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TRANSLUCENCY OF MINERAL AGGREGATES FOR BUILT-UP ROOFS

BY

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LES AGREGATS MINERAUX TRANSLUCIDES POUR LES TOITURES MULTICOUCHES

SOMMAIRE

Les recherches se sont déroulées dans le cadre de la norme ASTM D 1866-64 qui prévoit l'examen d'éléments individuels d'agrégats à la lumière ultraviolette. L'auteur, utilisant la même source lumineuse et la même méthode d'interprétation photographique avec des couches d'agrégats d'épaisseurs graduées, a remarqué que des épaisseurs déraisonnables seraient nécessaires pour empêcher la pénétration de la lumière par les interstices. Il a de nouveau modifié la méthode en remplacant l'interprétation photographique par l'utilisation d'une cellule photoélectrique en vue d'obtenir une mesure quantitative de la lumière transmise. Le type de l'agrégat et son épaisseur déterminent le courant de la cellule photoélectrique et les chutes de tension subséquentes sont mesurées par un voltmètre sensible. Les résultats ont montré qu'une faible fraction seulement du rayonnement ultraviolet est transmise au travers des agrégats des épaisseurs utilisées normalement pour les toitures, et qu'il existait une différence de 0.03 pour cent entre les rayonnements transmis par le marbre blanc et le gravier. Les résultats montrent que les avantages de l'utilisation d'un agrégat de couleur blanche pour la réduction de la température de la toiture peuvent contre-balancer tout désavantage découlant de sa translucidité.

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Translucency of Mineral Aggregates for Built-Up Roofs

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ABSTRACT: The investigation involved the application of ASTM Method D 1866-64 by subjecting individual pieces of aggregate to an ultraviolet light source. Using the same light source and the same method of photographic interpretation but using graded aggregate layers, it was noted that unreasonable layer thicknesses would be required to prevent penetration of light through void spaces. The method was further modified by replacing the photographic interpretation with a phototube to obtain a quantitative measure of transmitted light. Aggregate types and thicknesses influenced phototube current and consequent voltage drops were measured by a sensitive voltmeter. Results show that only a small amount of ultraviolet light is transmitted through thicknesses normally used in roofing application with an approximate 0.03 per cent difference between white marble and gravel. Results suggest that the advantage of white aggregate in reducing surface temperature may outweigh any disadvantages from its translucency.

KEY WORDS: aggregates (roofing), translucence, ultraviolet light, membranes (bituminous), voids, absorption (light), temperature, evaluation

The influence of sunlight on roof surface temperatures and the wide seasonal temperature range experienced by bituminous membranes over insulated roof decks in Canada have raised the question of the suitability of light-colored translucent aggregates as protection on bituminous built-up roofs. Color has a definite effect on roof surface temperature, since it influences the absorption of solar energy. The action of the ultraviolet fraction of sunlight on roofing, however, is not clearly understood, although it is thought to be largely responsible for the photo-oxidative process of bitumen degradation.

A method for determining the ultraviolet light translucency of com-

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monly used roofing aggregates is described in ASTM Test for Translucency of Mineral Aggregates for Use on Built-Up Roofs (D 1866-64). This test was employed by the Atlantic Regional Station of the Division of Building Research in Halifax in examining some of the properties of the aggregates commonly available in that region. Forty-two individual pieces of aggregate were set with putty into holes in a brass plate and subjected to filtered light from an ultraviolet light source. The ultraviolet light passing through the aggregate samples was allowed to expose a photographic film for 60 min.

Using an apparatus constructed as specified in ASTM Method D 1866-64, conventional roofing gravel, marble, and air-cooled slag were examined. Sufficient quantities were used to permit grading according

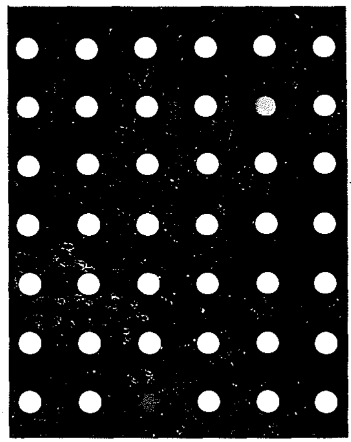


FIG. 1—*Photographic plate showing light transmission through marble aggregate.*

to ASTM Specifications for Mineral Aggregate for Use on Built-Up Roofs (D 1863-61 T). Tests for moisture and hardness were made according to the requirements of ASTM Test for Moisture in Mineral Aggregate for Use on Built-Up Roofs (D 1864-61 T) and ASTM Test for Hardness of Mineral Aggregate for Use on Built-Up Roofs (D 1865-61 T), and representative pieces were chosen from the graded portion for the translucency tests.

Figures 1 and 2 are exposed photographic plates representing light transmission through aggregate samples. It is clear from Fig. 1 that all the marble samples permitted light to pass through and exposed the film at the holes in the brass cover plate. The gravels and slags proved to be nontranslucent by this method, except for a few pieces

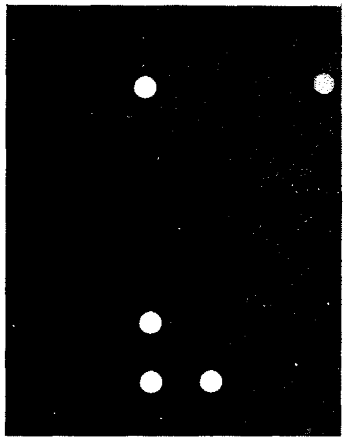


FIG. 2—*Photographic plate showing light transmission through gravel aggregate. Light penetrated quartz pieces contained in sample.*

of quartz that formed part of the gravel sample (Fig. 2). Three tests were conducted on each of four aggregate types. When the results were examined, however, it was concluded that the test method gave no quantitative results of practical use and took no account of the effect of gravel shape and void spaces in layers of aggregate.

Tests with Modified Test Box

A second series of tests was carried out to study the transmission through graded aggregate layers using a modification of the ASTM Method D 1866-64 (Fig. 3). A bakelite plate (4⅞ by 7 in.) was substituted for the brass plate of the ASTM apparatus. The holes in the bakelite were similar in size and location to those for the ASTM brass plate, and metal sides were provided to form a box (Fig. 4). This permitted the use of layers of graded aggregate of various thicknesses, including those corresponding to the usually specified thicknesses of 400, 350, and 300 pounds per square for gravel, marble, and slag, respectively. Ultraviolet light penetrating the aggregate layer in the box was allowed to expose a photographic film as in the ASTM test. By this method it was hoped that the thickness of aggregate required to stop the passage of ultraviolet light, regardless of translucency, might be determined.

In thicknesses up to 1 in., similar light transmission effects were observed for all the aggregates used, typical results being shown in Figs. 5 and 6. Unreasonable thicknesses, from a weight and cost point of view, would be required for all types to prevent penetration of ultraviolet light through the void spaces.

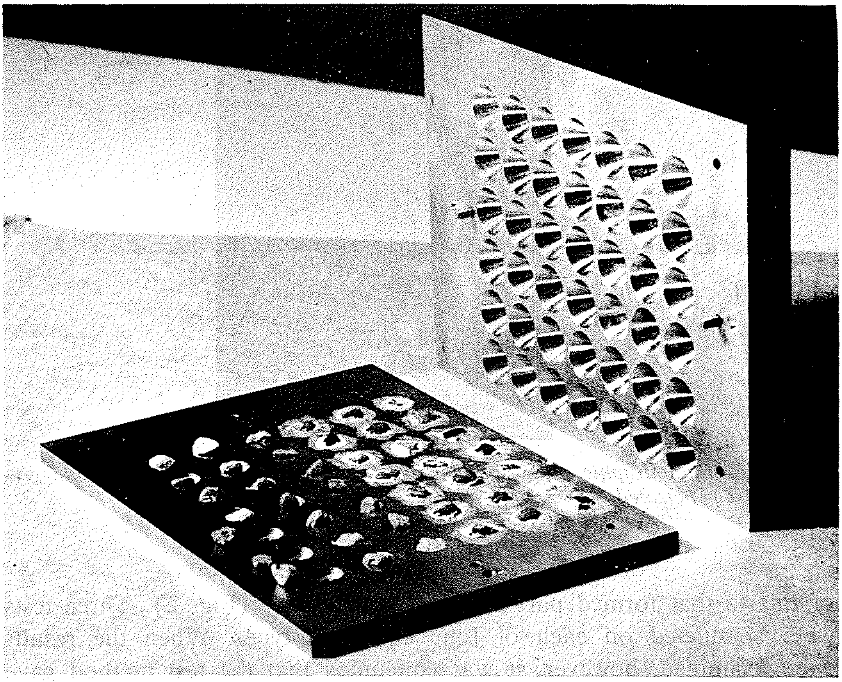


FIG. 3—*Perforated brass plate apparatus for ASTM Method D 1866-64, using individual pieces of aggregate.*

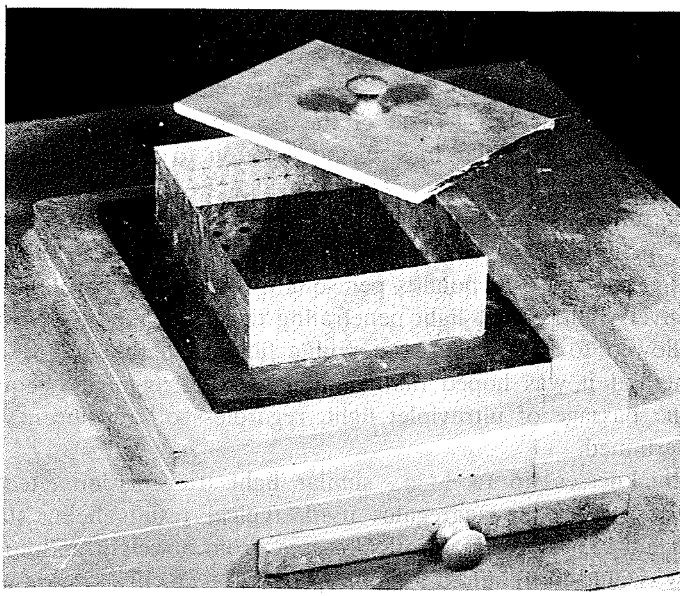


FIG. 4—*Perforated box allowing use of aggregate layers.*

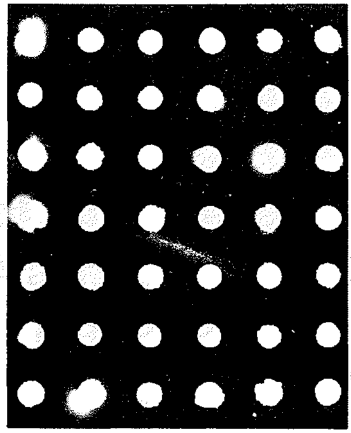


FIG. 5—*Light transmission through ½-in. layer of marble aggregate.*

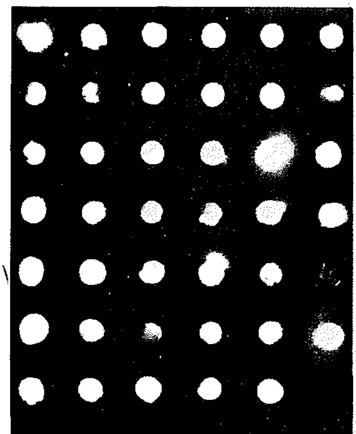


FIG. 6—*Light transmission through ⁹⁄₁₆-in. layer of gravel aggregate.*

Further Modification of ASTM Method D 1866–64

Having determined that the transmission of ultraviolet light through void spaces in layers of aggregate is of greater significance than transmission through individual pieces of aggregate, further modifications were made to the test apparatus. This was done to obtain a quantitative measure of the ultraviolet light transmission through layers of aggregate or through slabs of material.

The bottom of the test box was made of a 22-gage galvanized steel plate perforated with ¼-in.-diameter holes equally spaced and covering 44 per cent of the area to allow light to pass through (Fig. 7). Instead of the film used in previous tests, a tapered collector tube was made to direct the ultraviolet light passing through the test sample to an

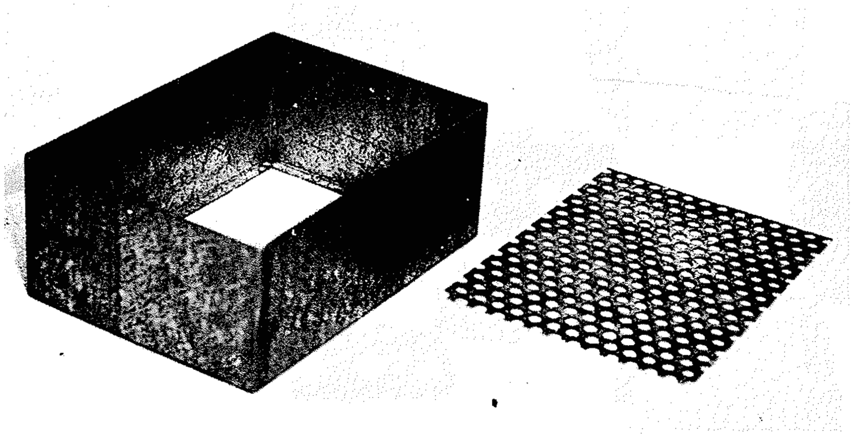


FIG. 7—*Sample box with bottom removed.*

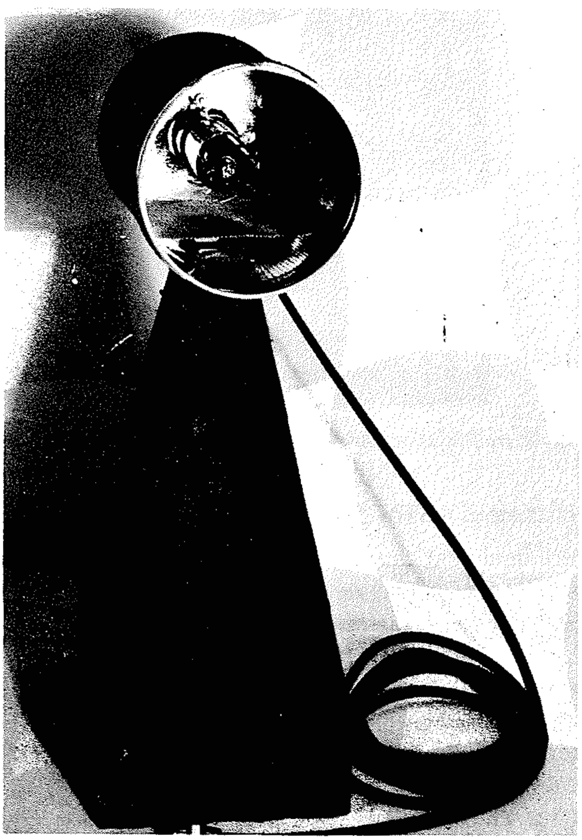
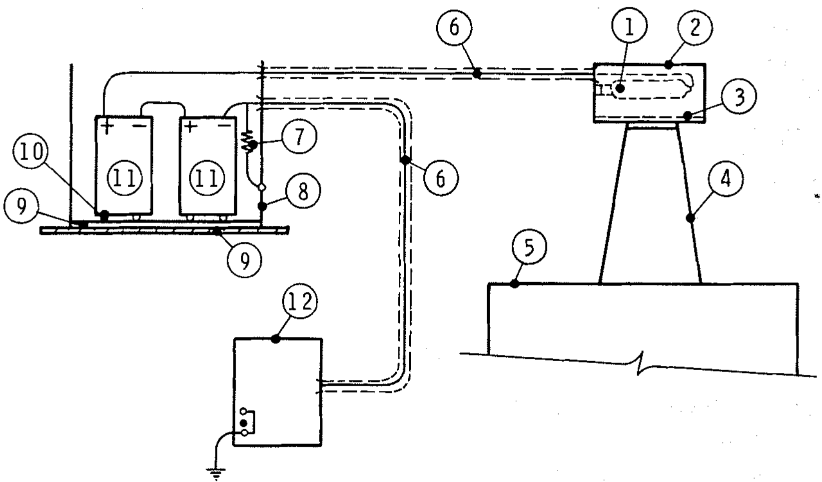


FIG. 8—*Tapered tube to direct ultraviolet light passing through sample to an opening under the phototube. Phototube enclosure shows brass screen over opening.*

opening under a phototube (Fig. 8) so that all stray light was included. The power supply and wiring were shielded to prevent electrical interference, and the opening in the metal can containing the phototube through which the collector tube directed the ultraviolet light was shielded with a brass screen.

A wiring diagram of the complete circuit is shown in Fig. 9. A No. 935 RCA phototube was chosen because of its relatively flat re-



(1) 935 RCA phototube
(2) Metal can as shield
(3) Brass screen over opening in can
(4) Light tube
(5) Light apparatus per ASTM D1866-64
(6) Shielded cable
(7) 2 megohm resistor
(8) Metal can
(9) Rubber insulating pad
(10) Alumina blocks
(11) 45v batteries (dry cell)
(12) Millivolt meter range 0-1000 mv
readable to 0.05 mv

FIG. 9—*Schematic diagram of ultraviolet light absorption measurement apparatus.*

sponse at anode voltages of 90 V; its range of maximum value (0.29 to 0.36 μm) corresponds quite well with the wavelength expected from the sunlamp and blue glass filter combination used in ASTM Method D 1866 (0.35 μm). The phototube is energized by the two 45-V dry-cell batteries; the current is passed through a series resistance of 2 megohms; and the voltage drop across the resistor is measured by a sensitive voltmeter.

The amount of ultraviolet light absorbed is influenced by the type of aggregate and the layer thicknesses. Changes in either result in changes in phototube current and consequently in the voltage drop across the 2-megohm resistor. This voltage is read by means of the millivolt meter and recorded for each change in thickness or type of material.

Theoretical Considerations

The intensity of radiation I passing through a uniform material of thickness t is related to the intensity of the entering radiation I_0 by the exponential law

$$\frac{I}{I_0} = e^{-\alpha t} \qquad (1)$$

This is commonly known as Lambert's law, and α is called the absorption coefficient.

Equation 1 can also be converted to the form

$$\frac{I}{I_0} = 10^{-\beta t} \qquad (2)$$

in which β is commonly referred to as the extinction coefficient.

When there is reflection at the surface, the intensity of the entering radiation I_0 is related to the incident radiation I^* by the relation

$$I_0 = I^*(1 - R) \qquad (3)$$

where R is the reflectivity of surface. By substitution in Eq 2

$$I = I^*(1 - R)10^{-\beta t} \qquad (4)$$

so that

$$T = \frac{I}{I^*} = (1 - R)10^{-\beta t} \qquad (5)$$

where T is the transmissivity of the sample.

When the described phototube circuit is used to measure the ultraviolet radiation, it is convenient to take the voltage drop across the resistor as a measure of ultraviolet intensity. Thus, when no sample is present the output voltage is proportional to I^*, and when a sample is interposed between the lamp and the phototube the output voltage is proportional to I. If it is assumed that the phototube current varies linearly with the ultraviolet intensity, the fraction of the incident radiation transmitted through a sample is the ratio of the output voltages with and without a sample.

Equation 4 indicates that log I should be a linear function of the sample thickness t, if the Lambert law is applicable to the type of sample being tested. Furthermore, if the log of the output voltage is a linear function of sample thickness, it indicates that the phototube response is linear as well as that Lambert's law is applicable.

Aggregate Screening

The samples to be tested were graded in accordance with ASTM Specifications D 1863-61 T. It was difficult, however, to obtain a uniform thickness of aggregate in the sample box, and all samples were further graded to pass a ⅜-in. sieve and be retained on a No. 4 sieve.

Test Procedure

The sunlamp was turned on, and the batteries were connected to the phototube at least 5 min before each test. The first reading (I_t) was taken on the millivolt meter with the dark slide in place, and the apparatus was assembled so that it shut off all light to the phototube. This reading was recorded. The dark slide was removed, letting the ultraviolet light pass through the perforated bottom of the empty sample box. This reading also was recorded as I^*.

A ½-in. layer of aggregate was placed in the box, and a meter reading was obtained with the dark slide removed to permit ultra violet light to pass through the sample; this reading was recorded as I. Aggregate was added in successive layers of approximately ¼ in., with meter readings taken at each stage to obtain an I-value for each thickness of the material until no difference was recorded between the readings taken with the dark slide in (I_t) and the total thickness of the sample with the dark slide removed (I).

Results

The results of tests made with eight different types of roofing aggregate and a ¼-in.-thick slab of white marble are shown in Fig. 10. The values plotted as corrected output of phototube are the actual measured values minus the output with the opaque slide in place. The scale on the right side of the figure gives the value of T directly. Although the results show some scatter, they are represented reasonably well by straight lines, so that the Lambert law is shown to be applicable and the linearity of the phototube output is confirmed.

The effect of voids can be seen by comparing the values for the marble slab and those for the layers of aggregate. The transmissivity of the ¼-in.-white marble slab is 0.0005 (Fig. 10). This means that the percentage of ultraviolet light transmitted is 0.05 per cent. An aggregate layer of the same material would have to be about ¾ in. thick to achieve the same percentage of ultraviolet light transmission. Note that at layer thicknesses of ¾-in. the difference in transmission between white marble and roofing gravel is only about 0.03 per cent. Even between silica and roofing gravel the difference in transmission is less than 1 per cent.

The results show that a small amount of ultraviolet light is transmitted through all of the materials tested at normal thicknesses of

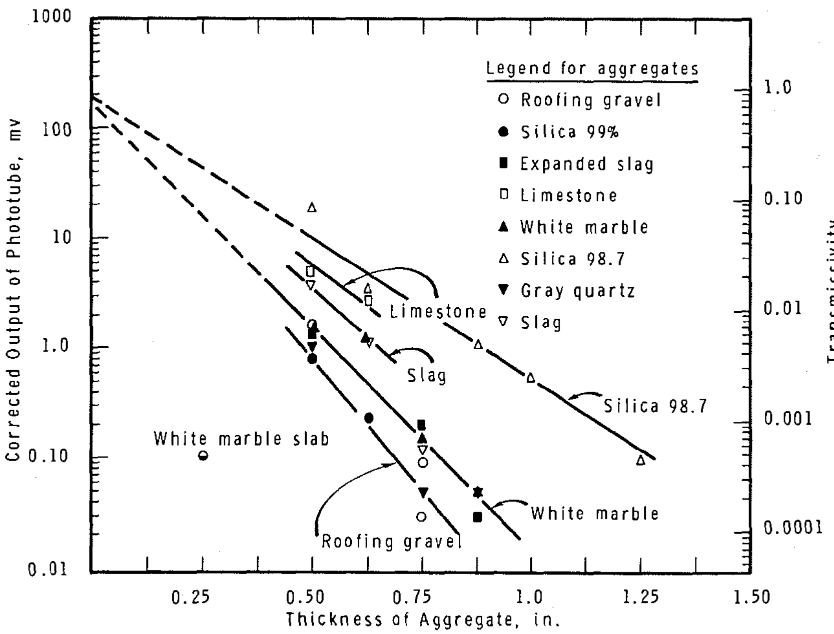


FIG. 10—*Results of tests on various materials.*

roofing aggregate. Note that white marble and silica samples would be classed as translucent when tested according to ASTM Method D 1866-64; whereas the others would be classed as opaque.

One basic difficulty in the test method may be noted; it arises from the practical difficulty of producing samples of granular materials with characteristics that change uniformly as thickness is increased. This is a physical impossibility, at least in some cases, when the maximum size of aggregate and the grading are held constant and only the thickness of the sample is changed. Results for thicknesses less than one diameter of the coarsest aggregate have no practical significance in the context of a uniform layer, and some critical changes are to be expected for thicknesses varying between one and two diameters of the coarsest aggregate.

Uniformity can only be expected from samples having thicknesses several times the diameter of the coarsest aggregate. Lambert's law cannot be expected to apply strictly to samples of thicknesses of the same order as the particle diameters. This does not invalidate the results measured for specific cases, but it does mean that the generalization of the results for all thicknesses from measurements on selected thicknesses, using Lambert's law, may be in error for samples having thicknesses of only a few particle diameters. This method should have application in the measurement of transmission through a wide range of materials in addition to roofing aggregates.

Conclusion

The results of these tests suggest that the translucency of white roofing aggregates may not be an important consideration in the protection offered bitumen against ultraviolet radiation. The actual amount of ultraviolet light passing through even highly translucent aggregates is very small, and for reasonable thicknesses of aggregate layers may even be insignificant. Until suitable evidence to the contrary becomes available, it seems reasonable to assume that the main advantage of white aggregate in reducing surface temperatures outweighs any slight disadvantage from ultraviolet translucency.

Acknowledgments

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