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Comparison of Measured and Calculated Heat Transfer Coefficient of External Wall at the Mechanical Engineering Faculty University in Sarajevo

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Abstract **– Aim of the research was measuring the heat transfer coefficient of the external walls at the Mechanical Engineering Faculty building with heat flow method, in order to obtain the real value of heat transfer coefficient. After performing the measuring according to the ISO 9869 for in-situ measurement, the average measured heat transfer coefficient was 0.23 W/m^{2}K, which is lower value compared to the calculated one, 0.33 W/m^{2}K, according to the program (KiExpert). Difference between values is the result of limitations in selection of materials and because heat accumulation in building elements is not sufficiently considered in algorithms of the program.**

Keywords **– building, external walls, heat flow method, heat transfer coefficient.**

1. Introduction

Thermal performance of building envelops is rarely validated after construction. One reason for this is that the current methods are either time consuming, costly or have low accuracy. Instead, new buildings are generally evaluated by indicators which are solely based on the architectural drawings together with assumptions regarding local weather conditions, occupant's behaviour and performance of heating systems, such as the specific final energy use. Such indicators seldom agree with the monitored energy performance after the building is built [1]. In the last years many studies concerning the evaluation of the thermal conductance of building elements via measurements have been carried out, with the aim to allow a more accurate evaluation of the real heating energy demand of a building [2].

Heat transfer coefficient or U-value, represents significant factor in the civil engineering and industry, determining thermal performance of the building envelope and representing the basis for calculation of the necessary energy for heating and conditioning, related to achievement of inside thermal comfort [3],[4]. Heat transfer through the envelope elements depends on several factors like: physical characteristics of materials which make the building structure (for example flat or cylindrical rounded walls etc.), quality of performed works, air permeability, vapor permeability, thermal bridges etc [3],[5].

Energy performance of the building and corresponding heat transfer coefficient in accordance with the standard ISO 9646 can be calculated by analytical method assuming that are known the values of the embedded materials (order, thickness and structure) and the environmental conditions. For new buildings, values that are related to the thermo-physical characteristics can be obtained directly from the producer, but for older buildings, these data are uncompleted, missing or there has been change in the characteristics over time. Methods that are recommended by standard are mostly based on the assumption of ideal conditions, although some small corrections of these values are predicted for some cases. Methods do not take into account variations due to the temperature differences of outside and inside air temperature, wind speed, sun radiation, different heat loads and air conditioning systems that

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change parameters of relative humidity, inside air and wall temperature, as well as irregularities in terms of the inadequacy of the applied material quality, possible inadequate installation or different possible degradation effects of thermal characteristics of the embedded materials [3],[4].

Due to the all above, significant differences can occur between calculated and actual heat losses of the building or building parts, which further results in calculation errors and may result in an incorrect assessment of the energy performance of the building [4].

2. Measurement of the heat transfer coefficient with *in-situ* method

In situ measurements of low thermal transmittance façades are required to ensure compliance with energy performance strategies for new nearly zero-energy buildings (nZEB) and with energy policies for the transition of existing building stock to nZEB [6]. Measurement of heat transfer coefficient *in-situ* theoretically is considered as simple method, but during the experimental research there are many factors, as meteorological and practical differences, which can cause significant errors and uncertainty. In practice, measurement of heat transfer coefficient of embedded structures is not simple, because thermal mass, variation of daily outside temperature, direct sun radiation, precipitation and other outside climatic conditions do not allow establishing stationary conditions for heat transfer.

In the building, different heat loads and heating systems influence on physical parameters of relative humidity, inside air and wall temperature. To achieve relevant reliable measurements, it is necessary to perform measurements during specific period and the duration of measurement directly depends on specific heat capacity of the construction, weather conditions or more precise, on everything that can finally influence the heat flux during measurement period.

Final heat transfer coefficient represents mean value of performed measurement. Measurement of heat transfer coefficient under real conditions can show significant different values in comparison with the data by calculation method. The reason is not only because of measurement reliability, but also due to the different behavior in laboratory conditions [4],[7],[8].

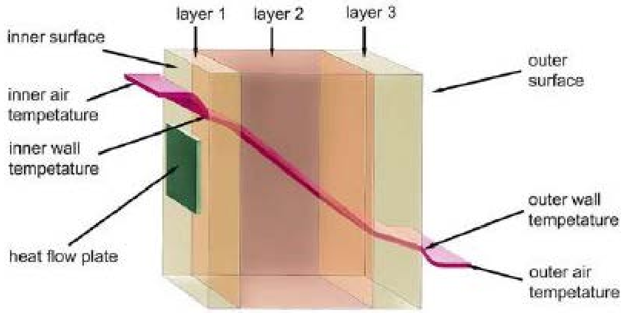

Figure 1. Illustration of the heat flow plate on the wall and parameters – indoor air and wall temperature, outside air and wall temperature.

3. Measurement of the heat transfer coefficient of the external wall at the Mechanical Engineering Faculty, University in Sarajevo

Measurement of the heat transfer coefficient of the outer wall is performed with the aim to determine real heat transfer coefficient, in real ambient conditions and based on existing wall characteristics of the Faculty building. As it is mentioned earlier, existing construction condition is influenced by several factors, as building age, characteristics of embedded materials, climatic factors which daily affect construction, thermal insulation of the building, quality of performed works etc. Measured heat transfer coefficient of the wall is compared to the coefficient calculated in the program KiExpert 2011, based on the referent values, meteorological data that are entered in the program and selected characteristics of materials from the material menu. Beside heat transfer coefficient, the outside air and the wall temperature were also measured as well as the inside air and the wall temperature. Program KiExpert is used for calculation of specific energy needs for heating and air conditioning of the building.

For calculation of heat transfer coefficient of the external wall, an office on the fifth floor of Mechanical Faculty was chosen, north oriented according to the recommendation of ISO 9869, due to the lower influence of sun radiation. The office in which the measurement was performed is being used mostly from 08:00-15:00 h, five days per week, depending on the schedule of the user. Heating of the building start at 06:00 AM and is turned off at 15:00 PM. Because the measurement period should be in accordance with the ISO 9869, measuring of the mentioned parameters lasted from 28th February till 22nd March 2017 and it is divided into three measurement periods.

4. Description of the measurement equipment

With ALMEMO measurement system for measurement heat transfer coefficient, it is possible to measure and record all physical parameters of existing building parts (for example walls) to calculate their heat transfer coefficient and other relevant energy performances.

Measurement is based on the method in which heat flow plate is used, mounted on the inside building surface, parapet, and in that way directly connected with the heat flow. Using known thermal characteristics of the plate and the measured temperature gradients within the pressure plate, the ALMEMO measuring system measured the heat flow density. In addition, it is used for measurement of temperature on the both sides of the external wall and inside and outside air temperature. Based on the obtained results, calculation of all relevant heat coefficients is feasibile.

5. Measurement conditions

To ensure reliable calculation of heat transfer cofficient of the wall, measurement should be performed under specific conditions:

- Measurement uncertainty is reduced if the temperature of the internal surface is kept constant as much as possible and the difference between indoor and outdoor temperature is higher than 10 ℃ [5].
- Any temperature fluctations (for example day/night) during measurement period should be minimum. Unlike the summer time, outside temperature fluctations during colder days are more relevant, because average difference between outside and inside surface temperature is generally higher.
- Measured values should be recorded on the location for long enough time (for example one whole day or several days). Parameters are being calculated based on the mean values.

6. Measurement methodology

Heat exchanger (250x250x1,5 mm with epoxy resin substrate) and four thermocouples for measurement of inside and outside wall temperature and inside and outside air temperature are connected with the logger, where data were recorder every 180 seconds. To avoid surface damage, sensors are fixed with paper adhesive tape, which color is similar to the wall surface color. The heat flow meter is mounted on the inside wall surface, centered between the openings, corners, floor and ceiling. Temperature sensors used for measurement of air and wall temperature are mounted near the heat flow plate, while the temperature sensors for measurement of outside wall and air temperature are mounted on the outside wall in the same position as the heat flow plate and secured from the sun radiation. According to the standard ISO 9869:1994, north façade is preferred due to reduced uncertainty related to the sun's radiation or it is necessary to protect external sensors with a small shield made of paper adhesive tape.

Since the inside air temperature oscillates due to the heating schedule and natural ventilation of the room, additional heater was used to establish stable inside temperature.

In Table 1. are shown layers of the outside wall, on which measurement of parameters was performed. Wall layers are selected from the KiExpert material menu. According to the specific characteristics of the wall, from the aspect of the maximum permissible heat transfer coefficient for external wall, U=0.45 W/m^2K, by Regulation on technical requirements for thermal protection of buildings and rational use of energy of the Federation of Bosnia and Herzegovina, the criteria for external wall is satisfied with the heat transfer coefficient of 0.33 W/m^2K [9].

Table 1. Layers of an external wall at the Mechanical Engineering Faculty according to the KiExpert

layer	d cm	λ W/mK	R m^2K
limestone cement	2.00	1.00	0.02
clay bricks	25.00	0.81	0.30
limestone cement	2.00	1.00	0.02
EPS	10.00	0.04	2.50
silicate plaster	1.00	0.90	0.01

7. Analysis of the measurement results

In Figure 2. are shown the measured values of heat transfer coefficient, outside air and wall temperature, inside air and wall temperature, for the period from 28th February to 22nd March 2017.

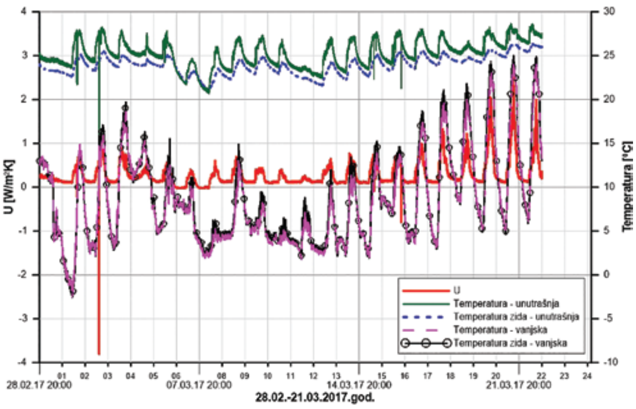

Figure 2. Measured values of heat transfer coefficient, inside air and wall temperature, outside air and wall temperature (28th February – 22nd March 2017).

In the next chapters, measurement results for the three measurement periods will be analyzed.

Analysis of the first measurement period

In Figure 3. are shown the measurement results for observing parameters for the first measurement period. The first measurement period has lasted from 28th February till 7th March 2017.

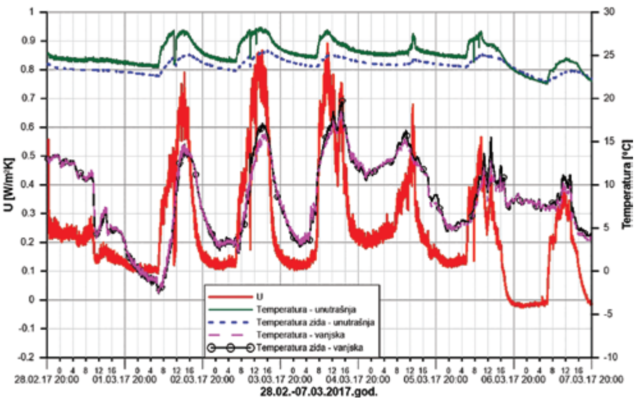

Figure 3. Measured values of heat transfer coefficient, inside air and wall temperature, outside air and wall temperature (28th February – 7nt March 2017).

During the first measurement day, inside air and wall temperature were linearly in the continuity without large oscillations, while the outside temperature of the air and wall gradually decreased during the day, with the average measured air temperature of 7.7 °C. Heat transfer coefficient followed the growth and the dropping of the temperatures. Average value of heat transfer coefficient from the first measurement period was 0.18 W/m^{2}K. Every morning at 6:00 AM, when the heating is on according to the schedule, air temperature increases, outside air temperature in that period also gradually increases, which affects the growth of wall's heat transfer coefficient. On the second measurement day, at 11:00 AM, significant fluctation of inside air temperature and heat transfer coefficient was observed, more precisely sudden fall and growth of the curve due to the opening and closing of the windows.

In the period when outside temperature drops, heating is switched off from 15:00 PM, at night period and during cloudy days, the heat transfer coefficient also decreases. During the night, the value of heat transfer coefficient was in the range 0.11-0.24 W/m^{2}K, depending on the differences between inside and outside temperature.

From 6th March till 8th March, a significant fall of heat flow coefficient was noticed, although the average inside-outside air temperature was 15 °C.

Average temperature difference for the first measurement period was 16.7 °C. Since ALMEMO recommends that for the accuracy of the measurement, inside-outside temperature difference should be around 20 °C, according to the average temperature difference for the first measurement period, that criteria is not satisfied and the first measurement period will not be analyzed for calculation of the real heat transfer coefficient of the external wall. Beside the mentioned reasons, the analysis measurements from 6th to 8th March are not included, due to the significant fall of heat flow coefficient.

Analysis of the second measurement period

In Figure 4. are shown the results of the second measurement period that include heat transfer coefficient, inside air and wall temperature and outside air and wall temperature. Second measurement period has lasted from 7th to 14th March 2017.

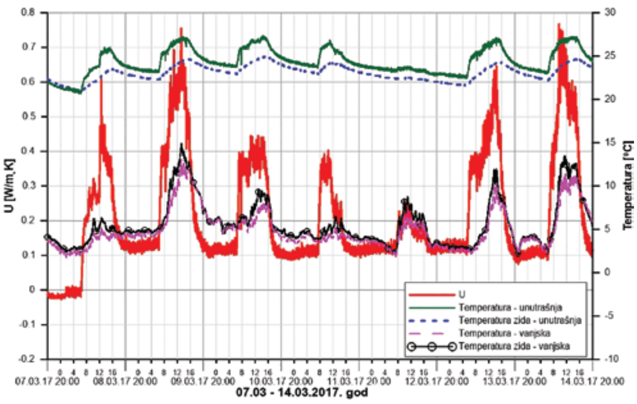

Figure 4. Measured values of heat transfer coefficient, inside air and wall temperature, outside air and wall temperature (7nt-14th March 2017).

Measurement results of the second period show similar pattern of behavior of temperature gradients and heat transfer coefficient. During the day, with the heating on in the morning hours and the raise of the internal air temperature, followed by the rise of outside air temperature, the heat transfer coefficient of the wall also increases. From the period when the heating is switched off, inside air temperature drops as does the outside air temperature during night period. During the night, the value of the heat transfer coefficient is relatively lower, which represents a reverse process in comparison with the daily period. Beside these fluctations, the growth and the fall of the curves is observed when the windows is open to ventilate the room, especially because the sensor is mounted near the window, on the parapet.

Average air temperature difference for the second measurement period was 19.4 °C, where average inside air temperature was 24.6 °C and outside air temperature was 5.21 °C. Average value of the measured heat transfer coefficient for the second measurement period was 0.23 W/m^2K.

Inside-outside air temperature difference of 19.4 °C, is close to the recommended value of 20˚C according to the ALMEMO, and due to the negligible difference it can be considered as a satisfactory condition. Beside that, because measurement period has lasted longer than 72 hours, measured values of the heat transfer coefficient of the external wall for second measurement period are being analyzed according to the standard ISO 9869, in order to examine the validity of the measurements and determine the real heat transfer coefficient of the wall.

Vaulation of the measured heat transfer coefficient of the wall according to the requirements of ISO 9869

According to the ISO 9869, measurement of the heat transfer coefficient should be completed when the following conditions are met [8],[10]:

Condition 1 – the duration of the test should last 24 hours or measurement should last longer than 72 hours (three days) if the temperature around heat flow plate is stable and temperature difference is above 19℃, according to [6]. In the buildings with larger heat capacity, the average value of the component's heat transfer coefficient can be obtained by measuring over a longer period (not less than 96 hours).

Condition 2 – surface wall resistance, R-value, obtained at the end of the measurement, should not deviate more than ±5 % from the value obtained 24 h earlier.

Condition 3 – R-value obtained by the analysis of data of the first measurement period (for example three days) should not deviate more than ±5 % from the value of data obtained at the end of the measurement of the same period of time (three days).

Data measurements for the second measurement period started on 7th March at 20:00 PM and finished at 14th March 2017 at 20:00 PM. Data was recorded in the interval of every 15 minutes.

Average difference of inside-outside air temperature during measurement was 19.4 °C, which satisfies the criteria of the ALMEMO measuring equipment manufacturer.

Condition 1 – duration of the measurement was longer than 72 hours (three days) – condition is satisfied.

Condition 2 – R-value obtained at the end of measurement period should not deviate more than ± 5 % from the R-value obtained 24 h earlier.

Heat transfer coefficient measured at the end of the measurement period was U=0.23 W/m^2K. Heat transfer coefficient measured 24 h before the end of the measurement was U=0.22 W/m^2K.

These values are used for calculation of R-value, surface resistance of the wall, and for estimation if the R-value obtained at the end of the measurement period does not exceed more than ±5 % of the obtained value 24 h earlier.

Calculation equation for R-value is

$$R=\frac{1}{U} - R_{si} - R_{se} \ \ (m^2K/W)$$

where

U – heat transfer coefficient of the wall.

R_{si} – coefficient of internal surface resistance, where the value is 0.13 m^2K/W for walls, according to the EU BS ISO 6946.

R_{se} – coefficient of external surface resistance, where the value is 0.04 m^2K/W for walls, according to the EU BS ISO 6946.

R-value obtained at the end of the measurement, when the U-value is 0.23 W/m^2K:

$$R_{\text{end of measurement}} = \frac{1}{0{,}23} - 0.13 - 0.04 = 4.18 \ m^2K/W$$

R-value obtained 24 h before the end of the measurement, when the U-value is 0.22 W/m^2K:

$$R_{\text{24 h-earlier}} = \frac{1}{0.22} - 0{,}13 - 0.04 = 4.38 \ m^2K/W$$

Deviation is 4.5 %, which means that the condition 2 is satisfied.

Condition 3 – R-value obtained by analysis of the data from the first measurement period (three days) should not exceed more than ±5 % from the data value obtained at the end of the measurement of the same duration period (three days).

For example, R-value obtained by analysis of the data of the first measurement period of two days, should not exceed ±5 % of the values from the last two days.

The heat transfer coefficient of the wall, measured at the first three days of the measurement was U=0.227 W/m^{2}K. The heat transfer coefficient of the wall, measured at the end of the last three days of the measurement was U=0.228 W/m^{2}K.

R- value obtained at the end of the first three days of the measurement, when U-value is 0.227 W/m^{2}K :

$$R_{\text{first-3-days}} = \frac{1}{0.227} - 0{,}13 - 0.04 = 4.228\ \text{m}^2\text{K/W}$$

R-value obtained at the end of the last three days of the measurement, when U-value is 0.228 W/m^{2}K:

$$R_{\text{last-3-days}} = \frac{1}{0.228} - 0{,}13 - 0.04 = 4.20\ \text{m}^2\text{K/W}$$

Deviation between calculated values is 0.50 % which means that Condition 3 is satisfied and the measurement is valid.

Because all the conditions are satisfied, it is possible to conclude that the measurement is valid and the measured heat transfer coefficient of the external wall at the Mechanical Engineering Faculty Sarajevo is 0.23 W/m^{2}K.

Analysis of the third measurement period

In Figure 5. are shown the measured values of the third measurement period, including heat transfer coefficient of the external wall, inside air and wall temperature and outside air and wall temperature. The third measurement period has lasted from 14th to 22nd March 2017.

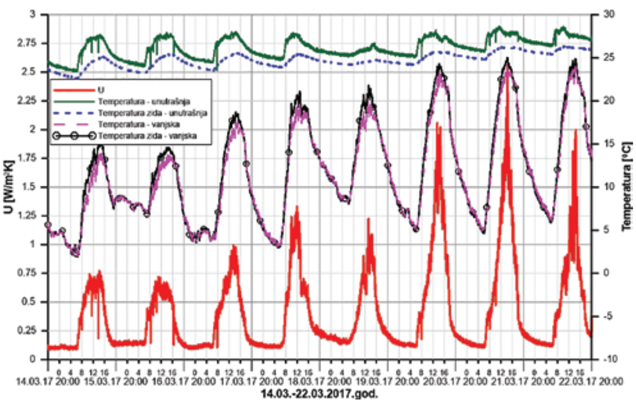

Figure 5. Measured values of heat transfer coefficient, inside air and wall temperature, outside air and wall temperature (14^{nt}-22nd March 2017).

According to the measurement values, during the third measurement period, higher outside temperature prevails on each day, with the rising from the morning to late afternoon hours, after which the outdoor temperature drops. Average inside-outside temperature difference of the air of 14.7 °C does not satisfy the condition that the difference should be 20˚C according to the ALMEMO, so the results of the third measurement period are not being used for calculation and examination of validity of the heat transfer coefficient for external wall.

Average value of the measured heat transfer coefficient was 0.42 W/m^{2}K, or the average value during the day was 0.59 W/m^{2}K, and during the night it was 0.14 W/m^{2}K, influenced by higher temperature differences.

In the office where the measurement was performed, the average inside air temperature was 27.2°C, influenced by higher outside temperature, heating during the day and additional use of heater to achieve constant temperature of the room. Difference between outside air and wall temperature was averagely 0.33 °C, and the difference between inside air and wall temperature was 1.4 °C. It is in accordance with the comfort criteria that the external building components should have such heat transfer coefficient that the minimum daily average of inner surface temperature does not deviate more than 4.2 °C from the operating temperature [11].

8. Discussion

The heat flow method is the method used to measure the heat flow coefficient of the external wall *in-situ*, at the Mechanical Engineering Faculty. The method is standardized according to the ISO 9869 that takes into account important influencing factors as external and internal climatic conditions and thermal wall mass. The standard requires a minimum period of the time necessary to obtain valid results.

In the north-oriented room, the external wall heat transfer coefficient was measured, inside air and wall temperature and outside air and wall temperature. Since the standard requires that the measurement covers an entire number of 24 hours, the measurement started on 28th February at 20:00 PM and ended on 22nd March 2017 at 20:00 PM.

The measured values from the first and third measurement periods did not satisfy the conditions by ALMEMO, measuring equipment manufacturer that recommends that the inside-outside air temperature should be 20 °C.

Average inside-outside air temperature of the second measurement period was 19.4 °C and thus the required condition was satisfied. Based on the requirements of the ISO 9869 standard for validation of measurements and conducted analysis, the measurement of the second period has satisfied the conditions and can be considered as valid. The measured value of the heat transfer coefficient of the external wall was 0.23 W/m^2K, while the calculated value of the heat transfer coefficient for the same wall according to the program KiExpert was 0.33 W/m^2K. The difference between values is understandable because there are constraints in the selection of the materials from the material menu, but beside that, the data cannot be relevant to the actual state of the external wall. Factors such as aging, the influence of climatic factors, quality of materials and the performance of the work can have influence of heat transfer coefficient of the external wall.

According to [12], the percentage absolute deviation between the notional and the measured *U*-values for IR thermography is found to be in an acceptable level, in the range of 10–20% and according to [5], the uncertanity of *in situ* measurement performed by HFM ranges from 10-28 %. However, in the scientific literature it is stated that the U-value of the walls measured *in situ* with different methods can vary up from 20-50 % [5], which is in accordance to the performed measurement at the Mechanical Engineering Faculty, where the deviation between the notional and the measured U-value is about 40 %.

9. Conclusion

The aim of the experimental research at the Mechanical Engineering Faculty in Sarajevo was to determine whether there are any differences between the real and the calculated heat transfer coefficient of the external wall, based on the input characteristics for the same wall in the used program KiExpert.

After the analysis according to the conditions of ISO 9869 for *in-situ* measurement of heat transfer coefficient, the measured value for the external wall was 0.23 W/m^2K, which is the lower value compared with the calculated value of 0.33 W/m^2K according to the program KiExpert for the same external wall. The difference between values is the result, first of all, of the constraints of the material selection in KiExpert program, in addition to the fact that the accumulation of the heat in building elements is not sufficiently considered in calculation algorithms. Heat accumulation is often underestimated, especially in the buildings that are intensively used and if they are massive, there is large difference in estimated and actual energy consumption for heating and cooling. In addition to the mentioned reasons, there is also influence of factors such age, external and internal environmental conditions, quality of performed works etc.

The method of measuring heat transfer coefficient *in-situ* is a useful method for measurement and verifying of actual heat transfer coefficient of the building element. The method can be used to obtain representative values of heat transfer coefficient for widespread use, i.e. the measured values can be used for similar buildings, due to the suspicions of poor quality, wall moisture resistance, aging materials, but assuming that the measurement and analysis were carried out in accordance with BS ISO 9869.

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