A NUMERICAL AND EXPERIMENTAL ANALYSIS OF THE AGING OF THE COOL ROOFS FOR BUILDINGS IN GREECE

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ABSTRACT

Cool roof coatings remain cooler than absorptive roofs and thus predominantly are used in buildings that require the reduction of the indoor temperature and the cooling loads. Cool roofs can also reduce the ambient temperature. A currently contentious aspect of solar reflective cool coatings is the extent to which an initially high solar reflectance decreases with time.

In the present study, the aging effect on the optical and thermal characteristics of two cool roofs is reported. The buildings under investigation are two schools in Greece, in the city of Athens. The research in this field is roughly divided in four phases and includes the assessment of the optical and thermal performance of the cool roof. For each one of the phases the documentation of the building's profile includes albedo measurements and infrared imaging of the roof. The first phase includes the above measurements on the existing roof. In the second phase the roof was cleaned at the points where the measurements were taken. The third phase includes albedo measurements and infrared imaging at the cleaned points. In order to estimate the change of the albedo and the surface temperature of the cool roof with time, the same cool coating was applied in a part of the roof. In the fourth phase the measurements were repeated for the new part of the cool roof.

With the aim of investigating what may cause this aging of the cool coating, chemical and biological analysis for two samples from the old and the new cool coating was also carried out.

This study also presents simulations of the buildings in order to estimate the effect of the aging of the cool roofs on the thermal comfort and the alteration of the cooling and heating loads using the EnergyPlus simulation Program.

KEYWORDS

High albedo roof coatings, albedo degradation, cooling energy savings

1 INTRODUCTION

Cool roof coatings remain cooler than absorptive roofs due to their properties of the high solar reflectivity and the high infrared emittance. Roofs with high albedo are used in buildings that require the reduction of the indoor temperature and the cooling loads. Cool roofs can also reduce the ambient temperature through the reduction of the sensible heat emmited. To maximize cooling energy savings, high albedo roof coatings should maintain the above properties for the service life of the coating (Bretz, 1997).

Roofing materials are exposed to environmental conditions (wind, sunlight, rain, hail, snow, atmospheric pollution) and consequently degrade over time (Berdahl, 2006). Weatherisation is a serious problem for

reflective roofs. Experimental data suggests that the reflectance of roofs decreases because of the dust load, ultraviolet radiation, microbial growth, acid rain, moisture penetration and condensation, wind and biomass accumulation. Other research shows that black carbon particles, known as soot particles, is the primary cause of reflectance loss. Reflective surfaces may have a longer useful life if surface temperature keeping low during the sunlight hours, because that result in less diurnal thermal expansion and contraction (Akbari, 2005).
This paper assesses the aging effect on the optical and thermal characteristics of two school buildings in Athens, Greece. A simulation analysis is carried out in order to estimate the alteration in the cooling and heating loads. The building description, the experimental and modeling procedure and the results are being discussed in the following sections.

2 DESCRIPTION OF THE BUILDINGS

The buildings under investigation are two schools located in Kaisariani, a densely built urban area near the centre of Athens, Greece. School A (Figure 1) was built in 1929 and School B (Figure 2) was built in 1980. The two schools share the same school-courtyard.

Figure 1 The location (a) and the school building A (b) at Kaisariani Athens

Figure 2 The location (a) and the school building B (b) at Kaisariani Athens

2.1 SCHOOL A

The school building A is a rectagular two-floor building. In the ground floor seven classrooms are located, the office of the staff as well as auxilary storage space's. In the first floor there are six classrooms, the principal's office and two more storage spaces. The ground floor and the first floor are connected with an internal staircase. The total area of the roof is 614.9 m^2. The masonry construction of the school building is stone without any insulation and the windows are simple glasses. Figure 3 describes the lay out and the orientation of the building. Each one of the two floors constitutes a thermal zone of the building that was used in the simulation model.
Regarding internal gains the artificial lighting was set equal to $16W/m^2$. Infiltration is being used by opening the windows during recess and it is considered to be $108m^3$/hour. Each classroom is occupied by twenty three children and fifteen adults in total as the school's staff. The operation schedule of the building is from 8:00 to

14:00 from Monday to Friday excluding national holidays Christmas (23 December–8 January), Easter (two weeks) and summer holidays (22 June–31 August).

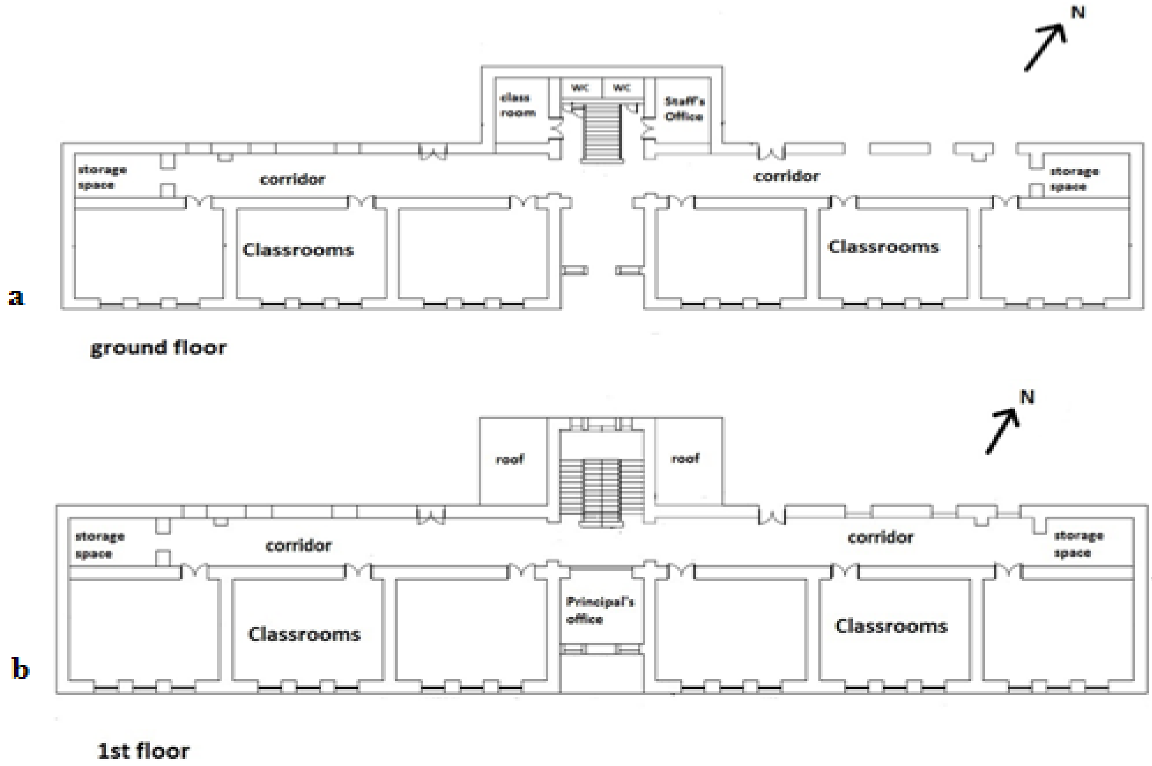


Figure 3 Plans of the school building A with lay out

2.2 SCHOOL B

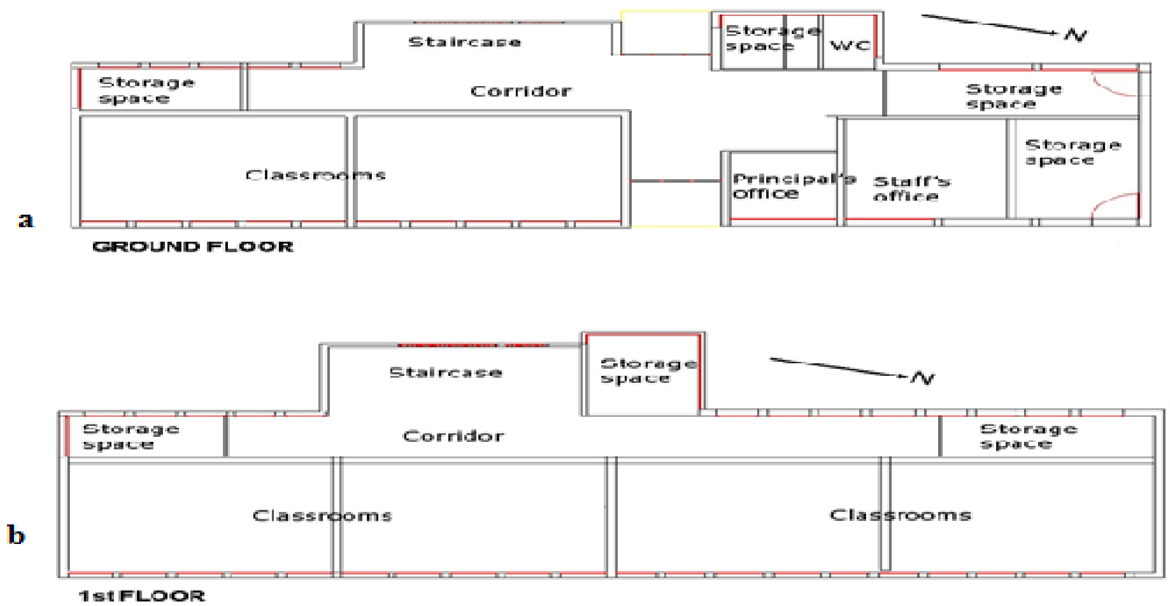


Figure 4 Plans of the school building B with lay out.

The school building B is also a rectagular two-floor building. In the ground floor two classrooms are located, the principal's office and the office of the staff as well as auxilary storage space's. In the first floor there are four classrooms and three more storage spaces. The ground floor and the first floor are connected with an internal staircase. The total area of the roof is 410 m^2. The masonry construction of the school building is reinforced concrete without any insulation and the windows are double-glazing windows. Figure 4 describes the lay out and the orientation of the building. For the simulation model each one of the two floors of the building constitutes a thermal zone.

Regarding internal gains the artificial lighting was set equal to $16W/m^2$. Infiltration is being used by opening the windows during recess and it is considered to be $108m^3$/hour. Each classroom is occupied by twenty children and fifteen adults in total as the school's staff. The operation schedule of the building is from 8:00 to 14:00 from Monday to Friday excluding national holidays, Christmas (23 December–8 January), Easter (two weeks) and summer holidays (22 June–31 August).

For the simulations carried out, which are described in the next sections, the set point temperature for heating is considered to be 21°C and for cooling is considered to be 26°C.

3 METHODOLOGY

The research for the assessment of the optical and thermal performance of the cool roof for the school building A is roughly divided in four phases and for school building B in two phases. For each one of the phases the documentation of the building's profile includes albedo measurements and infrared imaging of the roof.

3.1 Instrumentation

Albedo measurements were carried out in order to analyze the effective reflectance of the roof using two pyranometers (Kipp & Zonen), one for the incident solar radiation and one for the reflected radiation from the roof. The spectral range of the pyranometers is from 300 to 2800nm. Albedo was measured on clear days between 09:00am to 02:00 pm.
An infrared camera (AGEMA Thermovision) was used to detect heat patterns and temperature changes on the roof.

3.2 Monitoring Procedure

The monitoring procedure for school building A includes different phases. The first phase includes the albedo measurements and infrared imaging of the existing roof after 4 years of operation. In the second phase the roof was cleaned at the temperature as well the albedo are measured again. Figure 5 depicts the measured roof temperature of a cleaned point of the roof by using an infrared camera.

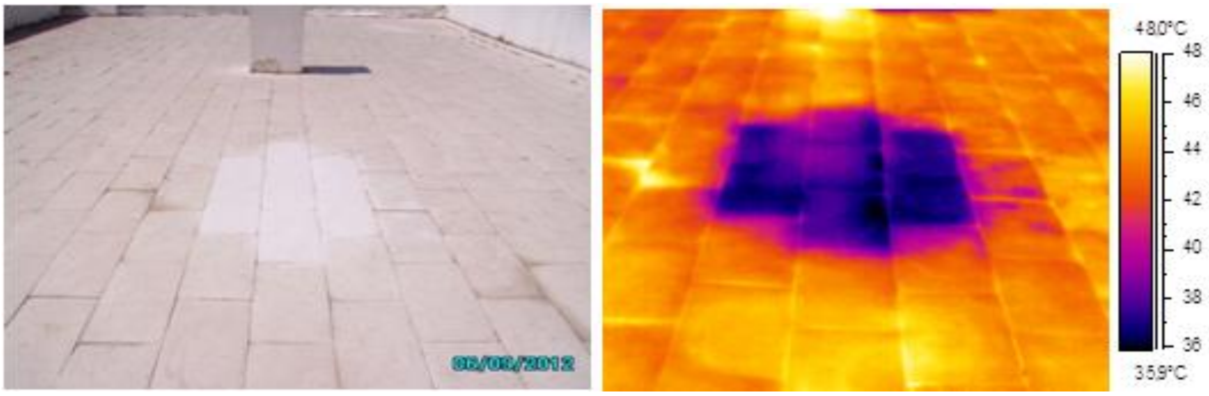


Figure 5 Visible and infrared imaging of the roof depicting the difference in the surface temperature between the existing roof and the cleaned point.

In order to estimate the change of the albedo and the surface temperature of the cool roof with time, the same cool coating was applied in a part of the roof. In the fourth phase the measurements were repeated for the new part of the cool roof. Figure 6 depicts the temperature difference between the existing cool coating and the new part of the cool coating.

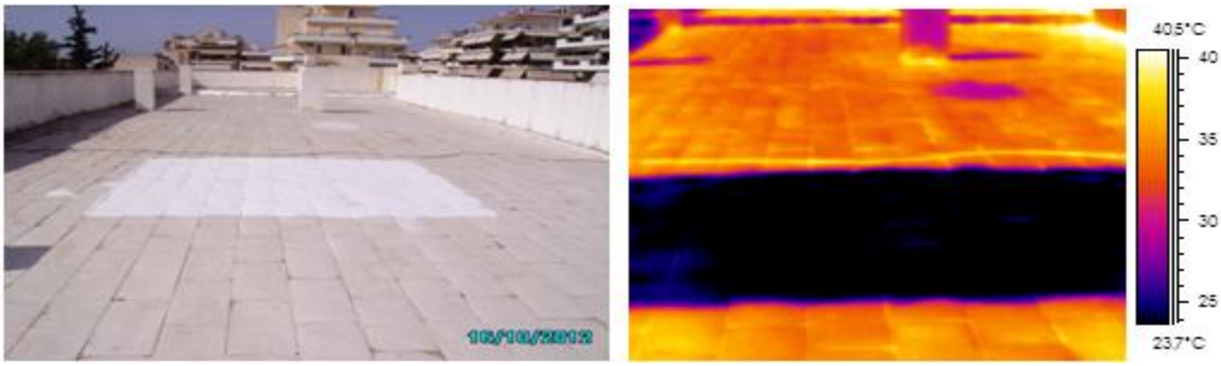


Figure 6 Visible and infrared imaging of the roof depicting the difference in the surface temperature between the existing cool roof and the new part of the cool roof

The monitoring procedure for school building B includes albedo measurements and infrared imaging of the existing roof and the same measurements for a new part of the cool coating in order to estimate the differences in albedo and surface temperature of the roof. Figure 7 depicts the difference on the surface temperature of the cool roof.

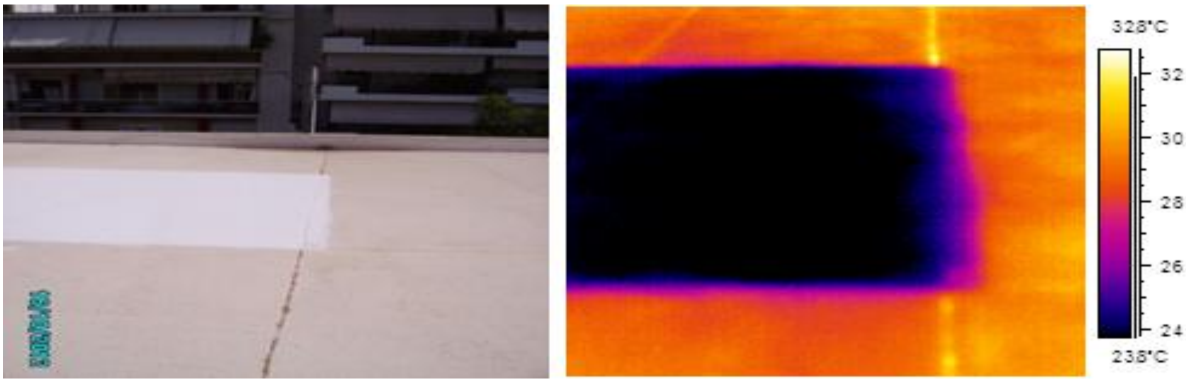


Figure 7 Visible and infrared imaging of the roof depicting the difference in the surface temperature between the existing cool roof and the new part of the cool roof

4 RESULTS

4.1 Measured decrease in albedo

In Figure 8 the albedo of the school buildings under study is given for all phases.

Figure 8a depicts the alteration of the albedo of the school building A as recorded during the measuring procedure. The results indicated that the albedo of the existing cool roof was decreased by 25% compared with the albedo of the new cool coating. Furthermore the increase in albedo resulting from washing the roof was significant (10%).

The results for the albedo of the school building B as presented in Figure 8b indicated a decrease of 23.5% for the albedo value of the existing roof.

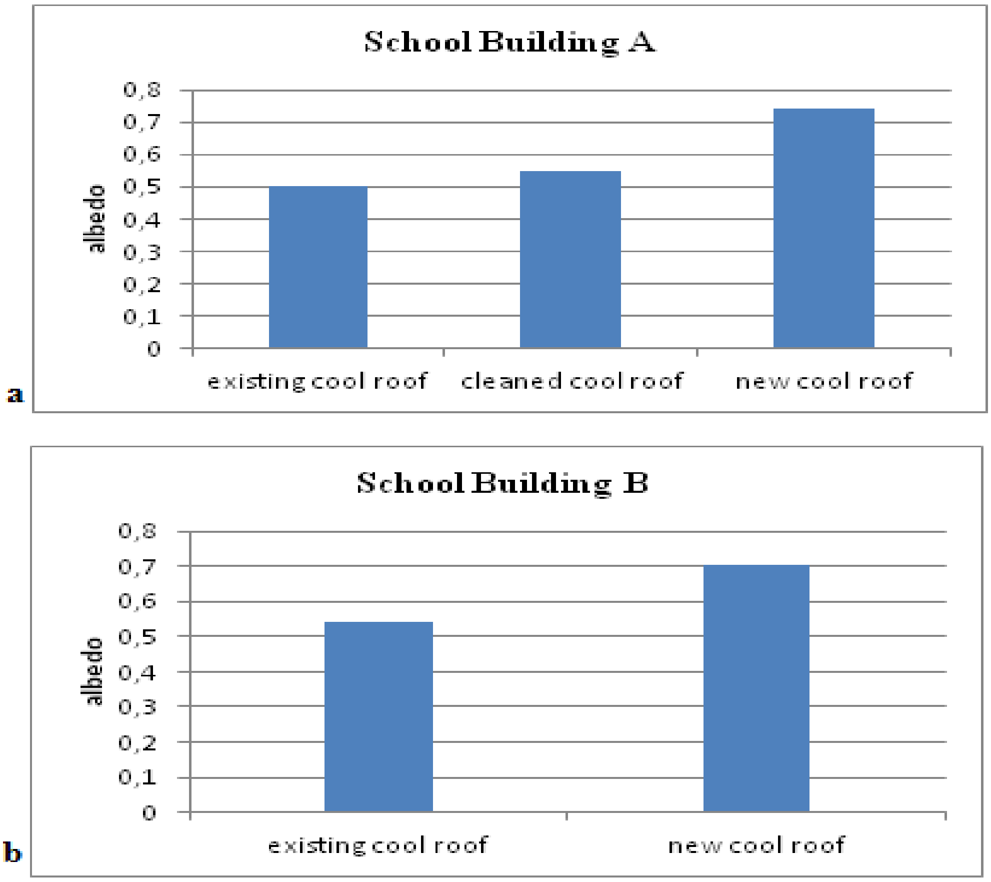


Figure 8 Albedo measurements for the different measuring phases for building A (a) and building B (b)

4.2 Chemical and biological analysis of the samples

The samples studied are extracted by the cool roof of building school A. Moreover a clean sample is also tested as reference. For the analysis the following techniques are used:

1. Optical stereoscopic microscopy and polarizing microscopy. The samples were impregnated in epoxy resin and the surface to be studied was polished in order to study a possible layer of pollutants in the cross section of the samples.
2. X-ray Diffractiometry using X-ray Powder Diffraction Spectrometer D8000 Advance by Bruker, with copper lamp. The qualitative analysis was performed with the Diffrac Plus software and database. The quantitative analysis was performed using the Rietveld method. Measurements were made directly on the surface of the samples while the X-ray beam's penetration on the sample's surface is 100 to 150 μm.
3. Scanning Electron Microscopy (SEM) in order to study the distribution of contaminants on the surface of samples

Table 1 The XRD quantitative analysis of samples

	Calcite	Rutile	Huntite	Quarz	Kaolinite	Illite	Talc	Dolomite	Epsomite	Albite
Koul 0/Ref.	50.2	46.3	-	-	2.6	-	-	-	-	0.9
Koul 1/1st sample	40.2	35.9	3.2	1	3.9	4.3	11.4	-	-	-
Koul 2/2nd sample	47.4	24.1	2.3	1.9	3.2	10.0	-	2.0	8.9	-

The KOUL0 sample's analysis shows that it is a plastic color. Calcite ($CaCO_3$), and Rutile (TiO_2) are the major mineral aggregates that are the plastic's fillers. Kaolinite ($Al_2Si_2O_5(OH)_4$) and Albite ($NaAlSi_3O_8$) and Albite (NaAlSi3O8) also belong to the inorganic inert of plastic color.

In KOUL1 sample, which is a part of the cleaned cool roof, we can see apart from the minerals of the reference sample, the existence of Quartz (SiO_2), Illite ($KAl_4Si_2O_9(OH)_3$), Huntite($CaMg_3(CO_3)_4$) and Talc ($Mg_3Si_4O_{10}(OH)_2$). The minerals Huntite και Talc can be found as Calcite and Rutile in high quality plastics.
The minerals Quartz and Illite are atmospheric pollutants that are disposed on the samples surface. Moreover is it very possible that part of the Calcite in KOUL1 sample is pollutant since the ratio Calcite/Rutile is higher than the one of the reference sample.
In the KOUL2 sample, which is a part of the existing cool roof, we can find Dolomite ($CaMg(CO_3)_2$) Epsomite ($MgSO_4 \cdot 7H_2O$) apart from the other minerals that exist in KOUL1 sample. Epsomite is attributed to water that has increased concentration in sulphates.

4.3 Implications for cooling energy use

In order to estimate the implications of cool roof aging on the cooling needs of the buildings, the schools have been simulated for a complete year, using Energy Plus simulation program. Simulations have been performed for all the measured cases of the roof albedo. Energy Plus is an energy analysis and thermal load simulation program. The following graphs (Figure 9-Figure 10) depict the annual cooling and heating loads for the school building A and school building B.

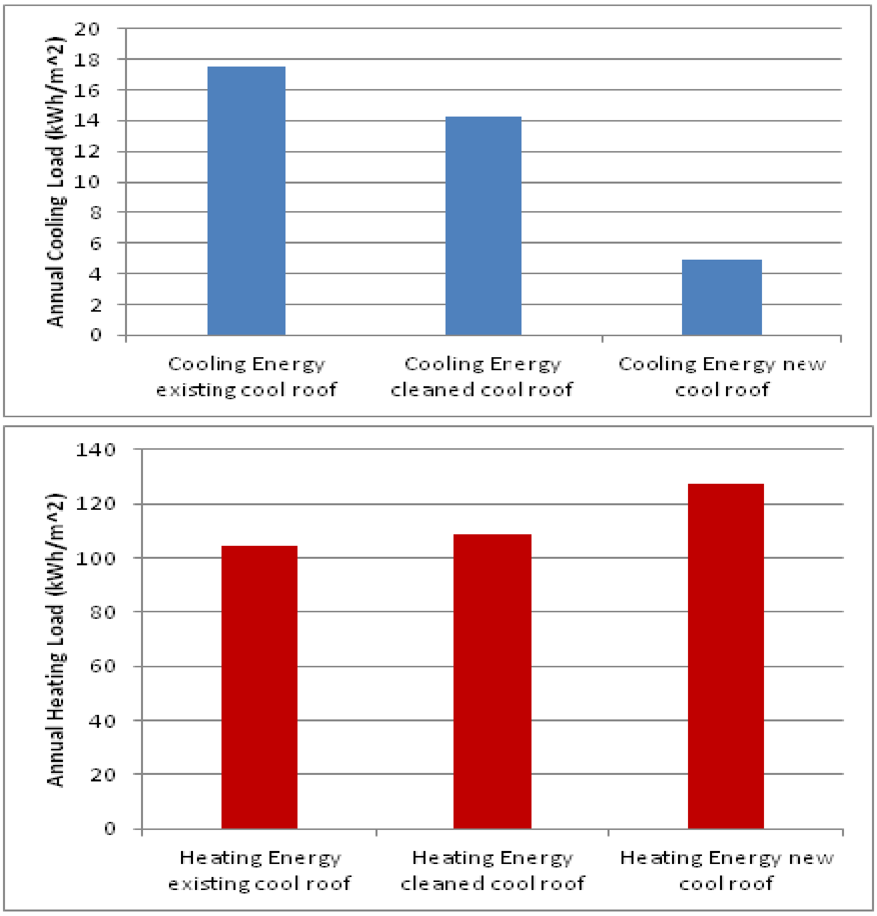
a
b


Figure 9 annual cooling (a) and heating (b) loads for building school A

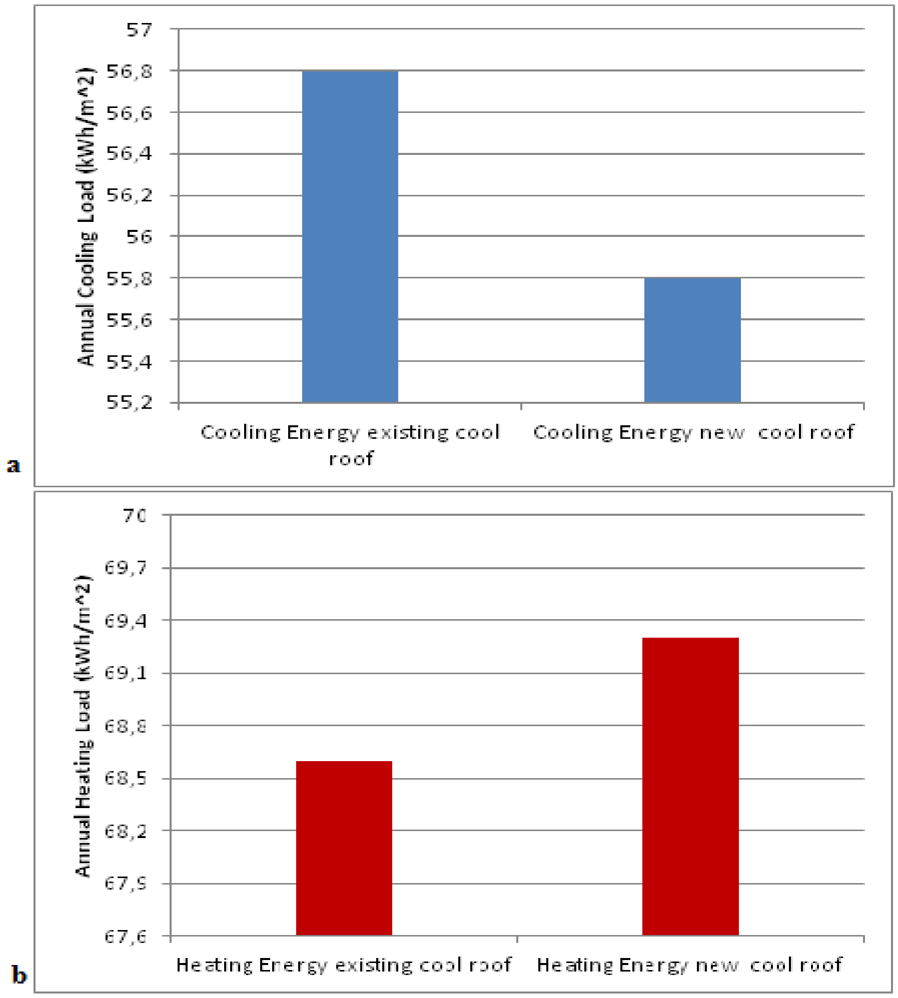


Figure 10 annual cooling (a) and heating (b) loads for building school B

After the cleaning of the cool roof the results of the annual cooling loads for the school A presents a decrease of 18.8% while after the application of the new cool coating there was a significant decrease of 72%. The simulation results indicated that after the cleaning of the roof the annual heating penalty was 4.2kWh/m^2, and after the application of the new cool roof was 23kWh/m^2.

For building school B the application of the new cool roof results to a decrease in the annual cooling load of 1.76 % while the heating penalty was 1% for a complete simulation year.

5 CONCLUSIONS

This paper describes a case study that examines the impact of the aging of the cool roof on energy loads and surface temperature through experimental and modeling testing. The buildings selected involve two school buildings located near the centre of the Athens, Greece. The solar reflectance of the school A roof has changed from 0.5 (existing cool roof) to 0.55 (washed cool roof) and finally to 0.74 after the new application of the same cool coating while the albedo of the school B has shown an alteration from 0.54 to 0.71 for the existing and the new cool coating application respectively. The results of the chemical and biological analysis of the samples of school building A suggest the presence of atmospheric pollutants. In both school roofs the surface temperature has a significant decrease between the part of the existing cool coating and the application of the new part. The simulation results indicated that the annual cooling load for school A has a decrease from 18.8% to 72% for the part of the cleaned roof and the part of the new cool roof respectively. The heating penalties were no as significant as the cooling potential savings.

The results of this study indicate the impact of the aging of the cool roof on the cooling and heating loads, the indoor and the surface temperature.

6 REFERENCES

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