INTERLABORATORY COMPARISON OF COOL ROOFING MATERIAL MEASUREMENT METHODS

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ABSTRACT

The present study aims at investigating different methodologies and standards for measuring and calculating solar reflectance and infrared emittance, the two main properties characterizing cool roofing materials. In order to achieve this goal, an interlaboratory comparison testing has been set up among several laboratories that are members of the European Cool Roofs Council. The measurement methods practiced by the labs include measurement of the reflectivity by using spectrophotometers equipped with integrating spheres and reflectometers and measurement of the emissivity using different emissometer devices and FTIR spectrometers equipped with integrating spheres. Seventeen different samples representing the range of commercially available roofing materials and covering the full range of reflectance and emittance values have been selected and tested. The results of this study provide information on the suitability of the various methods to be used for cool roof products assessment. This work could potentially lead to the adoption of a European Cool Roof Standard.

KEYWORDS

Solar reflectance, infrared emittance, measurement standards, cool roofs, interlaboratory testing

1 INTRODUCTION

Cool roofs can give an important contribution to mitigate climate change, reduce the urban heat island effect and increase the sustainability of buildings. Cool roofs technology has long been applied in the U.S. where there are measurement standards related to cool roofs, it is a part of the energy code in many states, and organizations like the U.S. EPA Energy Star, the U.S. Cool Roof Rating Council, programs (e.g. LEED) and incentives are promoting it. Cool roofs technology is also applied and promoted in other countries around the world like Japan, Australia, Brazil, India etc. In Europe, the foundation of the European Cool Roofs Council (ECRC) has given an important boost in the cool roofs technology and market. The ECRC is a non-profit association aiming at developing scientific knowledge and research in relation to “cool roof" technology and promoting the the use of cool roof products and materials in Europe, including developing a product rating programme for such products and materials. The foundation of the ECRC was supported by the IEE Project “Cool Roofs” (IEE/07/475/SI2.499428).

One of the core objectives of the ECRC is the development of a Product Rating Programme, in which roofing product manufacturers will be able to label various roof products with radiative property values rated under a strict programme administered by the ECRC. Code bodies, architects, building owners and specifiers can have credible radiative properties data provided by the ECRC Product Rated Programme. The radiative properties that will be reported by this product rating program are the solar reflectance and the infrared emittance. There exist several measurement methods for the determination of the solar reflectance and the infrared emittance. They can be measured using portable instruments i.e. reflectometers and emissometers in accordance with procedures defined in the ASTM C1549 (2004), ASTM E1918 (2006), ASTM C1371 (2010) and EN 15976 (2011) standards. They can also be determined using spectrophotometric techniques described in several standards like ASHRAE 74 (1988), ASTM E903 (1996), ASTM E1585 (1993), CIE 130 (1998), EN 410 (1998), EN 12898 (2001), EN 14500 (2008) and ISO 9050 (1990).

In order to provide the ECRC with information regarding its product rating programme under development, an interlaboratory comparison (ILC) of the measurement methods of reflectance and emittance (emissivity) has been organised and conducted. The main objective of this ILC is to compare different measurement methodologies for measuring and calculating solar reflectance (SR) and infrared emittance (e), mainly ASTM and European (EN) standards, and provide information on their suitability to be used for cool roof products assessment. This paper describes the main aspects of this ILC and discusses the first results.

2 EXPERIMENTAL DETAILS

The following sections report the details of the samples that have been tested for this ILC and also the process and measurement methods that have been followed.

2.1 Sample description

A set of 17 samples that represents the range of commercially available roofing materials was selected to be measured by the labs like coatings, membranes, tiles, shingles and metal products. These samples were selected to cover the full range of reflectance and emittance values. Consequently, the selected samples include white and black, coloured and cool coloured, variegated, profiled and rough and smooth surfaced products. The details of samples used for the ILC are given in Table 1.

All product samples have been prepared following specific guidelines. More specifically, field applied coatings were applied on an aluminium panel at the minimum dry mil thickness or coverage recommended by the manufacturer for use in the field. Factory applied coatings were also applied on an aluminium panel. The rest of the products were not applied on a substrate and tiles were provided as full uncut tiles. The size for all the samples was 10cmx15cm, except for tiles that were provided as full uncut tiles. An additional set of samples at the size of 22cmx22cm was prepared to be used with a large integrating sphere by one of the labs. In total 275 samples have been prepared and were measured for the purpose of this ILC.

Table 1: The samples measured for the ILC

Product type	Sample description	Sample code	Characteristics
Coating	Waterborne elastomeric acrylic coating	S1	White, smooth
	Elastomeric waterproof coating	S2	NIR reflecting black, smooth
	Elastomeric waterproof coating	S3	Black, smooth
	Elastomeric waterproof coating	S4	NIR reflecting brown, smooth
	Aluminium-thermoplastic hydrocarbon based roof coating	S5	Aluminium, smooth
Asphalt membrane (modified bitumen)	Granulated bituminous membrane	S6	White, rough
	Granulated bituminous membrane	S7	Black, rough
	Granulated bituminous membrane	S8	Green, rough
Shingle	Multicoloured asphalt shingle	S9	Red, rough
Single ply membrane	FPO membrane	S10	White, smooth
Concrete tile	High profile multi-colour coated tile	S11	Multicoloured, profiled, Rough
	Curved profile tile, monocolour	S12	Profiled, smooth
	Flat monocolour tile	S13	smooth
Metal roof	Prepainted metal	S14	Silver, smooth
	Prepainted metal	S15	Dark brown, slight textured finish
	Prepainted metal	S16	Off white, Smooth
	Bare pretreated metal	S17	Silver, Smooth

2.2 ILC participating labs and instrumentation

In total 12 Labs have participated at the ILC. The instrumentation used by the labs includes spectrophotometers equipped with integrating spheres of 150mm diameter, reflectometers and two portable emissometers (the Devices and Services Emissometer and the INGLAS TIR100-2 referred to as EN 15976 emissometer). Measurements were also performed using a spectrophotometer with an integrating sphere of 75cm diameter by one lab. Table 2 includes a short description of the labs and the instrumentation availability.

Table 2: The samples measured for the ILC

	Spectrophotometer	Reflectometer	ASTM C1371 Emissometer	EN 15976 Emissometer
Lab 1		x	x	
Lab 2		x	x	x
Lab 3	x		x	
Lab 4	x		x	
Lab 5		x	x	
Lab 6	x		x	
Lab 8	x		x	
Lab 9	x	x	x	

Lab 10	x	x	
Lab 11	x	x	
Lab 12			x

In order to minimize efforts and sample distribution costs, two measurement rounds (6 labs performing the measurements in each round) have been carried out using the same sets of samples.

3 MEASUREMENT METHODOLOGY

The two radiative properties that were measured by the labs were the solar reflectance and the infrared emittance. The different measurement methodologies followed by the labs are described in the following sections.

3.1 Solar reflectance

The solar reflectance was measured and/or calculated in two different ways:
a) Spectrophotometer with an integrating sphere
Measurements were conducted according to ASTM E903 (1996) or EN 14500 (2008). The solar reflectance was then calculated using all the following reference solar spectra:

- ✓ ASTM E891-87 (1992) or ASTM G159-98 (1998)
- ✓ ASTM Standard G173-03 (2008)
- ✓ CIE 85-1989 (The reference solar spectrum given in EN 410 (2011) – Glass in building. Determination of luminous and solar characteristics of glazing)

b) Reflectometer
Measurements were conducted according to ASTM C1549-04 (2004)
The solar reflectance of variegated products was determined according to the methodology described in the CRRC-1 Method #1: Standard Practice for Measuring Solar Reflectance of a Flat, Opaque, and Heterogeneous Surface Using a Portable Solar Reflectometer (CRRC-1 Standard, 2008).
The solar reflectance of tiles was determined using either the CRRC-1 Method #1 or the Template method as described in the CRRC-1 Standard (2008).

3.2 Infrared emittance

The infrared emittance was measured in two different ways:

a) D&S Emissometer
Measurements were conducted using equipment and procedures in accordance with ASTM C1371 (2010).

b) EN 15976 emissometer
Measurements were conducted using equipment and procedures in accordance with EN 15976 (2011)

4 ILC RESULTS

4.1 Homogeneity test

In order to check for any inhomogeneities between the samples to be tested by the labs, an initial characterisation of their radiative properties was performed by 4 labs using one of the methods for determining SR and e. More specifically, all the samples per product type were measured by a single lab.

The homogeneity of the samples was determined and checked using the statistical criteria according to ISO13528 (2005). The samples that were found to present inhomogenities were replaced by new ones. The final homogeneity check showed that the set of samples to be measured was suitable for the ILC.

4.2 Solar reflectance evaluation

The first step of the statistical analysis consisted of detecting and removing outlier data (ISO Guide 43, 1997). The Grubb's test (significance level equal to 0.05) was used to determine whether the larger or smaller observation in a set of data is an outlier. Five outliers were detected and removed from the datasets corresponding to the spectrophotometric measurements and three outliers were detected and removed from the datasets corresponding to the reflectometer measurements.

a) Spectrophotometer measurements:

Measurements with spectrophotometers equipped with integrating spheres were performed according to ASTME903 (1996) and the solar reflectance was calculated using the solar spectra mentioned in section 3.1.

The average values (AVG), standard deviation (STDEV) and coefficient of variance (C.V.) for solar reflectance values have been determined for each sample and are reported in Table 3. N represents the number of labs that have measured the specific sample.

Table 3: The results of the statistical evaluation of the solar reflectance measured according to ASTME903(1996)

Samples	N	Total Solar Reflectance (TSR) (ASTME903)									ΔSR	
		E891			G173			EN410			E891 – G173	E891 – EN410
		AVG	STDEV	CV	AVG	STDEV	CV	AVG	STDEV	CV		
S1	6	86	1.11	0.01	85	0.67	0.01	83	0.99	0.01	1	3
S2	7	21	2.07	0.10	20	0.98	0.05	18	0.54	0.03	1	3
S3	7	4	0.38	0.09	4	0.36	0.08	4	0.41	0.10	0	0
S4	7	42	1.72	0.04	40	0.97	0.02	38	0.54	0.01	2	4
S5	7	76	2.16	0.03	76	1.97	0.03	76	1.94	0.03	0	0
S6	7	31	1.29	0.04	31	1.04	0.03	31	1.24	0.04	0	0
S7	7	6	0.49	0.08	6	0.42	0.07	6	0.43	0.07	0	0
S8	7	11	1.11	0.10	10	0.80	0.08	10	0.54	0.05	1	1
S9	7	16	1.00	0.06	15	0.92	0.06	15	0.78	0.05	1	1
S10	6	86	1.33	0.02	86	0.83	0.01	85	0.56	0.01	0	1
S12*	4	30	2.83	0.09	28	0.97	0.03	27	0.63	0.02	2	3
S13*	3	38	2.00	0.05	36	1.26	0.03	35	0.59	0.02	2	3
S14	6	51	1.63	0.03	51	0.73	0.01	50	0.72	0.01	0	1
S15	7	13	0.49	0.04	13	0.41	0.03	13	0.42	0.03	0	0
S16	6	53	1.03	0.02	53	0.58	0.01	52	0.64	0.01	0	1
S17	7	57	3.10	0.05	57	3.22	0.06	57	3.07	0.05	0	0

A first observation from this work is that profiled and variegated tile samples cannot be measured with a spectrophotometer. The samples S12 and S13 represent a monocolour profiled and a monocolour flat tile. Four of the participating labs have cut smaller pieces of the full uncut tiles in order to be able to place them in the spectrophotometer port. These results are only indicative (marked with an asterisk in Table 3) and further investigation is necessary to explore the possibility of a spectrophotometer to accurately measure variegated and profiled products if smaller and flat samples are provided.

The differences in the average TSR values calculated with the three different solar spectra were also calculated for each sample and are included in Table 3. It was found that the highest differences were observed between the ASTM E891 and the EN 410 solar spectra. Also, the highest difference was observed for the sample S4 which is a near infrared reflective brown coating. This can be explained if we examine the spectral characteristics of the different spectra summarised in Table 4.

Table 4: Summary of the three solar spectral irradiances specified by the two ASTM and the CIE standards.

Standard	Description	NIR (%)
ASTM E891-87 (1992)	Hazy sky AM1.5 beam-normal irradiance	58.1
ASTM G173-03 (2003)	Clear sky AM1.5 beam-normal irradiance	54.3
CIE 85(1989)	Global radiation, AM1	49.5

The NIR solar irradiance (700-2500nm) as calculated for the ASTM E891 is by 8.6%NIRSR higher than that of the CIE standard, which explains the higher differences observed between the two standards and the fact that a higher difference was observed for the NIR reflective sample. It is obvious that the choice of the solar spectrum for the calculation of solar reflectance affects the calculated SR value especially for spectrally selective materials. It should be pointed out however that the observed differences are lower or equal to the total uncertainty quoted in the ASTME903, which is equal to ±3-4%TSR and includes potential differences from the use of different solar spectra.

Finally, an average standard deviation for each calculation method (E891, G173 and EN410) was evaluated as 1.5%TSR, 1%TSR and 0.9%TSR respectively. This result demonstrates that there is a very good inter-laboratory agreement when using the same method and calculation procedure since these errors fall well within the expanded uncertainties quoted in the ASTM E903 standard (total uncertainty according to ASTME903 equals with ±3-4%TSR).

b) Reflectometer measurements:

The solar reflectance of the samples was also measured by using a reflectometer according to the ASTM C1549 by four labs. The average values (AVG), standard deviation (STDEV) and coefficient of variance (CV) for solar reflectance values have been determined for each sample and are reported in Table 5. The average standard deviation of all the measurements is 0.87%TSR indicating a good inter-laboratory agreement when using this measurement method.

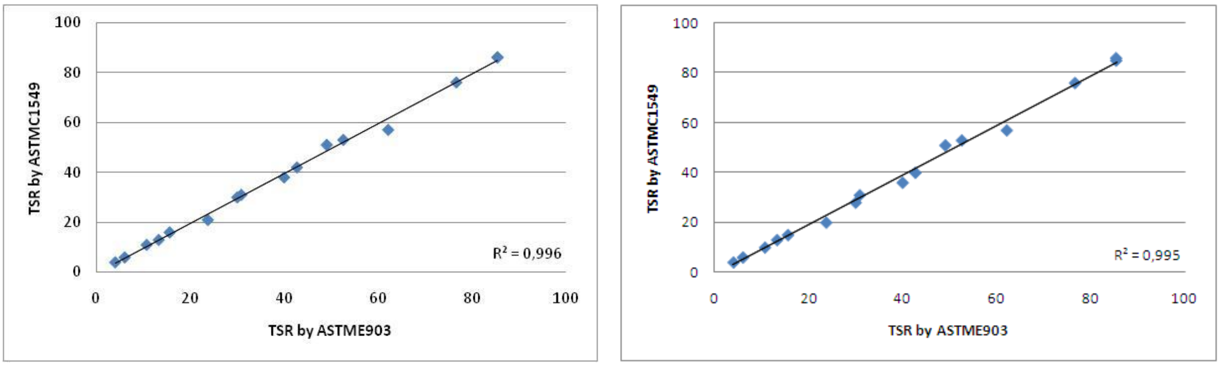
The results of the reflectometer measurements were compared with the results obtained with the spectrophotometer. The difference in the solar reflectance values obtained with the two standards (ASTM C1549 and ASTM E903) is also reported in Table 5. The highest absolute differences between the two methods were observed for the NIR reflective black sample (S2) and the bare aluminium sample (S17) and were equal to 3 and 5%TSR respectively. It should be pointed out though that the observed differences are comparable to the measurement methods' uncertainty which is estimated to be about 4%TSR.

In addition, the relation between the determination of TSR by reflectometer (ASTM C1549) and spectrophotometer (ASTM E903, using the solar spectrum of a) ASTM E891 and b) ASTM G173) are shown in Figure 1. The data show that although there are differences as great as 5% in the absolute values achieved using the two different methods on the same samples, the overall trends are very similar. The regression analysis gave an R^2 value of 0.996

when the ASTM E891 solar spectrum was used and an R^2 value of 0.995 for the ASTM G173 solar spectrum. The results indicate a strong and positive correlation between the two test methods.

Table 5: of the statistical evaluation of the solar reflectance measured according to ASTM C1549 (2004)

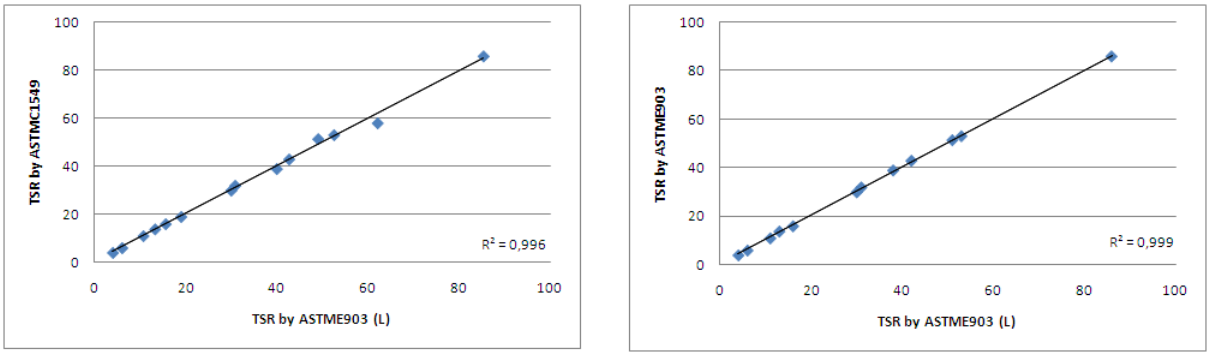
Samples	N	Total Solar Reflectance (ASTMC1549)			E903 - C1549
		AVG	STDEV	CV	
S1	4	85	1.94	0.02	1
S2	4	24	1.50	0.06	-3
S3	4	4	0.00	0.00	0
S4	3	43	0.98	0.02	-1
S5	4	77	1.04	0.01	-1
S6	4	31	1.31	0.04	0
S7	4	6	0.05	0.01	0
S8	4	11	0.48	0.04	0
S9	4	16	0.44	0.03	0
S10	4	85	0.53	0.01	NA
S11	4	19	1.24	0.06	1
S12	3	30	0.00	0.00	0
S13	3	40	0.00	0.00	-2
S14	4	49	0.35	0.01	2
S15	4	13	0.49	0.04	0
S16	4	53	0.49	0.01	0
S17	4	62	4.03	0.06	-5



a) b)

Figure 1: Relation between the estimate of TSR by reflectomer (ASTMC1549) and spectrophotometer (ASTM E903, using the solar spectrum of a) ASTM E891 and b) ASTM G173)

Finally, comparing the TSR results for the samples obtained by the lab that has used the spectrophotometer with the large diameter integrating sphere with the average TSR values obtained by the labs using the small diameter integrating spheres, it was observed that the absolute differences between these values range between 0-1.1%TSR. The comparison of the TSR results for the samples obtained by the spectrophotometer with the large diameter integrating sphere with the average values obtained with the ASTMC1549 range between 0-4%TSR. These results and the R^2 values calculated (Figure 2) indicate a strong correlation between these test methods.



a) b)

Figure 2: Relation between the estimate of TSR a spectrophotometer with a large diameter integrating sphere (ASTM E903(L), using the solar spectrum of ASTM E891 and a) by reflectometer (ASTM C1549) and b) by a spectrophotometer with a small diameter integrating sphere (ASTM E903, using the solar spectrum of ASTM E891)

4.3 Infrared emittance evaluation

The first step of the statistical analysis consisted of detecting and removing outlier data (ISO Guide 43, 1997). The Grubb's test (significance level equal to 0.05) was used again to determine whether the larger or smaller observations in a set of data are an outlier. Three outliers were detected and removed from the datasets corresponding to the measurements with the D&S emissometer and two outliers were detected and removed from the datasets corresponding to the EN15976 measurements.

Table 6 contains the measurement results for the 17 samples as well as the average (AVG), standard deviation (STDEV) and the coefficient of variation (CV) that have been calculated from the different labs, for each method. N indicates the number of labs that have the performed the specific measurement on the specific sample.

The standard deviations range from 0.01 to 0.04 emittance units for the measurements of the emissivity with an average standard deviation of ±0.02. When considered in the context of the determined expanded uncertainty for this procedure (calculated at ±0.04 emittance units), the data indicate that there is good consistency in the measured thermal emissivity between the participating laboratories.

Also, as it can be observed few labs were able to measure the emissivity of the profiled tile samples. These measurements present several difficulties. First these are low conductivity samples and because they are large they cannot be applied on the D&S emissometer heat sink. Second, for the profiled tiles, the detector of the emissometer is not completely in contact with sample as there is not a wide enough flat area on the sample to perform the measurement correctly. For the first problem there exist a method called the "slide method" that is proposed by the manufacturer and it was followed by the labs. For the second problem, there is a special adapter that can be used that provides a smaller port size reducing errors due to the non-flat surface geometry by permitting good contact of the detector and sample. The remaining error due to the cylindrical shape can then be approximately corrected. Not all the labs were equipped with this adapter. The EN15976 emissometer is not fit for measuring low conductivity and profiled samples and only one lab tried to perform the measurement with instrument. This explains the high differences in the emissivity values measured by the two standards for the Samples S11 and S12

Finally, the relation between the determination of e by the ASTM C1371 and the EN 15976 is shown in Figure 2. The data shows that although there are differences as high as 0.08 in the absolute emissivity values achieved using the two different methods on the same samples, the overall trends are quite similar. The regression analysis gave an R^2 value of 0.991. The results indicate a strong correlation between the two test methods. This means that both standards can be used to measure the emissivity of flat roof products.

Table 6: Results of the statistical evaluation of the infrared emittance measured according to the ASTM C1371 and the EN 15976

Samples	Infrared emittance (e)								Δe
	ASTMC1371				EN15976				ASTMC1371 – EN15976
	N	AVG	STDEV	CV	N	AVG	STDEV	CV	
S1	9	0.88	0.03	0.03	3	0.91	0.01	0.01	-0.03
S2	10	0.87	0.03	0.03	3	0.90	0.01	0.01	-0.03
S3	9	0.90	0.01	0.01	3	0.93	0.02	0.02	-0.03
S4	9	0.88	0.01	0.02	3	0.89	0.01	0.01	-0.01
S5	10	0.24	0.04	0.16	3	0.19	0.02	0.11	0.05
S6	9	0.89	0.02	0.03	3	0.93	0.03	0.03	-0.04
S7	9	0.87	0.02	0.03	3	0.92	0.01	0.01	-0.05
S8	9	0.91	0.02	0.03	3	0.95	0.01	0.01	-0.04
S9	9	0.91	0.02	0.02	2	0.95	0.00	0.00	-0.04
S10	9	0.88	0.02	0.02	2	0.93	0.00	0.00	-0.05
S11	4	0.90	0.03	0.03	1	0.97	NA	NA	-0.07
S12	5	0.92	0.03	0.03	1	1.00	NA	NA	-0.08
S13	6	0.83	0.02	0.03	2	0.83	0.01	0.02	0
S14	9	0.71	0.04	0.06	3	0.67	0.02	0.02	0.04
S15	9	0.86	0.01	0.01	3	0.90	0.02	0.02	-0.04
S16	9	0.85	0.02	0.03	3	0.89	0.01	0.01	-0.04
S17	8	0.06	0.01	0.24	3	0.05	0.02	0.33	0.01

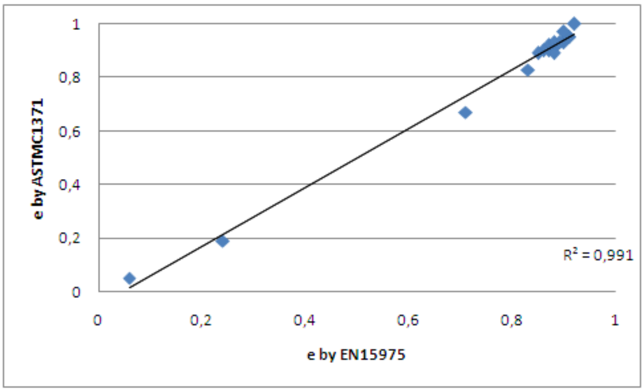


Figure 3: Relation between the determination of emissivity by the ASTM C1371 and the EN 15976.

5 CONCLUSIONS

This paper presents the results of an interlaboratory comparison aiming at investigating the suitability of different measurement methods and standards in determining the radiative properties, *i.e.* the solar reflectance and infrared emittance, of roofing materials. Regarding the measurement of reflectance using a spectrophotometer equipped with an integrating sphere and the differences in the average TSR values determined by using three different solar irradiance spectra (ASTM E891, ASTM G173 and EN 410), it was found that the observed differences are in the range of 0-4%TSR and they are more important for spectrally selective materials. These differences contribute to the total uncertainty of the measurement method indicating that the use of single solar spectrum would provide comparable and “fair” results in the framework of a product rating programme. It was also found that profiled and variegated tile samples provided as full uncut tiles cannot be measured with a spectrophotometer. Further investigation is needed to assess the suitability of spectrophotometers in measuring the TSR of variegated and profiled samples if smaller dimension samples are provided. The regression analysis performed gave a strong correlation between the TSR determined by a spectrophotometer (ASTM E903) and a reflectometer (ASTM C1549). A strong correlation was also found between the determination of TSR with a spectrophotometer with a large diameter integrating sphere and by both reflectometers (ASTM C1549) and spectrophotometers with ~~a~~ small diameter integrating sphere. The ASTM C1371 and EN 15976 standards give comparable results for infrared emittance of flat roof products

6 ACKNOWLEDGEMENTS

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