass		Reference cell	
day	*δ*	*Φ (min)*	*δ*	*Φ (min)*	*δ*	*Φ (min)*	*δ*	*Φ (min)*
1	0.46	139	0.43	170	0.43	147	0.62	72
2	0.51	91	0.45	103	0.46	92	0.72	51
3	0.48	121	0.43	145	0.43	104	0.71	56
4	0.54	127	0.49	139	0.49	117	0.77	65
5	0.46	89	0.42	109	0.42	86	0.69	52
6	0.50	130	0.46	140	0.46	116	0.68	51
7	0.50	85	0.46	97	0.45	85	0.72	51
8	0.48	127	0.45	145	0.45	135	0.70	85
9	0.52	82	0.46	103	0.48	86	0.70	47
Average	**0.50**	**110**	**0.45**	**127.8**	**0.45**	**107**	**0.70**	**59**
Std deviation	**0.03**	**23**	**0.02**	**25.4**	**0.02**	**22**	**0.04**	**13**

	Hight roof albedo (0.9) and ventilated airspace							
	Radiant Barrier		Polystyrène		Fibber glass		Reference cell	
day	*δ*	*Φ (min)*	*δ*	*Φ (min)*	*δ*	*Φ (min)*	*δ*	*Φ (min)*
1	0.30	182.0	0.33	217.0	0.44	139.0	0.40	73.0
2	0.30	61.0	0.34	95.0	0.42	130.0	0.43	45.0
3	0.32	68.0	0.33	104.0	0.42	92.0	0.44	45.0
4	0.28	68.0	0.37	85.0	0.42	65.0	0.42	45.0
5	0.30	76.0	0.35	132.0	0.41	83.0	0.41	46.0
6	0.33	174.0	0.37	179.0	0.40	100.0	0.43	54.0
7	0.34	113.0	0.40	170.0	0.46	138.0	0.38	60.0
8	0.39	98.0	0.41	170.0	0.46	138.0	0.50	60.0
9	0.39	121.0	0.43	170.0	0.48	102.0	0.49	100.0
10	0.35	83.0	0.37	104.0	0.43	100.0	0.51	54.0
Average	**0.33**	**104.40**	**0.37**	**142.60**	**0.43**	**108.70**	**0.44**	**58.20**
Std deviation	**0.04**	**43.53**	**0.04**	**44.46**	**0.03**	**26.11**	**0.05**	**17.25**

Polystyrene and fibre glass provide a better resistance to heat transfer than radiant barrier. If this is a good advantage during day time, this can be a disadvantage during night time. A high resistance value *R* helps in minimizing the heat transfer inside the cells during day time. During night time, the heat transfer is going from inside the cell to the outside. With an insulation material, the heat transfer is not totally 'stopped', it is delayed according to the time lag of the material. With polystyrene, the heat flux is transmitted into the cell by the end of the day.

The last test is dedicated to the study of the roof air space ventilation. Ventilation of the airspace helps in reducing the decrement factor and thus the heat transfer trough the roofs. In this configuration, all the roofs have a decrement factor less than 0.5. The radiant barrier gives best results in this configuration.

CONCLUSION

In this study, the results of an experimental comparison of different roof insulation materials under tropical climate are presented. Radiant barriers were compared to polystyrene and fibre glass. For this study, four thermally identical test cells were used. Their roofs was equipped with the respective insulation material to be tested. Temperature measures were simultaneously made on the four cells, allowing comparisons between the different cells and thus the insulation material.

The first two tests allow comparison of the material with different roof albedo. Having a low albedo coefficient helps in reducing the temperature in the cells. With a low roof albedo, (0.3), polystyrene, fibre glass and the radiant barrier are more efficient in reducing heat transfer through the roof than an air layer. The differences observed between these three insulation materials are not significant in this case. With a high roof albedo (0.9), polystyrene and fibre glass provide a better resistance to heat transfer than radiant barrier. However, during night time, this can be a disadvantage (for hot tropical climate) because the heat is kept in the cell.

Ventilation of the air space is necessary when a radiant barrier is used. When the air space is not ventilated, the predominant heat transfer is done by conduction in the air. A radiant barrier associated with a ventilated airspace leads to a reduction of 67% of the amplitude of the temperature.

In a future study, the influence of ventilation on the different heat transfer modes will be studied in detail. More over, the effect of dust accumulation on the radiant barrier in such an air space (5 cm) has to be characterized.

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