NATIONAL BUREAU OF STANDARDS REPORT

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THE SELECTION OF BUILDING SYSTEM BY A DECISION PROCESS USING CLIMATOLOGICAL, ENGINEERING AND ECONOMIC DATA

by

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Building Research Division
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Office of the Chief of Engineers, U.S. Army
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U.S. DEPARTMENT OF COMMERCE
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I. INTRODUCTION

The selection of a roofing system by a decision maker is ofter based on either past experience with the performance of a specific roofing system under the service conditions in his area or on the results of simulated service tests conducted in the laboratory. Frequently these sources of information are not available especially in the case of new products or inovations in building systems. The building industry in general and those involved with military construction could profit by having a criterion or criteria to assist in the selection of the more economical building systems which will perform adequately under service requirements.

The object of this report is to propose a simple model to provide a logical and systematic approach to the selection of a building system based on a scientific method.

An attempt has been made to verify the model by deductively processing currently available economic, climatic and engineering information to obtain an indicator which will assist in the selection of one of two asphalt shingle roofing systems. Further an attempt has been made to extrapolate present and past information into the future in order to provide a basis for the selection of a system.

2. ASPHALT ROOFING SYSTEMS

Asphalt roofings account for over 80% of the roof covering materials used in the United States [1]*. In 1965 the number of shingles produced was sufficient to cover about 4 billion square feet of roof area [2] which alone is adequate testimony of their usefulness as a roof covering. However, they possess, like most building materials, some inherent weaknesses. The most frequent cause of failure of conventional (free-tab) asphalt shingles, which in 1965 amounted to about two-thirds of the total production of asphalt shingles, is damage by wind. To overcome this deficiency various types of wind-resistant shingle is the self-sealing shingle which has been described by Cullen [3]. Suggested criteria for the performance of a wind-resistant shingle was proposed by Cullen [4] and label service is currently being offered for this type of roof covering by Underwriters' Laboratories Inc., based on these criteria [5].

The wind-resistant shingle may be classed as a premium product since the purchaser of these materials must pay a slight additional cost for the additional protection against wind which is afforded. The increased cost is justified in high wind areas where conventional shingles are vulnerable to damage but their use in areas experiencing low wind velocities is sometimes questioned. The question now arises regarding the economic benefit to be gained by the selection of a shingle commensurate with its projected exposure conditions in service.

*Figures in brackets indicate literature references at the end of this paper.

3. PERTINENT PARAMETERS

3.1 Economics

The cost of asphalt shingles including installation, like other building systems, varies to a large degree depending on the type of shingle, the roof area, the method of application, the labor market and the geographical area. Therefore, an accurate assessment of costs is often difficult to make. However, for the purpose of this report and based on information from a number of reliable sources, an approximate installed cost of $20.00 per square (100 square feet of roof area) has been used for conventional asphalt shingle roofings. A cost differential of one dollar per square has been used for wind-resistant shingles as compared to the use of the conventional type. Assuming the roof area of an average house to be 1500 square feet it follows that the cost to apply a roof with conventional shingles will be about $300.00. The premium which must be paid for using wind-resistant shingles amounts to an additional penalty of $15.00 per house.

3.2 Engineering Properties

In a study of the wind resistance of conventional (free-tab) asphalt shingles, Cullen [6] has reported that sustained winds of 30 miles per hour or over are frequently sufficient to lift the unrestrained shingle tabs so that the shingles may become vulnerable to damage by wind gusts of much greater velocity. Therefore, we have used these data to select, for this study only, the criterion of 30 miles per hour wind speed for predicting whether or not conventional asphalt shingles may be vulnerable to damage by wind.

3.3 Climatology

We have selected as our criterion the daily fastest observed one-minute wind speed as reported in Local Climatological Data published by ESSA's Weather Bureau. The climatic condition of the Washington, D. C. area for the year 1965 was used as the weather parameter in the model. These data were obtained from Weather Bureau publications [7]. An examination of these data revealed that the daily fastest observed one-minute wind speed exceeded 30 miles per hour on 30 of the 365 days in the Washington, D. C. area or on 8.2% of the total days in 1965.

4. THE DECISION PROCESS

Once the decision maker has arrived at the judgement that the new or replacement roof will be asphalt shingles, he has two possible courses of action regarding the selection of the type of shingles in respect to wind resistance. One will be more advantegous under high wind conditions while the other will be the better choice under less severe wind conditions. For example, if potential damaging winds are infrequent to the area in question he can elect to use conventional (free-tab) shingles. On the other hand, the selection of wind-resistant shingles appears to be the logical choice if the building is located in a high wind area. The economics associated with these decisions will depend to a large extent on the actual wind conditions which occur subsequent to the application of the roofing.

This can best be visualized with the aid of the matrix shown in Figure 1.

Wind Conditions	Cost of Roofing	
	Choice A_1	Choice A_2
W_1	C_{11}	C_{21}
W_2	C_{12}	C_{22}

Figure 1. MODEL FOR DECISION PROCESS

The symbol C in Figure 1 represents the respective cost or loss associated with the decision makers choice in respect to the wind conditions to which the roofing may be subjected.

Let us assume that Choice A_1 is the more economical if wind conditions W_1 are frequently experienced in the Area. On the other hand choice A_2 appears to be the better one where wind conditions W_2 prevail. Costs C_{11} and C_{22} would represent the minimum expected costs while C_{12} and C_{21} would represent maximum expected costs associated with the decision makers judgement. In the cases where the decision maker correctly matches his choice to the wind conditions of the area, the maximum economic benefit will be attained.

The application of the decision process to the selection of the roofing system can be expressed on a cost-effectiveness basis. Let W_1 represent a wind condition where the <u>daily fastest observed one-minute wind speed</u> is less than 30 miles per hour and let wind condition W_2 represent a daily wind condition

in excess of the 30 mph value. Let Choice A_1 represent the selection of conventional (free-tab) asphalt shingles and Choice A_2 the choice of the wind-resistant variety.

A review of the 1965 local climatological data [7] for the Washington, D.C. area showed that the percentage of days the wind velocity fell below the 30 mph criterion was 91.8% while the value was exceeded on 8.2% of the days. This can be expressed as follows:

$$P(W_1) = .918 \text{ and } P(W_2) = .082$$

The cost associated with the action can be expressed by the regret matrix in Figure 2.

Wind Condition	Action Choice A_1 (Free-Tab)	Choice A_2 (Wind-Resistant)	
W_1 (< 30 mph)	C_{11} ($0)	C_{21} ($15)	$P(W_1)=.918$
W_2 (> 30 mph)	C_{12} ($300)	C_{22} ($15)	$P(W_2)=.082$

Figure 2. REGRET MATRIX

In areas where wind conditions W_1 are prevalent and Choice A_1 is made, the cost, C_{11}, to the decision maker is zero. Under similar wind conditions and Choice A_2 is decided upon the cost C_{21} is $15.00 per house or the additional cost of the wind-resistant roofing over conventional shingles. However, if under wind conditions W_2, Choice A_1 is made, the potential loss C_{12} is $300.00 per house, i.e., if the roof were heavily damaged by strong winds with subsequent damage to the building and its contents. The cost C_{22} associated with Choice A_2 is $15.00 per house and subsequent wind conditions do not vary this cost.

If the decision maker ignores or is unaware of local wind conditions in respect to the performance of asphalt roofing shingles, he may elect for various and sundry reasons to make either Choice A_1 all the time or to make Choice A_2 all the time. The expected costs $\bar{C}_1$ and $\bar{C}_2$ for always making Choices A_1 and A_2 respectively may be expressed as equations (1) and (2).

$$\bar{C}_1 = P(W_1)\ C_{11} + P(W_2)\ C_{12} \qquad (1)$$

$$\bar{C}_2 = P(W_1)\ C_{21} + P(W_2)\ C_{22} \qquad (2)$$ where:

$P(W_1)$ and $P(W_2)$ are fractions of the time when wind conditions W_1 (30 mph) and W_2 (30 mph) prevail in the selected location.

The costs associated with the decision makers choice may be calculated by substituting values given in Figure 2 in equation (1). If he selects conventional (free-tab) shingles all the time (Choice A_1) his cost is:

$$\bar{C}_1 = (.918)\ (0) + (.082)\ (300) = \$24.00 \text{ per house} \quad (3)$$

On the other hand, if he always chooses to use wind-resistant shingles his expected cost will be from equation (2):

$$\bar{C}_2 = (.918)\ (15) + (.082)\ (15) = \$15.00 \text{ per house} \quad (4).$$

Therefore if the assumptions made herein are correct the conclusion may be made that in the absence of an accurate long range forecast of wind conditions the only rational decision for the Washington, D.C. area is to use wind-resistant asphalt shingles all the time and accept the expected cost of \$15.00 per house as opposed to the expected ocst of \$24.00 per house if the choice of conventional shingles were made.

If it were possible for the decision maker to obtain perfect wind information for the area in question he would obviously choose conventional shingles when wind conditions W_1 were prevalent and the wind resistant type when wind conditions W_2 prevailed. Under these set of circumstances his cost ($\bar{C}_p$) can be expressed by equation (5).

$$\bar{C}_p = P(W_1)\ C_{11} + P(W_2)\ C_{22} \qquad (5)$$

By substituting values given in Figure 2 in equation (5) the cost is:

$$\bar{C}_p = (.918)\ (0) + (.082)\ (15) = \$1.25 \text{ per house.}$$

The cost of $1.25 per house based on perfect wind information would be $13.75 less than his best choice based on wind information obtained from climatology. In actual practice the decision maker will not be able to obtain perfect wind information since this product is not available, therefore he will probably make the more economical choice for his area if he uses the climatological data which is available from the ESSA's Weather Bureau for most localities.

5. SUMMARY

Economic, climatic and engineering data can be integrated by means of a decision process so as to serve as a guide in the selection of the more economical roofing system. In this report certain assumptions have been made which will not meet with universal agreement but are, nevertheless, necessary for such an analysis. For example, the 30 miles per hour criterion based on the daily fastest observed one-minute wind speed for conventional asphalt shingles is probably not realistic for all classes of asphalt shingles and, of course, the cost of the applied roof and the price differential between conventional and wind-resistant shingles will vary considerably from area to area.

The utilization of the decision process proposed herein and using values based on the best current information from engineering, economic, and climatological sources has shown that the use of wind-resistant shingles on residential structures in the Washington, D. C. area would effect cost economies. On the other hand the use of similar data available for other areas of the United States may indicate that the conventional shingles are the more economical choice.

The decision process provides a very useful tool to determine cost-benefit rations based on the climate, price structure including labor and materials, engineering properties and performance characteristics. For example, if the wind resistance of conventional asphalt shingles were improved by manufacturing processes or application procedures by increasing the value of the criterion from the assumed 30 miles per hour daily fastest observed one-minute mile to just 33 miles per hour, a toss of the coin would determine the most economical choice. Further if advances in material and/or labor costs increased the cost differential from $15.00 to $25.00 per house between the conventional and wind resistant types of shingles, the choice of either type would be optional on a cost-effectiveness basis.

In comparing cost-usefulness of using wind-resistant shingles in relation to exposure location, the analysis indicated that the wind-resistant shingles offer an economical advantage in those areas where the number of days the 30 miles per hour criterion is exceeded about 4% of the time.

On the other side of the coin the decision process indicated that the conventional shingles appeared to be the more economical choice when:

a) cost differential of wind-resistant shingles over the conventional type is greater than $25.00 per house (15 squares) or

b) criterion for wind damage exceeds the 33 miles per hour fastest observed one-minute wind speed, or

c) the fastest-observed one-minute wind speed criterion occurs less than 4% of the days of the year.

6. COMPLICATING FACTORS

The decision process used to assist in making a choice to use or not to use the wind-resistant asphalt shingles is much more complex than indicated herein. In actual practice many other factors play roles of varied importance in respect to the wind-resistance of asphalt shingles. For example, a number of the more important factors are:

a) type, weight and composition of shingle

b) the exposure, type and slope of roof deck

c) the number and placement of fasteners used to secure shingles to the deck

d) the age and temperature of asphalt shingles.

Ideally a probabilistic model should be constructed to take into account all of these factors. However, these factors are either inherently complex or their influence on the performance of a roofing in service is currently unknown. Therefore the development of a model will to include all these factors require a rather large effort both in the laboratory and in the field.

It should be noted that the complicating factors do not necessarily render our simple model useless. On the contrary, it provides the manufacturer, architect, roofing contractor or the home owner with a scientific method to assist him in making a proper and economical choice of a roofing system based on available economic, climatological and engineering information.

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