Impact Verification of Aerogel Insulation Paint on Historic Brick Facades

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Abstract. Increasing the sustainability of existing buildings is being motivated by reduction of their energy demands. It is the above all the building envelope and its refurbishment by substitution or addition of new materials that makes the opportunity for reduction of energy consumption. A special type of refurbishment is conservation of historical buildings. Preservation of historic buildings permits also application of innovative methods and materials in addition to the original materials if their effects are known and the gained experience ensures their beneficial effect. On the market, there are new materials with addition of silica aerogel in various forms of products. They are also potentially useful in conservation of monuments. However, the effects of aerogel application in these cases are not known. For refurbishment is commercially available additional transparent insulation paint - Nansulate Clear Coat which is containing aerogel and can be used for structured surfaces such as bricks. A series of experiments examined the thermo-physical manifestation of an ultra-thin insulation coating of Nansulate Clear Coat containing silica aerogel on a brick façade. The experiments of active and passive thermography have observed effects of application on the small-scale samples of the brick façade of a protected historical building. Through a series of experiments were measured thermal insulation effect and influence on the aesthetic characteristics such as change in colour and gloss. The treated samples were compared to a reference. Results have shown no thermal-insulating manifestation of the recommended three layers of insulation paint. The three layers recommended by the manufacturer did not significantly affect the appearance of the brick façade. Color and gloss were not significantly changed. Experiments showed the absence of thermal insulation effect of Nansulate transparent triple coating. The thermal insulation effect could likely be reached by more layers of application, which, on the other hand may be unacceptable on the heritage conservation because of number of applications, time demand and financial costs. The effects of multiple layers on heritage attributes were not researched. Extrapolating the measured results, it can be expected that application of more than three layers of paint can significantly affect the aesthetic characteristics of the monument such as gloss and colours of historic brick facades. Due to specific material consistence of historic architecture and new insulation paint materials on the market, it is recommended to provide independent laboratory testing and on-site tests on facades of historic buildings in cooperation with the Monument Protection Board.

1. Introduction
Currently, there are demands on the energy performance of the existing buildings to enhance their sustainability. Historical buildings in their use mostly cannot offer sustainable options to the current
standards of interior well-being because they were built at the time, when the current energy efficiency demands were not considered. Reconstruction of historic buildings is a special case because of their values. Standard procedures of insulation of the exterior envelope by adding insulation boards come into consideration as a solution to this problem. The consequence can be the change of the architectural expression of the building. In the case of valuable historical architecture, this means a loss of cultural (aesthetic) values of the original building, which is, in terms of cultural interests, the unwanted result. On the market with construction materials, there are new thermal insulation materials containing aerogel [1, 2, 3, 4]. Many of them are potentially useful for the restoration of cultural monuments [5, 6, 7, 8, 9, 10]. However, the cost of aerogel products is roughly 8 times higher [11] when compared to conventional materials with the same added insulation effect. There is expectation of decrease in price. By an experiment, this article verifies the use of an aerogel insulation coating and its effect on thermal insulation and appearance properties on a cultural monument façade surface.

2. Paint insulation
Transparent coating insulation Nansulate Clear Coat (1 fresh coat of 100 μm, dry coat 50 μm, 1 cured coating 19 μm - proper to measure) [12], which according to the manufacturer acts as an effective thermal insulator, offers many promising properties that could be used to restore cultural heritage. The manufacturer does not provide the value of the coefficient of thermal conductivity \( \lambda \) or thermal transmittance \( U \)-value in the product prospectus [13]. As indicated by producer, building physics formulas are not designed [14] for thermal insulation in thickness of layer. The manufacturer offers on its website successful case studies from Italy and US [15], declared by radical heat savings (in %). The studies provide insufficient data and do not use standard methods of detection. The quantity effects are not available for details. In contrast is an independent study by Cold Climate Housing Research Center, which independently tested the Nansulate® [16] insulation painting. An Australian study [17] shows positive results (determined by mathematical simulation) of the saved space and energy by adding 4 mm thick coating. After the calculation (according to the Application Handbook), for thickness of 4 mm (4000 μm), it would be necessary to paint 210 layers (1 matured layer - suitable for measuring according to the Application Handbook is 19 μm). The published study [18] of applications does not measure the improvement in thermal insulation properties of the insulation coating when applied Nansulate in extremely thin films (100 nm) in comparison to reference samples. Other aerogel coatings (Enova Aerogel) are generally promoting thermal insulation properties [19] and other beneficial properties such a hydrophobicity, vapour permeability and non-flammable treatment. The investigated thermal improvements are not shown clearly in the product brochure [20].
The question of the appropriateness of the use of thermal insulation coatings for rough masonry facades of listed buildings has already been laid by Petra Ambrusova in her thesis: 

"There remains a controversial question, how the layers will be influenced by exposure to long term weather conditions, although in principle, the coating can be used to structures with cultural values and listed heritage." [21] According to Ambrusova, it is necessary to reconsider the use of insulation coating. The effect of coating on the visual characteristics of structures and measured thermal improvement effects are inconsistent. The exact level of impact has not yet been proved. This article meets this challenge. In the dissertation thesis, extensive research was conducted [24].

Active and passive infrared thermography and measurement of the thermal transmittance U-value were used in the experiments. The experiments were carried out on a small-scale in-situ samples (ca. 50 x 50cm) (Fig. 2, b) and a on a sample brick. The insulation coating was applied to the surface according to the producers’ Application Handbook using the “Cool Surface Application Method” - layers applied at not more than 99°C. There were three recommended coating layers applied. In the experiment, together with the observed area (b), there is always an uncoated reference surface left (a) for the immediate observation and comparison.

2.1. Method 1 – Passive thermography

The test of passive thermography measurement was conducted on a small-scale sample (50x50cm) at a winter night (November 2015) in order not to interfere during the measurement with the infrared radiation from the daylight. This non-contact, non-invasive method is used in research for historic buildings after conversion (change of a building’s purpose), at the time of their use. The interior was already heated up. Between the interior and exterior of the building in use was sufficient temperature difference min. ΔT = 15°C. The measurement was taken in the winter time, to heat-stabilize the structure with the environment. The measurement should demonstrate the response of the layers (b) to internal heat passing through overall brick perimeter wall. With this method, it is possible to diagnose the thermal bridges and thermal insulation efficiency of other façade parts, or reveal whether other facade defects have impact on the temperature of the sample.

The task was to compare the behavior of untreated - the reference surface (a) and the treated sample (b), exposed to real environmental conditions. The stated effective thermal insulation effect of the coating should be noticeable. The heat escapes through the construction of the wall evenly. The thermal insulation effect of the coating should hinder heat escaping through a small-scale sample. In the case of positive effect, the treated sample in comparison with the untreated surface should be
substantially visually different on the thermography. The effective thermal insulation, as a barrier of flow and heat transfer, should reduce the thermal losses, which should be visible on thermography of the treated sample (b) by lower surface temperature from exterior side.

2.2. Method 2. Active thermography

Figure 3. Infrared thermovision measurement called. Active Thermography, provided on the sun light side of an unused power plant wall – case study I

2.3. Method 3. – measuring of U-value

It is not possible to calculate [22] the added thermal insulation improvement of the coating Nansulate®. There is still a question: How much will the transparent thermal insulation coating, applied in three layers, improve the insulation properties of the brick perimeter walls? Therefore, a method of measurement of samples in real in-situ conditions was used. For comparison of thermal transmittance U-values, a method for measurement by Testo-635 test kit was chosen. The measurement of thermal transmittance U-value has been calculated from real-time flow of heat through construction. The measurement by Testo-635 kit is a non-standard method.

Figure 4. Measurement of Thermal transmittance U-value by using Testo 635-2 test kit
3. Results and Discussion

3.1. Result 1—Passive thermography

Passive thermography on a winter night was carried out. Coating layers did not appear as a thermal barrier to the escaping heat. The heat insulating effect of the coating was not shown. The treated sample (b) with thermal insulation effect should appear cooler than the reference (a) surface. There are not observed contours of the treated sample (b) caused by coating. The surface of the sample (b) shows the higher temperature for leaks in the corner of the structure, which was not affected by coating.

Figure 5. Photography vs. thermal thermography. Passive thermography was carried out during night, the building was heated. The treated sample (b) in case of effective insulation should appear to be cooler. There are not readable contours of the treated sample (b). The sample surface (b) was warmer for leaks in the corner of the structure.

3.2. Result 2—Active thermography

Figure 6. The sample brick (1) with reference surface on the left (a) and treated surface on the right (b); Active thermography on the brick specimen (2). No effect was observed in Infrared spectrum between (a) and (b) during one hour of exposition on direct sunlight (December 2015).
Figure 7. Photography vs. Infrared thermography of case study I. The average temperature of the treated sample (b) is slightly higher by 0.25°C.

There were not observed significant temperature differences between the treated (b) and untreated sample (a). The average temperature of the treated sample was slightly higher. This marginal difference can be given "randomly" for example by colour of the bricks. The thermography (Fig. 7) shows that untreated sample (a) contains some significant bright bricks that appear on the thermography much cooler. The measured temperature differences between (b) and (a) in the case study I were only 0.25°C (Fig. 7). The difference is smaller than the standard deviation of the measurement (± 0.97 to 1.17°C). It can be stated, that significant temperature variations of the observed samples (a) and (b) were not noticed. The samples which were placed in direct sunlight behaved equally.

3.3. Result 3 – measurement of U-value

The measurement of thermal transmittance, U-value: In the time of monitoring the samples, they behaved relatively the same way. There has been a no stable level achieved of the mean thermal transmittance U-value during the measurement. Because of an insufficient temperature difference between interior and exterior, it was not possible to determine the exact value of U-value, and reliably compare its value between the untreated (a) and treated sample (b). It is proposed to repeat the experiment in the winter time.

The interrogation point on the thermal insulation coating

Although the researched coating contains the active substance of excellent thermal insulating material silica aerogel [23], even at a high concentration (> 80%), at the ultra-thin layer of the application, e.g. enormously low use of aerogel (because of thickness), coating can act more likely as "thermal insulation homeopathy". In general use, the material in application can act as a placebo for several reasons. For application in the frost-free months (late spring to summer) and relatively long "time of maturation" of the coating and the possible measurement experiments in winter there are no immediate verifiable differences in the action of "before and after". When measuring the energy savings, the data of the previous period do not represent an appropriate reference for comparison of thermal effects due to differences in conditions. Measuring conditions before and after the full-scale application may be significantly different. The past winters (for example 2013/2014) surprised by unusually "high temperature" which lasted long for this time of year. The used buildings in such conditions show significantly lower energetic requirements than is in previous winters. Insignificant differences in energy demand in the full façade surface application on one building seem to be harder to objectively comparable to the prior conditions. This is due to the uniqueness of the seasons. Moreover, only few investors carry out an energy audit before application of insulation coating for a building. This can be considered as an absolute absence of appropriate reference data for comparison.
Comparison of energy demands during the period of heating by electricity could ensure relative objectivity of comparisons, without taking differences of conditions into consideration. It seems that the applied "small-scale" samples help fully to solve the problem of parallel comparison.

4. Conclusions

- The paint insulation product did not show thermal insulation effect on in-situ samples in the tests of passive and active thermography;
- The paint insulation layers did not contribute noticeably to the U-value of the building structure that they were used on.

It is likely that more effective application would require multiple layers of coating (more than three). The criterion for selecting the coating can be the comparison of the coating price and the energy bill savings. Already the application of three coats (Sample b) is technically difficult and economically a costly process. Multiple large-scale repetitions of paint layers on the building are timely, and technologically and economically an untenable requirement. The visual impact of three layers was observed in the dissertation [24]. Three layers demonstrated visually neutral impact on the colour and glossiness of the facade. More than three coatings can provide more intense visually intrusive impact than in the case of three layers. This is, in terms for preserving the authenticity of the original appearance of historic façade, considered as an inappropriate result. Except for the thermal insulation property, aerogel coatings can provide also other beneficial improvements of original historic facades for their sustainability [11, 20]. In order to increase the sustainability of historic buildings, the specific verification research on the use of the new material is required.

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