TECHNICAL UNIVERSITY OF CRETE –
SCHOOL OF ENVIRONMENTAL ENGINEERING

Cool Roofs
Cool Pavements

Actual case study of environmental impacts and changes in the town hall of Acharnes

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ΕΥΧΑΡΙΣΤΙΕΣ

Με την ολοκλήρωση της διπλωματικής μου εργασίας, θα ήθελα να ευχαριστήσω όλα τα άτομα που βοήθησαν, ο καθένας με τον τρόπο του, στην πραγματοποίησή της.

Καταρχήν, ευχαριστώ την επιβλέπουσα καθηγήτριά μου κ. Διονυσία Κολοκοτσά για τη συνεργασία μας και τη καθοδήγησή της κατά την διάρκεια των σπουδών μου στο μεταπτυχιακό πρόγραμμα των Μηχανικών Περιβάλλοντος του Πολυτεχνείου Κρήτης.

Επίσης, τους καθηγητές κ. Λαζαρίδη και κ. Τσούτσο, που δέχτηκαν να είναι στην εξεταστική επιτροπή και να αξιολογήσουν αυτή τη μεταπτυχιακή εργασία.

Οφείλω ένα μεγάλο ευχαριστώ στον υποψήφιο Διδάκτορα Γομπάκη Κωνσταντίνο, για τη βοήθεια που μου προσέφερε κατά τη διάρκεια της διπλωματικής μου εργασίας και όχι μόνο.

ΤΡΙΜΕΛΗΣ ΕΞΕΤΑΣΤΙΚΗ ΕΠΙΤΡΟΠΗ

- **Κολοκοτσά Διονυσία**, Αναπλ. Καθηγήτρια **(Επιβλέπουσα)**
- **Λαζαρίδης Μιχάλης**, Καθηγητής
- **Τσούτσος Θεοχάρης**, Καθηγητής

ΠΕΡΙΛΗΨΗ

Σκοπός της παρούσας έρευνας είναι να πραγματοποιηθούν πειραματικές μετρήσεις και αναλύσεις σχετικά με το δυναμικό της ενεργειακής απόδοσης των περιβαλλοντικά καινοτόμων ψυχρών υλικών μέσα από μια σειρά μετρήσεων. Στα πλαίσια του έργου MAIN MED Pilot Case Study πραγματοποιήθηκαν μετρήσεις στο δημαρχείο Αχαρνών για την μελλοντική εφαρμογή ψυχρών υλικών. Η πειραματική ανάλυση περιλαμβάνει μια σειρά μετρήσεων που πραγματοποιήθηκαν στο κτίριο που στεγάζει τις υπηρεσίες του Δήμου Αχαρνών, προκειμένου να εκτιμηθεί το δυναμικό των ψυχρών υλικών για τη μείωση της ενεργειακής κατανάλωσης για δροσισμό. Το προς μελέτη κτίριο ανεγέρθηκε το 1998 και έκτοτε στεγάζει τα γραφεία και τις υπηρεσίες του Δήμου Αχαρνών. Το κτίριο βρίσκεται στη Λεωφόρο Φιλαδέλφειας 87 & Μπόσδα, Αχαρνές.

Το Εργαστήριο Δομημένου Περιβάλλοντος και Διαχείρισης Ενέργειας της σχολής Μηχανικών Περιβάλλοντος, Πολυτεχνείο Κρήτης με επιστημονική υπεύθυνη την Κα Κολοκοτσά Διονυσία, τοποθέτησε μετρητές στους εσωτερικούς και εξωτερικούς χώρους των ορόφων. Αυτοί περιγράφονται παρακάτω αναλυτικά:

<u>ΕΞΩΤΕΡΙΚΟΙ ΧΩΡΟΙ</u>

1) **Θερμόμετρα τύπου Tinytag**

   Για τη μέτρηση της θερμοκρασίας του αέρα και της υγρασίας χρησιμοποιήθηκε καταγραφικό τύπου Tinytag. Το καταγραφικό τοποθετήθηκε σε ύψος 1,80μ προστατευμένο εντός μικρού μετεωρολογικού κλωβού ώστε να μην υφίσταται την επίδραση των διαφόρων ακτινοβολιών. Η καταγραφή και των δύο μεγεθών πραγματοποιήθηκε ανά 15 λεπτά.

2) **Θερμόμετρα τύπου HH309 Omega data loggers**

   Αυτού του τύπου θερμόμετρα μετρούν επιφανειακή θερμοκρασία σε εξωτερικούς χώρους με την βοήθεια ηλεκτροδίων τα οποία προσκολλούνται στις επιφάνειες προς μελέτη. Χρησιμοποιήθηκαν 3 θερμόμετρα αυτού του τύπου, τα οποία τοποθετήθηκαν ως εξής:

- Ένα θερμόμετρο τοποθετήθηκε στην ταράτσα του 2ου ορόφου. Σε αυτό τον μετρητή επιλέχθηκε η καταγραφή θερμοκρασίας τεσσάρων σημείων. Η καταγραφή ξεκίνησε στις 01/08/2014 και ολοκληρώθηκε στις 02/09/2014 με συχνότητα καταγραφής δεδομένων τα 10 λεπτά.
- Δύο θερμόμετρα τοποθετήθηκαν σε διαφορετικά σημεία του εξωτερικού χώρου του 3ου ορόφου. Κατά τον ίδιο τρόπο τοποθετήθηκαν στο 1ο θερμόμετρο τρία ηλεκτρόδια καταγραφής επιφανειακής θερμοκρασίας και στο 2ο τέσσερα ηλεκτρόδια. Η καταγραφή των δεδομένων ξεκίνησε στις 01/08/2014 και έληξε για το 1ο θερμόμετρο στις 02/09 και το 2ο στις 04/09. Η συχνότητα καταγραφής παρέμεινε και αυτή στα 10 λεπτά.

3) Θερμοκάμερα τύπου FLIR

Στις 04/09 πραγματοποιήθηκε θερμογράφηση των εξωτερικών χώρων των δύο ορόφων στις 09:45 πμ. Αυτή περιελάμβανε πλήρη θερμογράφηση όλων των επιφανειών (οριζόντιων και κάθετων) των εξωτερικών χώρων. Οι φωτογραφίες αυτές έπειτα συγκρίθηκαν με φωτογραφίες κοινής κάμερας για την αξιολόγηση των διακυμάνσεων στις θερμοκρασίες.

ΕΣΩΤΕΡΙΚΟΙ ΧΩΡΟΙ

4) Θερμόμετρα τύπου Supco LOGiT Series

Ο τύπος αυτών των θερμομέτρων καταγράφει την θερμοκρασία και την σχετική υγρασία των εσωτερικών χώρων. Τοποθετήθηκαν 3 θερμόμετρα τέτοιου τύπου στον εσωτερικό χώρο (γραφεία εργαζομένων) του 2ου ορόφου και ένα θερμόμετρο στον 3ο όροφο. Η έναρξη καταγραφής των δεδομένων επιλέχθηκε η 31/07/2014 με συχνότητα καταγραφής τα 10 λεπτά.

Στο πλαίσιο της 2ης φάσης του έργου, πραγματοποιήθηκε έρευνα για την μελέτη των οπτικών ιδιοτήτων των καινοτόμων ψυχρών υλικών που θα χρησιμοποιηθούν στην πιλοτική εφαρμογή του ερευνητικού προγράμματος MED MAIN και σύγκριση των ιδιοτήτων αυτών με συμβατικά υλικά κατασκευής κτιρίων. Πιο συγκεκριμένα έγινε καταγραφή των οπτικών ιδιοτήτων διαφόρων υλικών που μπορούν να χρησιμοποιηθούν στην πιλοτική εφαρμογή στο κτίριο του Δήμου Αχαρνών και στην πλατεία του Δήμου. Επίσης δόθηκαν οι απαραίτητες τεχνικές προδιαγραφές και τα πρότυπα ώστε να προχωρήσει ο Δήμος σε προμήθεια των κατάλληλων υλικών για την εφαρμογή.

Στο πλαίσιο της 3ης φάσης του ερευνητικού προγράμματος MED-MAIN πραγματοποιήθηκε η εφαρμογή καινοτόμων ψυχρών υλικών και συγκριτική αξιολόγηση των ενεργειακών χαρακτηριστικών που αποκτούν οι χώροι εφαρμογής τους. Η εφαρμογή των ψυχρών υλικών πραγματοποιήθηκε σε δύο χώρους. Πρώτος ήταν το δημοτικό κτίριο που στεγάζει τμήμα των κεντρικών υπηρεσιών του Δήμου Αχαρνών. Η εφαρμογή πραγματοποιήθηκε σε τμήματα του δευτέρου και τρίτου ορόφου του κτιρίου. Δεύτερη περιοχή εφαρμογής ήταν η πλατεία του Δήμου Αχαρνών. Η εφαρμογή πραγματοποιήθηκε σε τμήμα πεζόδρομου μπροστά από ένα σχολικό κτίριο. Τα ψυχρά υλικά επιλέχθηκαν έτσι ώστε οι ιδιότητες ηλιακής ανακλαστικότητας (SR) και εκπομπής (e) να είναι σύμφωνα με τα πρότυπα ASTM E903 / ASTMG159 and emissivity ASTM C1371. Μετά από την εφαρμογή των ψυχρών υλικών πραγματοποιήθηκαν μετρήσεις θερμοκρασίας εσωτερικού και εξωτερικού περιβάλλοντος στο κτίριο του Δημαρχείου, όπως επίσης και μετρήσεις θερμοκρασίας επιφάνειας εδάφους στο χώρο εφαρμογής των ψυχρών υλικών στην πλατεία του Δήμου Αχαρνών. Επιπλέον, πάρθηκαν εικόνες θερμοκάμερας με τα εξής χαρακτηριστικά:

IR information	Value
Imager type	THV 570
Imager serial number	348016
Imager lens	24
Imager filter	NOF
Imager range min	-20,0°C
Imager range max	120,0°C
Object parameter	Value
Emissivity	0,95
Object distance	1,5 m
Ambient temperature	20,0°C
Atmospheric temperature	20,0°C
Transmission	0,99
Relative humidity	0,50

Στη συνέχεια αναπτύχθηκε η προσομοίωση του κτιρίου του Δημαρχείου στο μοντέλο Energy Plus, και συγκρίθηκαν τα αποτελέσματα του μοντέλου με τις πραγματικές μετρήσεις ώστε να δοθεί η ακριβέστερη αποτύπωση του κτιρίου σε υπολογιστικό περιβάλλον και να γίνει ο υπολογισμός των ενεργειακών κερδών.

Τέλος αναπτύχθηκε επίσης το μοντέλο του περιβάλλοντα χώρου της περιοχής του πεζοδρομίου όπου εφαρμόσθηκαν τα ψυχρά υλικά σε ακτίνα 100m, στο μοντέλο Envimet, ώστε να μελετηθεί η αλλαγή στο μικροκλίμα της περιοχής, ήτοι η επιφανειακή θερμοκρασία και η θερμοκρασία σε ύψος 1,8m. Μετά την εφαρμογή των ψυχρών υλικών αξιολογήθηκε η ενεργειακή κατανάλωση στο κτίριο του δημαρχείου και το μικροκλίμα στο χώρο μπροστά από το σχολικό κτίριο. Η υλοποίηση των παραπάνω δράσεων επιτεύχθηκε μέσα από τη συνεργασία του Δήμου Αχαρνών και του Πολυτεχνείου Κρήτης.

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1 INTRODUCTION

One of the main problems of modern urban life nowadays is the continuously increasing urban temperature resulting to the well-known urban heat island phenomenon. Urban Heat Island (UHI) effect causes an increase of air temperature in cities versus suburban areas, resulting in the rapid increase in energy consumption for cooling during summer. The ongoing growing urbanization rate, in fact, exacerbates the problem as more and more part of natural vegetation is converted into structured urban areas.

The search for durable solutions to address the phenomenon, led the scientific community in the development of various technologies. One of them, the synthesis technology of reflective materials in recent years is preferred over multiple applications because of mild adjustment in urban structures.

In the present diploma thesis application of cold material (ceiling tiles - paving stones) is performed on Acharnon municipality hall - Attica under the European MAIN MED Pilot Case Study program undertaken to prepare from the Environmental Engineering department of the University of Crete. The purpose of this research is to perform experimental measurements and analysis concerning the potential of energy efficiency and environmentally innovative cool materials through a series of measurements. The present work is executed in the framework of the tasks and actions undertaken by the Municipality Acharnes as a partner in the program MAIN - MED. The experimental analysis includes a series of measurements performed in the Acharnes Municipality Building in order to evaluate the potential of cool materials to reduce the energy demand for cooling.
For performing the master thesis, climatic measurements in interiors and exteriors of the town hall were made before applying cold tiles. With computer simulation programs ENVI-MET and ENERGY PLUS cold materials were placed, from where exported comparative results.

Last but not least, I would like to thank my supervisor, Ms. Kolokotsa Dionysia, for the knowledge and the assistance she gave me and also the patience showed until the end of this diploma thesis.

2 THEORITICAL BACKGROUND

2.1 HEAT ISLAND EFFECT

Heat island effect is known for almost a century and is related to higher urban temperatures compared to the adjacent suburban and rural areas. Higher urban temperatures are due to the positive thermal balance of urban areas caused by the important release of anthropogenic heat, the excess storage of solar radiation by the city structures, the lack of green spaces and cool sinks, the non-circulation of air in urban canyons and the reduced ability of the emitted infrared radiation to escape in the atmosphere of the phenomenon are much better documented. Summer urban heat islands with daytime average air temperatures 5.6°C higher than the surrounding rural areas are present in many cities around the world (Kyriakodis & Santamouris, 2016).

Heat island in the city of Athens, Greece, doubles the cooling load of buildings and almost triples their peak electricity demand, while decreasing the Coefficient of Performance (COP), of mechanical cooling systems up to 25%. The indoor thermal comfort levels are seriously decreased and health problems are intensified due to the increase of cooling energy (air-conditions) during the warm seasons of the year.

Building materials and their thermal properties play significant role to the heat island effect. The presence of dark colored surfaces, particularly roofs and pavements, absorb solar radiation during daytime and reradiate it as heat during the night. Moreover the replacement of natural soil and vegetation by the urban materials reduces the potential to decrease ambient temperature through evapotranspiration and shading.

Mitigation techniques developed by years' of research aim to balance the thermal budget of cities by increasing thermal losses and decreasing the corresponding gains. Among the more important of the proposed techniques are those targeting to increase the albedo of the urban environment, to expand the green spaces in cities and to use the natural heat sinks in order to dissipate the excess heat.

Albedo, or reflection coefficient, is the diffuse reflectivity or reflecting power of a surface. It is the ratio of reflected radiation from the surface to incident radiation upon it. Its dimensionless nature lets it be expressed as a percentage and is measured on a scale from zero for no reflection of a perfectly black surface to 1 for perfect reflection of a white surface.

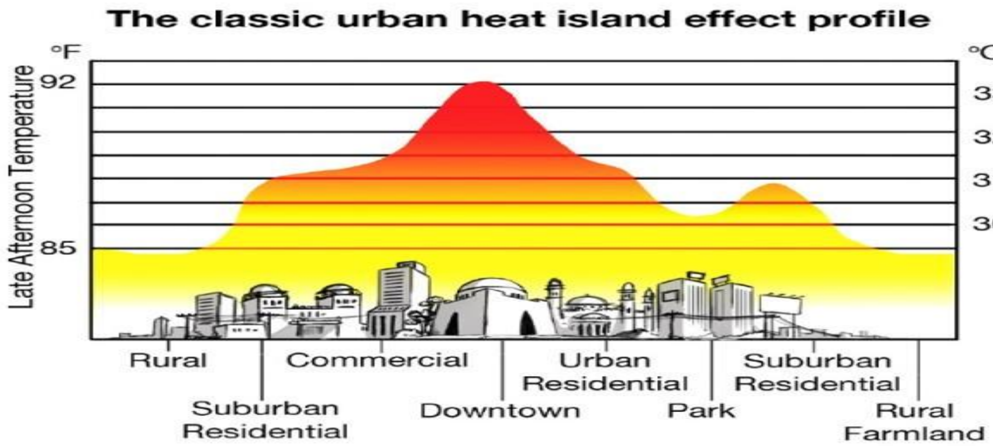

Figure 1 Description of Urban Heat Island effect diagrammatically (http://edu.glogster.com/?ref=com)

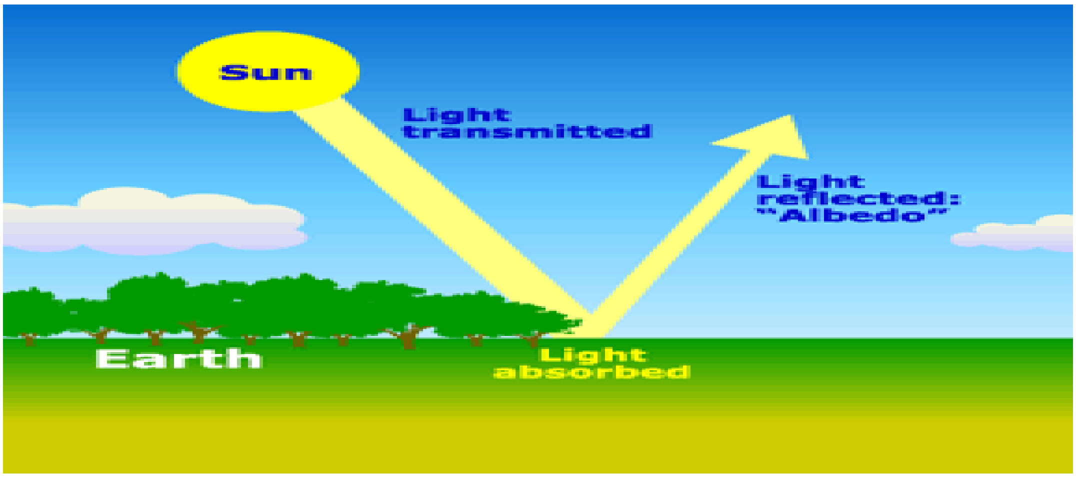

Figure 2 Description of ''Albedo'' (http://edu.glogster.com/?ref=com)

2.2 COOL MATERIALS

Highly reflective, or 'cool materials' are a cost effective, environmentally friendly and passive technique which contributes to achieving energy efficiency in buildings by lowering energy demand for cooling and improving the urban microclimate by lowering surface and air temperatures. Cool materials are characterized by:

- High solar reflectance (SR) - Albedo
- High infrared emittance (e)

Thermal emittance is the ratio of the radiant emittance of heat of a specific object or surface to that of a standard black body. Emissivity and emittivity are both dimensionless quantities given in the range of 0 to 1, but emissivity refers to a material property (of a homogeneous material), while emittivity refers to specific samples or objects.

For building products, thermal emittance measurements are taken for wavelengths in the infrared. Determining the thermal emittance and solar reflectance of building materials, especially roofing materials, can be very useful for reducing heating and cooling energy costs in buildings. Combined index Solar Reflectance Index (SRI) is often used to determine the overall ability to reflect solar heat and release thermal heat. A roofing surface with high solar reflectance and high thermal emittance will reflect solar heat and release absorbed heat readily. High thermal emittance material radiates thermal heat back into the atmosphere more-readily than one with a low thermal emittance.

If the cool surface is on the building envelope, this would result in decreasing the heat penetrating into the building. This will result in significant reduction of surface temperature something which will contribute to decrease the temperature of the ambient air as the heat convection intensity from a cooler surface is lower (See Figure 3). Fig. 4 depicts four concrete pavement tiles. Two of them (1 and 4) have been painted with cool coatings with a solar reflectance of 0.82 and 0.83 respectively, number 2 has been painted with a black coating (SR = 0.05) and the last one (number 3) is left unpainted but has an off-white color (SR = 0.65).

The impact of solar reflectance on surface temperature is clearly depicted in the infrared image (See Figure 4). Measurements were performed under hot summer conditions in Athens, Greece.

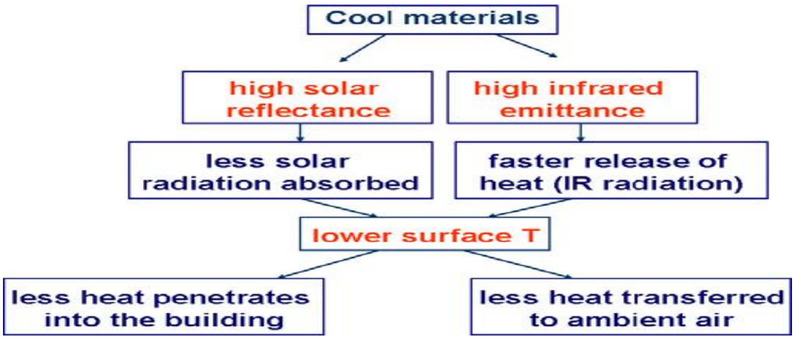

Figure 3 Effects of using cool materials

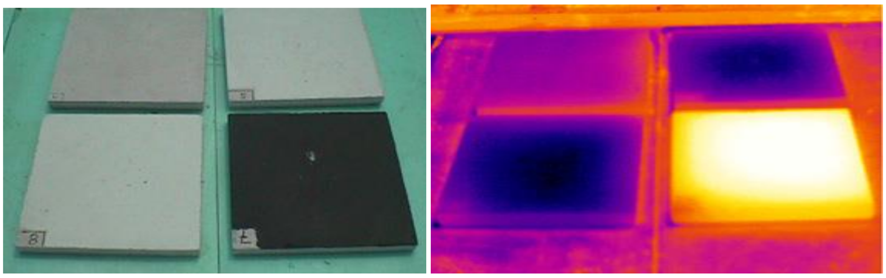

Figure 4 Thermal differences between cool materials and non

The SRI has a value of zero (for the standard black surface) and of 100 (for the standard white surface). From the definition of the SRI it is expected that very hot materials can actually have negative values and very cool materials can have values greater than 100. As mentioned previously cool materials are defined as materials having high solar reflectance and high infrared emittance. Another way to assess how "cool" is a material, is to calculate its solar reflectance index (SRI). This is an index that incorporates both solar reflectance and infrared emittance in a single value.

Cool materials can be divided into two main categories: cool materials for roofs and cool materials for roads and pavements. The main characteristics and benefits of each category are described in the following paragraphs.

2.2.1 COOL ROOFING MATERIALS

Roofs present a very high fraction of the exposed urban area. It is estimated that urban areas occupy almost 1% of all land, and the total roof area of the urban world is close to 3.8×10^{11} m^2.

In general, there are two types of roofs, low-slope or flat roofs with an inclination of less than 9.5° from the horizontal, and steep-slope roofs with an inclination of more than 9.5° from the horizontal. Low-slope roofs are found on the usually on commercial, industrial, warehouse, office, retail, and multi-family buildings, as well as some single-family homes while steep-slope roofs are found most often on residences and retail commercial buildings and are generally visible from the street. Most cool roofs focus on the low-sloped roofing sector, but cool roof options are becoming available for the steep-sloped sector as well.

Main roof products include single-ply membranes, modified bitumen roofs, coatings, built-up roofs, metal roofs, shingles and tiles. For all these roof types exists or has recently been developed, a cool option. As reported by Levinson et al. (2005a,b), a built-up roof can have an initial reflectance of 0.04 if covered with a smooth, black asphalt surface, or 0.80 if coated with a smooth, white surface. A single-ply membrane can have an initial reflectance of 0.04 if black, 0.20 if gray, or 0.80 if white.

Modified bitumen with mineral surface has a reflectance of 0.1–0.2 but if a white coating is applied on top, the solar reflectance reaches a value of 0.65–0.7. For all these cases the emissivity is considered 0.9. Cool white coatings (usually elastomeric or cementitious) have typically solar reflectance values ranging from 0.7 to 0.85 and an emissivity about 0.85–0.90. Aluminium coatings, silver in color, contain aluminium flakes in an asphalt-type resin. Aluminium flakes enhance the solar reflectance to above 0.5 for the most reflective coatings and although such value is significantly higher compared to the performance of a black material (SR = 0.05), the aluminium content has the offsetting effect of lower infrared emittance ranging usually from 0.25 to 0.65.

For steep-slope roofs that are typically non-white and visible, cool colored materials have been developed addressing the desire for different appearances and potential glare problems. These cool colored materials have been developed by using infrared reflective pigments and other techniques. According to ASTM G173-03 Standard Tables for Reference Solar Spectral Irradiance at Air Mass 1.5 (see below the detailed description), about 50% of the solar energy arrives as near infrared invisible energy. A surface that absorbs in the visible part of the solar spectrum in order to have a specific color, but strongly reflects in the near infrared part, would have an overall solar reflectance that is higher compared to a similarly colored surface (same visible reflectance) that absorbs also in the near infrared part.

Levinson et al. (2007a) have developed methods based on one-coat (substrate/topcoat) and two-coat (substrate/ basecoat/topcoat) systems depending on the near infrared (NIR) reflectance of the substrate. For metal and clay tile products that have originally high NIR reflectance, a topcoat containing NIR reflecting pigments has been used. For grey-cement concrete tile or grey aggregate that have low NIR reflectance, a cool topcoat or basecoat with high NIR backscattering is necessary. Applying the one-coat (cool topcoat) process to metal and glazed clay-tile roofing products, they report NIR reflectance of 0.50 and 0.75, respectively.

The application of a thick coating colored by rutile white NIR scattering pigments on gray-cement concrete tiles achieved NIR reflectance as high as 0.60. A two-coat process (TiO_2 rutile white basecoat + topcoat colored by NIR-transparent organic pigments) resulted in a NIR of 0.85. For asphalt shingles this method yielded a NIR of 0.45.

Levinson et al. (2010) also developed a novel technique based on a two-layer spray coating process where both layers are pigmented latex paint based on acrylic or PVDF/acrylic technology, that increases solar reflectance of concrete tiles and asphalt shingles. Instead of using thick white acrylic basecoats and cool color acrylic topcoats as in the previous study, this factory applied method uses as a first layer a TiO_2 rutile white and a second layer cool color topcoat with weak NIR absorption and/or strong NIR backscattering.

The results show significant increase of the initial solar reflectance that for the cool colored tiles ranged from 0.26 (dark brown) to 0.57 (light green) and for the cool colored shingles from 0.18 (dark brown) to 0.34 (light green). Synnefa et al. (2007) have developed ten prototype cool colored coatings/paints using near infrared reflective complex inorganic color pigments and an acryl based binder. Compared to conventionally pigmented color matched coatings, the cool colored coatings were found to have the same visible reflectance, but they exhibit a more selective absorption band in the infrared part of the spectrum. The measured differences in the solar reflectance range from 2 (light blue) to 22 (for the black paint).

A number of studies (Bretz and Akbari, 1997; Levinson et al., 2005a, 2007a,b, 2010a,b; Synnefa et al., 2006, 2007; Stathopoulou et al., 2009; Prado and Ferreira, 2005; LBNL cool roofing materials database) report values of the solar reflectance of conventional and cool roofing materials. Furthermore, Energy Star Roof Products voluntary program, has a list of cool roofing materials that meet certain criteria (low-slope roofs: initial solar reflectance > 0.65 and aged SR > 0.50, for steep-slope roofs: SRinitial > 0.25 and SR aged > 0.15, emissivity should be reported).

2.2.1.1 THERMAL PERFORMANCE OF COOL ROOFING MATERIALS

The main factors affecting the thermal performance of the surface are the solar reflectance and the infrared emittance, considering that the roof is insulated underneath.

During the day the dominant factor is solar reflectance and emissivity affects less the surface temperature but during night-time the surface temperature and the infrared emittance are strongly correlated which means that emissivity becomes the most important factor affecting the thermal performance of a surface.

A number of experimental studies (Synnefa et al., 2006; Konopacki et al., 1998; Parker and Sherwin, 1998; Simpson and McPherson, 1997; Taha et al., 1992; Miller et al., 2004) have demonstrated that surfaces with low solar reflectance and high infrared emittance (e.g. black coating, asphalt shingle, black gravel surface) can reach temperatures as high as 75–80°C, surfaces with medium to high solar reflectance and low infrared emittance (e.g. unpainted metal roofs, aluminum coatings) can reach temperatures as high as 60–75°C and surfaces with high solar reflectance and infrared emittance (cool white coatings, white membranes, etc.) can reach temperatures of averagely 45°C, depending of course on local ambient conditions.

Synnefa et al. (2006) have measured the optical properties and the thermal performance of 14 types of reflective coatings (white and aluminum ones). They have found that a cool coating can reduce a white concrete tile's surface temperature under hot summer conditions by 4°C and during the night by 2°C. It can be warmer, than the ambient air by only 2°C during the day and cooler than the ambient air by 5.9°C during the night. Cool coatings were found to have a superior thermal performance even compared to other cool materials like white marble and white mosaic. The statistical analysis carried out showed that the differences in the thermal behavior that were observed even among coatings of the same type and color, are due mainly to the differences in their reflectance which mainly affects their performance during the day and their emissivity that is the predominant factor affecting the thermal performance of the samples during the night.

These studies refer to mid-latitude summer conditions. Replacing dark colored materials with materials of the same color containing near infrared reflecting pigments also reduces surface temperatures significantly. Synnefa et al. (2007) measured the temperature differences between 10 prototype cool colored coatings and 10 conventionally pigmented coatings of the same color from August to December. The maximum temperature difference observed was 10.2°C for summer conditions (corresponding to a difference in solar reflectance of 0.22). During winter, this temperature difference between cool and standard colored coatings diminishes to less than 1°C which is desirable in order to avoid any heating penalty. Miller et al. (2005) report that applying a cool coating to medium-profile concrete tile reduced the heat penetrating the ceiling of a demonstration home by about 70% of that measured for an identical home with the same standard production medium - profile tile.

2.2.1.2 BENEFITS OF COOL ROOFING MATERIALS

The benefits from the use of cool roofing materials arise from their lower surface temperature. It can be accounted for at building, city and global scale. At building scale, the application of cool materials results in the reduction of cooling energy use and peak energy demand for cooling, as less heat is transferred from the cooler roof into the building. A large number of experimental studies have been performed in residential and non-residential buildings documenting these savings. Haberl and Cho (2004) have performed a literature review and based on 27 articles, they report that cooling energy savings from the application of cool materials (mainly white roofing systems) on residential and commercial buildings vary from 2% to 44% and averaged about 20%. The literature indicated that the peak cooling energy savings from cool roofs are between 3% and 35%, which depends on ceiling insulation levels, duct placement and attic configuration.

Levinson et al. (2005a,b) have compiled several experimental studies on the impact of cool materials in non-residential buildings in warm-weather climates and report measured summertime daily air-conditioning savings and peak demand reductions of 10–30%. More extreme values have been observed (2–40%). Miller et al., 2005 have measured energy savings of 15% by applying a cool brown coating on conventionally pigmented brown coated roof tiles (DSR = 0.3). These values depend on a lot of parameters like the building characteristics and use, local ambient conditions, etc. Energy savings are found to be more significant in older houses that have little or no insulation. Akbari et al. (2005) calculated energy savings from increasing roof solar reflectance from a typical dark roof of 0.1 to a cool-colored roof of 0.4, for various climatic conditions worldwide. The estimated savings range from approximately 250 kWh per year for mild climates to over 1000 kWh per year for very hot climates.

Increasing the roof solar reflectance can potentially lead to the increase of heating energy demand. Studies have shown that this increase is far less important than the corresponding cooling energy savings, resulting into positive net savings for warm/moderate climatic conditions. This is explained by the fact that during winter, the sun is much lower in the sky and solar radiation arriving to a horizontal surface less intense.

There is a higher probability of overcast skies and there is less solar availability (fewer hours of sunshine), so less total energy arrives on a surface to be absorbed or reflected over the same period of time as during the summer.

If the building is not air conditioned, the reduced heat transfer from the cooler roof results in lower indoor temperatures and improved thermal comfort conditions. Various monitoring and simulation studies indicate indoor temperature decrease ranging averagely from 1 to 2.7°C. Cool roofs provide additional benefits associated with sustainability. It has been argued that the application of cool materials has also the effect of increasing the lifetime of the roof.

This can be explained first because of their lower temperature. The degradation of materials is associated with chemical reactions that progress faster with higher temperatures. Furthermore, temperature swings impose stresses due to differential thermal expansion. It has been demonstrated that daily fluctuations of surface temperature for cool materials are much less significant than those for a dark, absorptive surface. Synnefa et al. have demonstrated that daily fluctuations for a conventional dark colored roof material (SR = 0.18) reach 25°C during summer and when this material is replaced by a cool one (SR = 0.89) the daily surface temperature fluctuations dropped to 8°C. Therefore, the roof surface suffers from less thermal fatigue.

In addition, a cool white material for example can absorb the UV part (UV photons have enough energy that allows them to break many chemical bonds) of solar radiation preventing it from reaching and thus protecting the surface underneath. Large scale increases of urban albedo can affect the urban microclimate by lowering air temperatures, due to less heat transfer from a cooler surface to the ambient air, and mitigating the heat island effect. Several modeling studies have used mesoscale meteorological modeling in order to estimate the impact of surface modification scenarios (increase of surface albedo and/or vegetation cover using realistic values for the scenarios) and report a temperature change pattern consisting of a decrease during daylight hours of averagely 1–3°C and less significant or no decrease during the night in Athens.

For the case of increased albedo (from 0.2 to 0.8) it was demonstrated that the total number of hours for which the air temperature is more than 30°C during daytime by more than 60h. This decrease in air temperature resulting from the large-scale use of cool materials can lead to a reduction of cooling energy use and peak cooling loads (Rosenfeld et al., 1998; Taha et al., 1999; Akbari and Taha, 1992). Akbari and Konopacki (2005) have calculated the cooling energy savings due to the application of heat island mitigation strategies (application of cool materials and increase in vegetation cover) for 240 regions in the United States. It was found that for residential buildings, the cooling energy savings vary between 12% and 25%, for office buildings between 5% and 18%, and for commercial (retail stores) buildings between 7% and 17%.

Furthermore, the city-scale application of cool materials can potentially reduce air pollution both directly and indirectly (Rosenfeld et al., 1995, 1998). Direct reduction of air pollution is due to the fact that less cooling energy is used; therefore fewer power plant emissions are produced (CO2, NOx, and PM10 particles). Indirect air pollution reductions reflect the fact that the reaction of ozone formation (that produces smog) accelerates at higher temperatures, therefore at lower urban air temperatures the probability of smog formation is decreased (Taha, 1997).

At the global scale, Akbari et al. (2009) have calculated that widespread adoption of high albedo structural surfaces ("cool roofs" and "cool pavements" that would increase albedo of urban areas by 0.1) in low- and mid-latitude cities worldwide would generate a significant negative radiative forcing at a global scale, and they estimate that this could potentially contribute to mitigating global warming effect by offsetting the equivalent of 44 Gt of CO_2 emissions.

2.2.2 COOL PAVING MATERIALS

A significant percentage of urban and suburban surfaces are covered by pavements including roads, parking spaces, etc. They absorb solar radiation, store this energy in the pavement subsurface, and they release it as infrared radiation and through convection to their surrounding area during the evening and night-time. Consequently their thermal characteristics are very significant as they affect the air temperature of the lowest layers of the urban atmosphere contributing to the formation of the urban heat island effect.

2.2.2.1 TECHNOLOGIES - PROPERTIES

Solar reflectance values of conventional pavements (made of concrete and asphalt) are usually ranging from 0.04 to 0.45. Other materials are also used to pave surfaces of the urban environment like stone, rubber, granite, marble, pebble but they are not as common. Conventional paving materials can reach surface temperatures of 48–67°C. Table 1 shows the solar reflectance of some common paving materials.

Table 1 Solar reflectance of common paving materials

Material	Solar Reflectance
Black conventional asphalt	0.04 – 0.06
Aged conventional asphalt	0.09 – 0.18
White topping on asphalt	0.3 – 0.45
Cool colored thin layer asphalt	0.27 – 0.55
Grey concrete slab	0.12 – 0.2
White concrete slab	0.6 – 0.77
Cool colored pigmented concrete block (red, yellow, grey)	0.45 – 0.49
Cool colored pigmented concrete tile (grey, green, beige)	0.61 – 0.68
Photocatalytic white concrete tile	0.77
White marble	0.65 – 0.75
Dark colored marble	0.2 – 0.4
Red rubber tile	0.07 – 0.1
Dark colored granite	0.08 – 0.12

However, there are more parameters than this of solar reflectance which affect the performance of the material. These are emissivity such as permeability, thermal conductivity, heat capacity, and convection, and need to be taken seriously into account for the assessment of their performance. Cool pavements refer to a range of existing and new materials that tend to store less heat and may have lower surface temperatures compared with conventional products.

As reported in Cambridge Systematics, Inc., possible mechanisms for creating a cool pavement that have been studied to date are:

- increased surface reflectance, which reduces the solar radiation absorbed by the pavement,
- increased permeability, which cools the pavement through evaporation of water and
- a composite structure for noise reduction, which also has been found to emit lower levels of heat at night.

In order to increase the solar reflectance of a pavement several methods have been proposed. For asphalt pavements one technique is to use white or light colored aggregate (gravel, white stone, etc.) or pigment in the asphalt mix, increasing solar reflectance by about 0.3. Chip seals is a maintenance technique that consists of pressing rock chips over an asphalt binder so that the solar reflectance of the road is determined by the reflectance of the light color aggregate. Concrete pavements can become cooler if lighter color binders, aggregates, and sands experimented with the composition and environmental exposure of the albedos of Portland cement concrete and developed concrete samples with albedos as high as 0.77. They also found that concrete albedo is more strongly correlated with cement albedo.

Increasing the solar reflectance of pavements can potentially cause glare problems, when driving for example, reducing also visibility of the white line; or it may not be appropriate in places where people will be uncomfortably exposed to the reflected radiation for long periods. For this reason there is an effort to develop cool colored pavements, i.e. pavements that absorb in visible part of the spectrum in order to be dark in appearance but exhibit high reflection in the NIR part of the solar spectrum (similarly to cool roofing materials).

2.2.2.2 BENEFITS OF COOL PAVEMENTS

The benefits of cool pavements result from the fact that increasing the solar reflectance of a paved surface keeps it cooler under the sun, reducing convection of heat from pavement to air and also thereby decreasing the ambient air temperature. As mentioned previously, lower air temperatures decrease demand for cooling energy and slow the formation of urban smog. Akbari et al. (2001) report measured data that clearly indicate that increasing the pavements' solar reflectance by 0.25 causes significant decrease of the pavement temperature by 10°C. It is an indisputable fact that the combined effect of increasing the albedo of both roofs and pavements can reduce the summertime urban temperature and improve the urban air quality.

Apart from these benefits it has been shown, that reduced pavement surface temperatures can result in increasing the useful life (durability) of pavements and reduce waste from maintenance. Furthermore, reflective pavements can enhance visibility at night, potentially reducing lighting requirements and saving money and energy.

It should be pointed out that although the application of cool pavements can contribute to the reduction of surface temperatures, it is important that a thorough study is carried out in order to estimate the impact of such surfaces at a specific site on the surrounding microclimate, avoiding increased glare or unwanted solar gains and ensure optimum application of such materials.

2.3 POLICY and LEGISLATION

The technology, policies, and public acceptance of cool roofs are far more advanced than those of cool pavements. Cool roofs policies are typically presented in the form of building standards, public awareness information programs, and rebate and incentives programs. Such policies have not been implemented for cool pavements. An aggressive international program to install cool roof and cool pavements can potentially increase the solar reflectance of majority of roof and paved surfaces within a 20-year period.

Provisions for cool roofs in energy-efficiency standards can promote the building- and climate-appropriate use of cool roofing technologies. Cool-roof requirements are designed to reduce building energy use, while energy-neutral cool-roof credits permit the use of less energy-efficient components (e.g., larger windows) in a building that has energy-saving cool roofs. Both types of measures can reduce the life-cycle cost of a building.

Since 1999, several widely used building energy-efficiency standards, including ASHRAE 90.1, ASHRAE 90.2, the International Energy Conservation Code, and California's Title 24 have adopted cool-roof credits or requirements. The techniques used to develop the ASHRAE and Title 24 cool-roof provisions can be used as models to address cool roofs in building energy-efficiency standards worldwide.

Building energy-efficiency standards typically specify both mandatory and prescriptive requirements. Mandatory requirements, such as practices for the proper installation of insulation, must be implemented in all buildings subject to the standard. A prescriptive requirement typically specifies the characteristics or performance of a single component of the building (e.g., the thermal resistance of duct insulation) or of a group of components (e.g., the thermal transmittance of a roof assembly). Prescribing the use of cool roofs in building energy-efficiency standards promotes the cost-effective use of cool roofs to save energy, reduce peak power demand, and improve air quality. Another option is to credit, rather than prescribe, the use of cool roofs.

This can allow more flexibility in building design, permitting the use of less energy-efficient components (e.g., larger windows) in a building that has energy-saving cool roofs. Such credits are energy neutral, but may still reduce peak power demand and improve air quality. They may also reduce the first cost of the building.

In much of the world, the design, construction, and materials used for residential and commercial buildings are guided by building codes. Building codes are an obvious leverage point for promoting cool roofs. The bulk of the codes are dedicated to ensuring the integrity of the building from a health and safety perspective, but the codes also cover matters relating to energy use, and have, in recent years, become increasingly inclusive of requirements that save energy in buildings as long such measures are cost competitive. Because building codes are focused on the energy savings potential of individual buildings, they do not consider the climate benefits of cool roofs or the micro-climate benefits of reducing the heat island effect. As a result, building codes inherently undervalue cool roofs within the suite of efficiency options (e.g., insulation, efficient windows, and radiant barriers).

The process for updates, degree of centralization, and level of enforcement of building codes vary greatly by country. For example, in the European Union (EU), building codes are decentralized, determined at the country level. The variation in building codes creates a range of different possible strategies for the promotion of cool roofs.

The European Union (particularly its southern countries that require significant summertime cooling) also offers significant opportunities. In February 2009, the European Cool Roof Council (ECRC) organized its first meeting to promote and provide support for installation of cool roofs in Europe.

2.3.1 GREEK POLICY FOR COOL ROOFS/PAVEMENTS

The Greek policy concerning cool roofs and pavements building materials is following the European policy except from several paragraphs which is described below.

Coatings of external floors, roofs, pavements and squares with cement tiles containing cold material (cool materials), white or colored, measuring 30 x 30 cm must have the following requirements:

- The required high reflectivity of cement-slab of concrete class will be imparted by incorporating cold material in the surface layer them, not coated, dusting or spreading cold material in conventional construction cement tiles.
- When called for the development of joints in tiling, the filling will be by cementitious material, resistant to high and low ambient temperatures, the to be applied carefully syringed jointing without overflows in surface of the plate.
- Prohibited in any case with slurry grouting mortar applicable to conventional paving, because in this way decrease occurs and / or loss of cold characteristics of the coating.
- The performance of cold cement slates dependent reflectivity of their surface to sunlight (Solar Reflectance, SR), and if not specified different study, the new plates will meet the minimum requirements of following table:

Table 2 "Cool" requirements of cement tiles - Greek Legislation and Policy

Product classification	Initial rate reflectivity to solar radiation (SR)	Initial rate reflectance in the near infrared spectrum	Initial rate reflectivity in the infrared
GROUP A (Slabs area - Disabled)	>=0.60	>=0.65	>=0.85
GROUP B (Shades – yellow, ocher, blue, green,)	>=0.50	>=0.50	>=0.85
GROUP C (White slabs)	>=0.40	>=0.50	>=0.85

The “cold” cement tiles, in terms of physical and mechanical characteristics and dimensional tolerances will satisfy the requirements of Standard ELOT EN 1339.

It will also be accompanied by reflectivity measurement laboratories tests reports to sunlight (Solar Reflectance, SR) (based on the Standards ASTM E 903 / ASTM G159) and the emissivity in the infrared (based Standards ASTM E408 / ASTM C1371).

Where cement slates with textured or embossed surface (striatal, stamped, etc.), laboratory measurements to determine the cold properties will relate possible smooth, homogeneous and uniform surface areas. For a square meter fully finished coating according to the study, materials and micro-situ material and workmanship the cost is 79,81€.

All the ASTM Standards concerning materials for cool roofs and pavements, it is described in the following section.

The required high reflectivity of the flags of the given category (exterior floor coating, pavements) will imparted by incorporating cold material in the surface layer them, not coated, dusting or spreading cold material in conventional blocks construction. The performance of cold flags depends on the reflectivity of the surface to sunlight (Solar Reflectance, SR), and unless otherwise specified in the study, the newer blocks will meet the minimum requirements of the following table:

Table 3 Requirements of cool pavement – Greek policy

Product classification	Initial rate reflectivity to solar radiation (SR)	Initial rate reflectance in the near infrared spectrum	Initial rate reflectivity in the infrared
GROUP A (Shades – yellow, ocher, orange)	>=0.50	>=0.50	>=0.85
GROUP B (Shades –blue, green, grey, brown)	>=0.40	>=0.50	>=0.85

The materials containing cool pavements in terms of physical and mechanical characteristics and dimensional tolerances should satisfy the requirements of Standard ELOT EN 1338.

It will also be accompanied by reflectivity measurement laboratories tests reports to sunlight (Solar Reflectance, SR) (based on the Standards ASTM E 903 / ASTM G159) and the emissivity in the infrared (based Standards ASTM E408 / ASTM C1371).

Where cement slates with textured or embossed surface (striatal, stamped, etc.), laboratory measurements to determine the cold properties will relate possible smooth, homogeneous and uniform surface areas. For a square meter fully finished coating according to the study, materials and micro-situ material and workmanship the cost is 79,81€.

2.4 COOL MATERIALS STANDARDS

Table 4 Reporting Standards ASTM for cool materials

ASTM E1980 – 01	Standard practice for calculating solar reflectance index of horizontal and sloped opaque surfaces
ASTM E903 – 96	Test methods for solar absorptance, reflectance, and transmittance of materials using integrating spheres
ASTM E408 – 02	Standard test methods for total normal emittance of surfaces using inspection meter techniques
ASTM G173	Standard Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface
ASTM G159 - 98	Standard Tables for References Solar Spectral Irradiance at Air Mass 1.5: Direct Normal and Hemispherical for a 37° Tilted Surface
ASTM C1371	Standard Test Method for Determination of Emittance of Materials Near Room Temperature Using Portable Emissometers

3 DESCRIPTION OF THE PILOT CASE STUDY BUILDING/AREA

The case study building was built in 1998 and since then it accommodates the offices and departments of the municipality of Acharnes. The building is located in Philadelphia 87 Avenue & Bosda, Acharnes. Acharnes is a suburban town in Attica, Greece. With 106,943 inhabitants (2011 census), it is the most populous municipality in East Attica. It is part of the Athens metropolitan area.

Figure 1 shows the aerial view of the building while Figure 2, Figure 3 Figure 4 and Figure 5 show the different sides of the building from the surrounded streets.

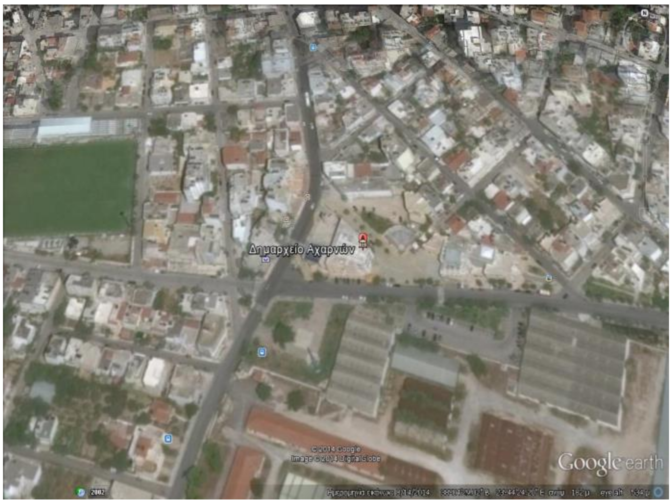

Figure 5 Aerial view of the area from Google Earth

Figure 6 Northern side of the town hall

Figure 7 Western side of the building

Figure 8 Southern side of the building

Figure 9 Eastern side of the town hall

The building is heated using oil fired boilers as well as heat pumps as a backup system. Heat pumps are mainly used for cooling. The parts of the town hall that will be studied and renovated using cool materials are the roof of the second and third floor (terrace).

The overall assessment for the cool materials is focusing on the 2nd and 3rd floor of the building which is attached to the flat roofs where the cool materials' testing will be performed.

3.1 DESCRIPTION OF THE BUILDING'S 2nd FLOOR & ROOF TERRACE

This floor houses the Directorate of Local Economic Development and the Department of Planning Applications. The external (to study) area is about 90 m^2.

The roof terrace is covered with tiles made of marble Verias. The tile's size is 30 cm ×30 cm. The photos below briefly describe the study area (Figure 6).

Figure 10 Different sides of second floor

3.2 DESCRIPTION OF THE BUILDING'S 3rd FLOOR & ROOF TERRACE

This floor houses the office of the General Director of the Municipality and some of the offices of the Directorate of Technical Services. The exterior of the third floor is estimated at approximately 200m^2. Moreover in this terrace, the roof tiles are made from Veria marble and their dimensions are 30 cm × 30 cm (Figure 11).

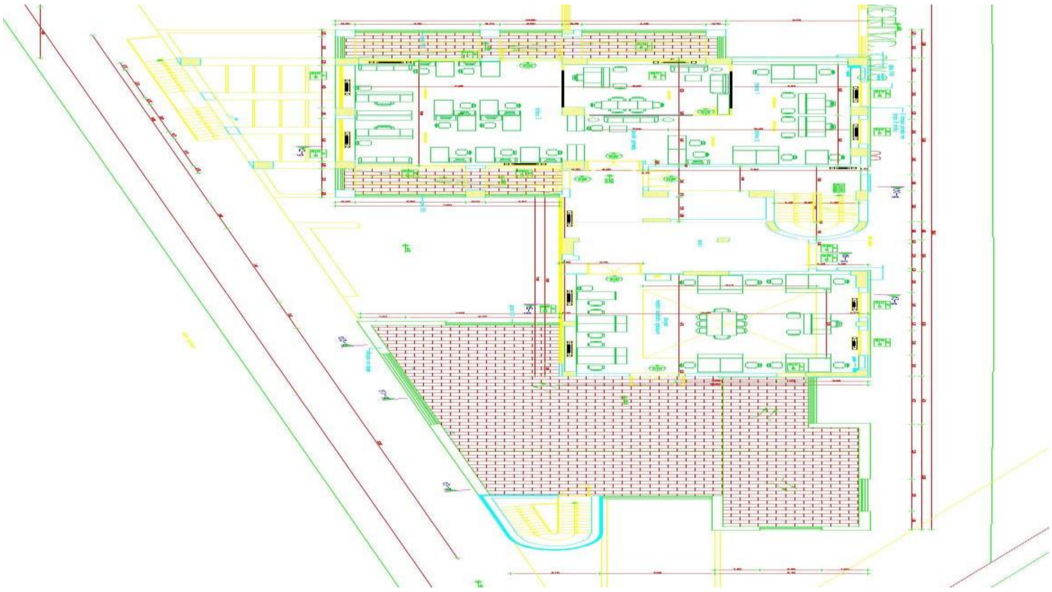

Figure 11 Top view of the third floor of the Municipality Building.

Figure 12 Different sides of 3rd floor

3.3 SHORT DESCRIPTION OF THE URBAN AREA

The intervention area for reconstruction using cool pavements was the central square of Saint Vlassios in Acharnes city. In the following picture we can see the exact position of the cool pavement application.

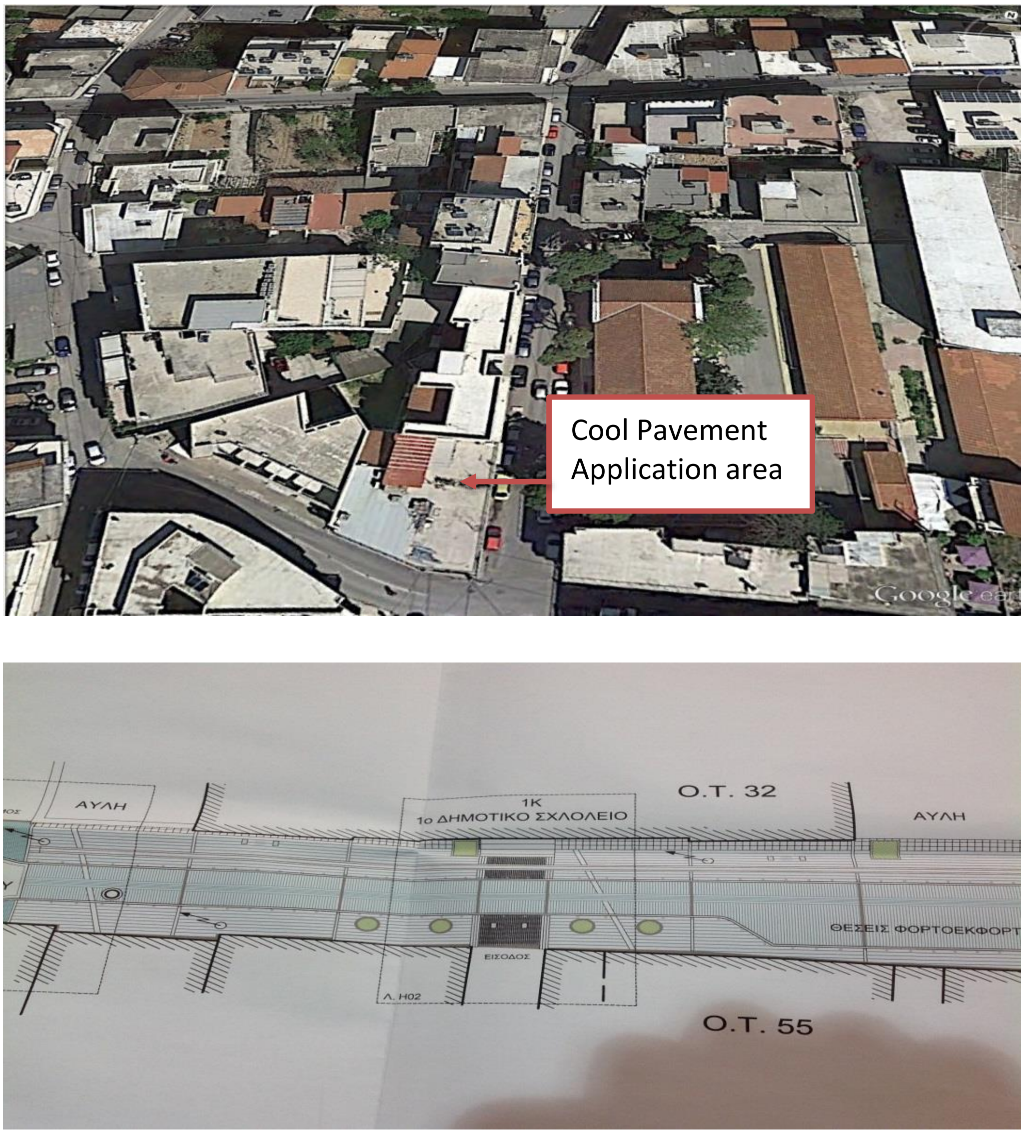

Figure 13 Top view of the cool pavement application area

4 MONITORING PROCEDURE & EQUIPMENT

The monitoring procedure (Kolokotroni, Gowreesunker, & Giridharan, 2011; Kolokotsa, Diakaki, Papantoniou, & Vlissidis, 2011; Romeo & Zinzi, 2011; Synnefa & Santamouris, 2012; Zinzi & Bozonnet, 2013) includes measurements of the outdoor climatic conditions, the indoor environmental parameters and the surface temperature measurements of the roof. All measurements were performed during summer 2014.

4.1 MEASUREMENTS OF METEOROLOGICAL/MICROCLIMATIC CONDITIONS

The outdoor conditions of the specific building were measured during summer 2014. More specifically:

1. Meteorological parameters measured: outdoor air temperature and outdoor relative humidity.
2. Instrumentation used: Logger type Tintag placed in a meteorological protection box (Figure 8).
3. Sample time 15 minutes.
4. Position: The logger was placed at a height of 1.80 m in the terrace of the second floor. (Figure 9)

Figure 14 Thermometer Tinytag

Figure 15 Position of logger Tinytag (See red circle)

4.2 MEASUREMENTS OF INDOOR ENVIRONMENTAL CONDITIONS

1. Parameters measured: Indoor air temperature and indoor relative humidity.
2. Instrumentation used: Thermometers (type: Supco LOGiT Series) were placed indoors of the 2nd and 3rd floor. (See Figure 16)
3. Sample time: 10 min
4. Position: Three Loggers were placed in the 2nd floor and one in the 3rd .The following photos describe in detail the position of the thermometers in both floors (See Figure 17, Figure 18, Figure 19 and Figure 20).

Figure 16 Supco LOGiT Thermometer

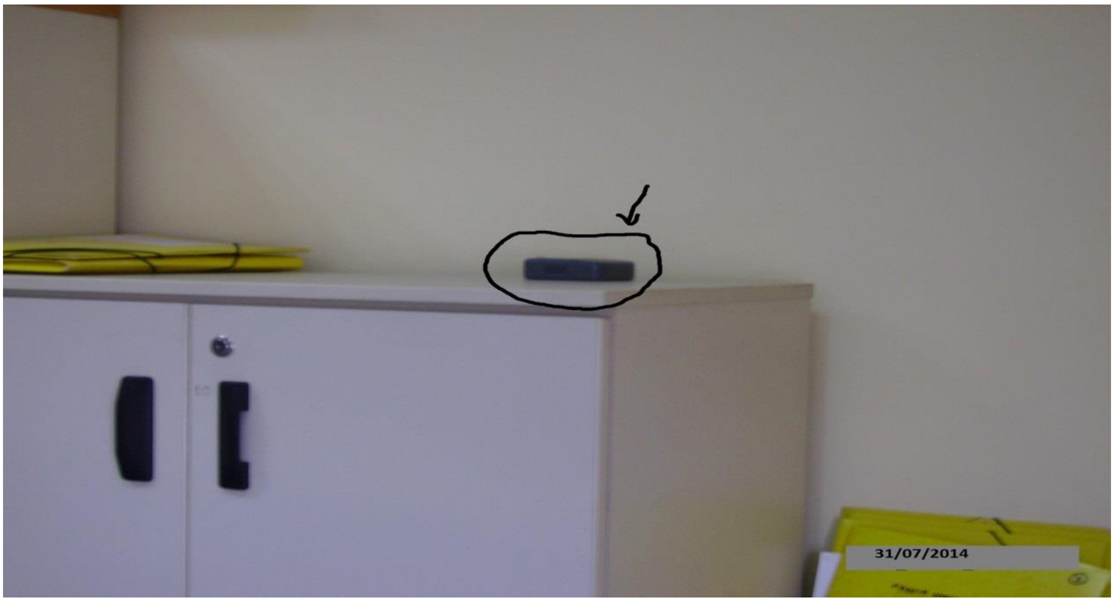

Figure 17 Location of Logit Logger #1 - 2nd floor

Figure 18 Location of Logit Logger #2 - 2nd floor

Figure 19 Location of Logit Logger #3- 2nd floor

Figure 20 Location of LOGiT Logger #4 – 3rd floor

4.3 MEASUREMENTS OF THE TWO ROOFS' SURFACE TEMPERATURE

1. Parameters measured: Surface temperature
2. Instrumentation used: The 2nd the 3rd floors' roof surface temperature was measured using HH309 Omega data loggers with K type thermocouples. Each data logger has four outputs where the K type thermocouples are connected. (See Figure 21)

Figure 21 Omega HH309 data logger and K type thermocouples

3. Three data loggers were used to measure all surfaces of the two roofs. The positioning of the K-type thermocouples can be seen in Figure 22.

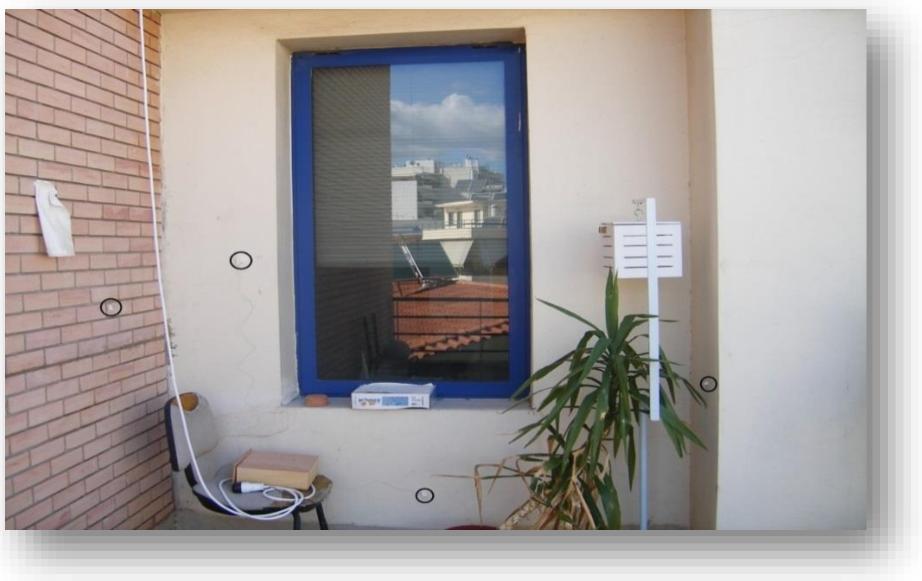

Figure 22 K type thermocouples' positions (in black circles) for the 2nd floor's roof

On 3rd floor's roof the positioning of the two data loggers is depicted in Figure 23 and Figure 24.

Figure 23 Positioning of the K type thermocouples # 1 positioning (black circle) in the 3rd floor's roof

Figure 24 Positioning of the K type thermocouples # 2 positioning (black circle) in the 3rd floor's roof

The measurement period of for the surface temperature measurements of the 2nd floor's roof started on 01/08/2014 and ended on 02/09/2014 with sample time 10 min. The surface temperature measurements for the 3rd floor's roofs started on 01/08/2014 and ended on 04/09/2014.

4.4 INFRARED THERMOGRAPHY

A thermal – camera (type: FLIR) was used for the infrared thermography of the two floor's terraces (Figure 25)

Figure 25 Infrared camera

5 EXPERIMENTAL RESULTS & DISCUSSION

In this section the experimental results are presented and discussed. The section is divided into four subsections following the monitoring procedure's subsections (see Section 3).

5.1 ANALYSIS OF OUTDOOR METEOROLIGAL CONDITIONS

The Tinytag thermometer recorded the meteorological conditions during the last days of July, the whole August and September and these are shown in the following diagrams. (See Figure 26, Figure 27)

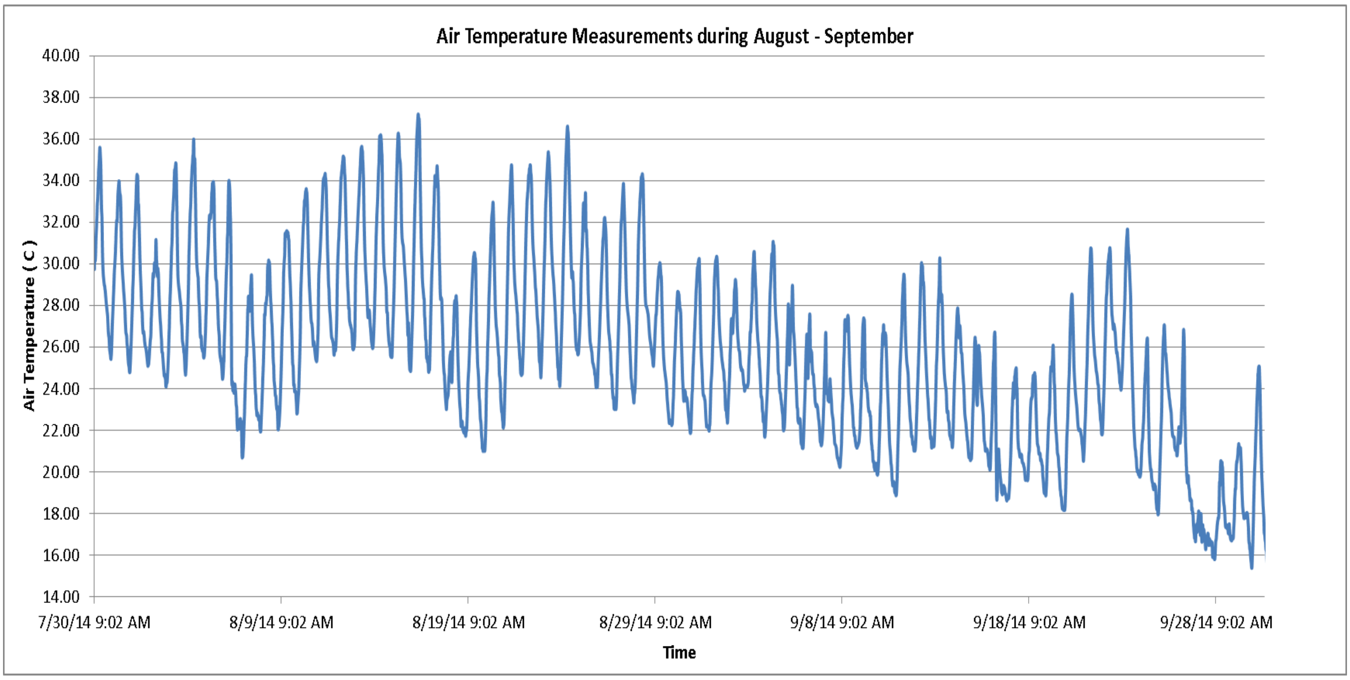

Figure 26 Air Temperature Measurements August-September

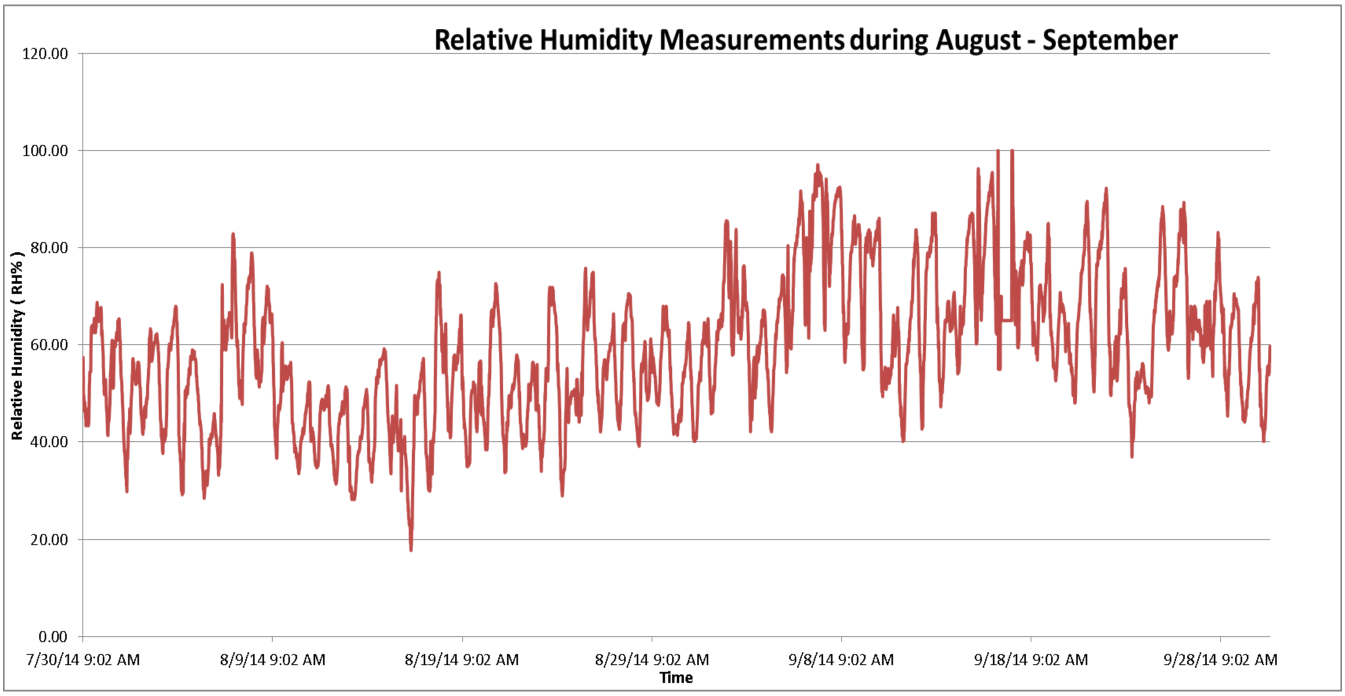

Figure 27 Relative Humidity Measurements August-September

The following diagrams present the air temperature and relative humidity measurements for 3 days. (See Figure 28, Figure 29, Figure 30, Figure 31, Figure 32 and Figure 33) The first one is Thursday 31/07/2014, the second one is Monday 11/08/2014 and the third Monday 01/09/2014. These days were selected by the reasoning of typical weekday working days so that there is a comparison with the measurements in the indoor space which we will present them in the following section.

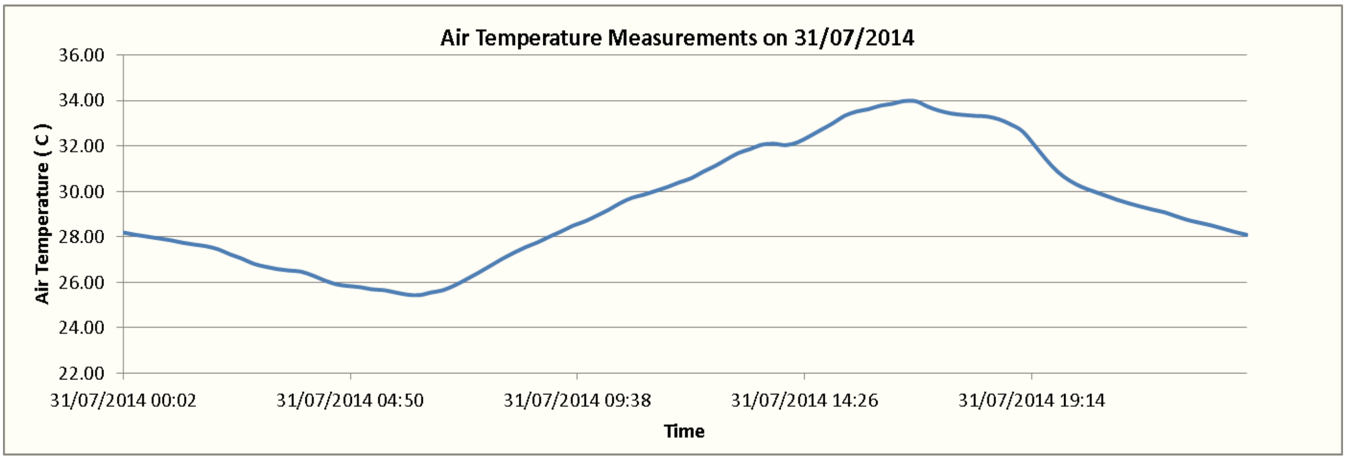

Figure 28 Air Temperature Measurements on 31/07

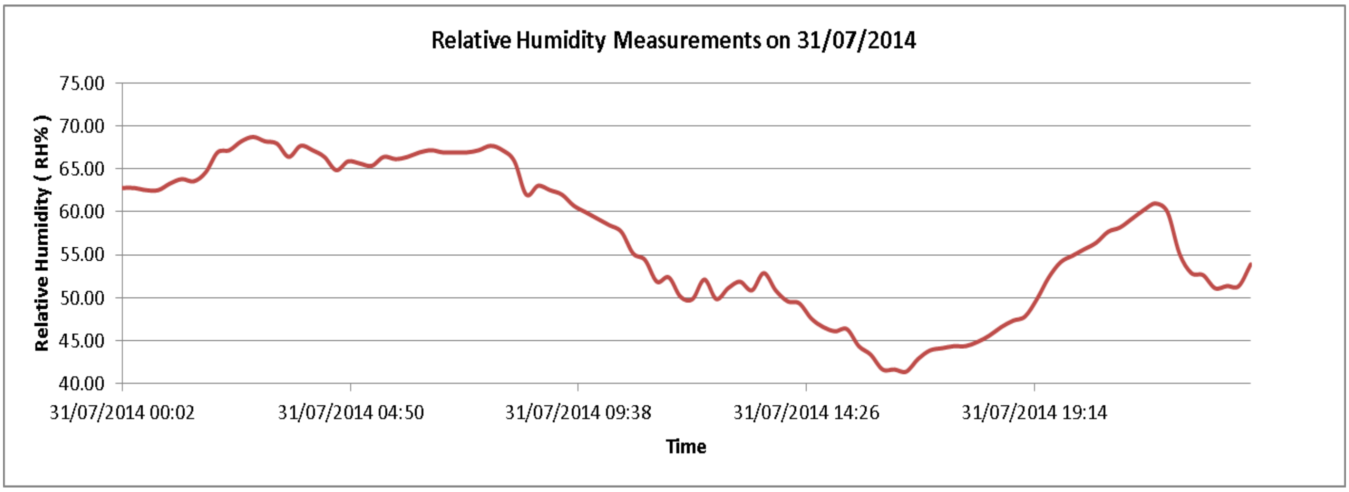

Figure 29 Relative Humidity Measurements on 31/07

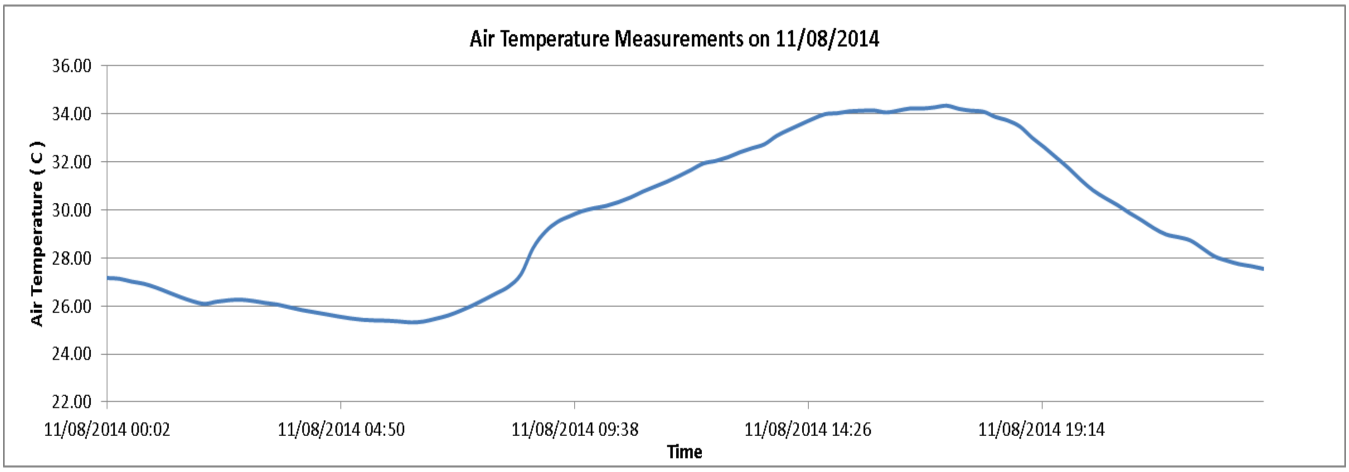

Figure 30 Air Temperature Measurements on 11/08

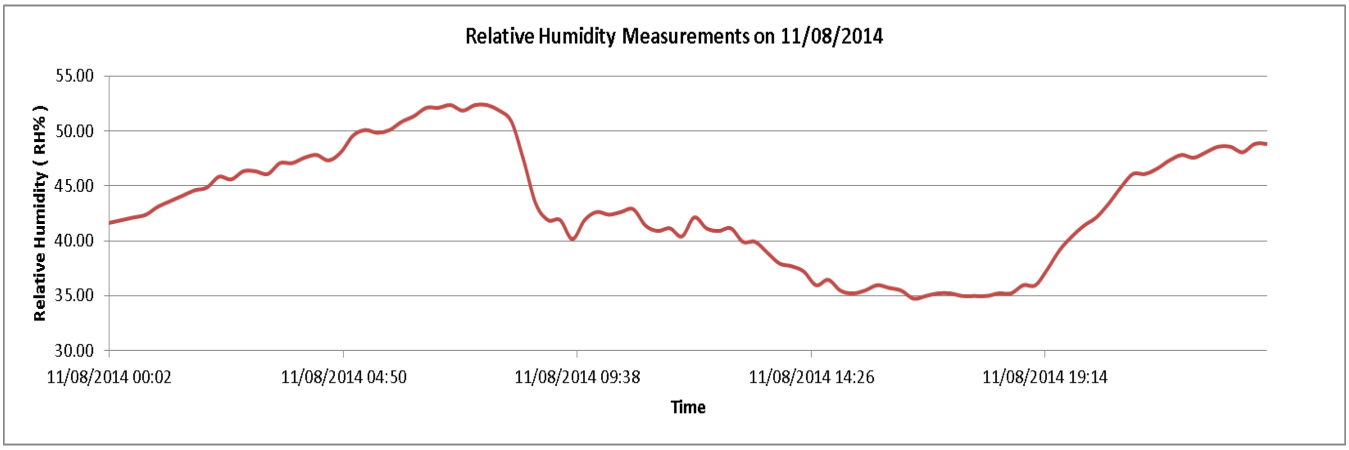

Figure 31 Relative Humidity Measurements on 11/08

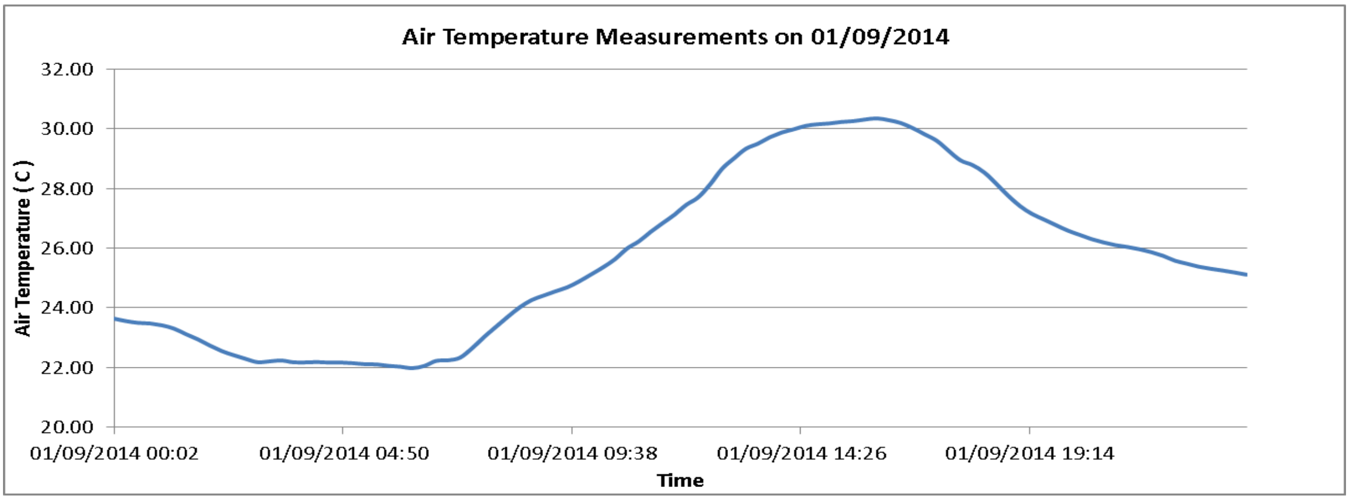

Figure 32 Air Temperature Measurements on 01/09

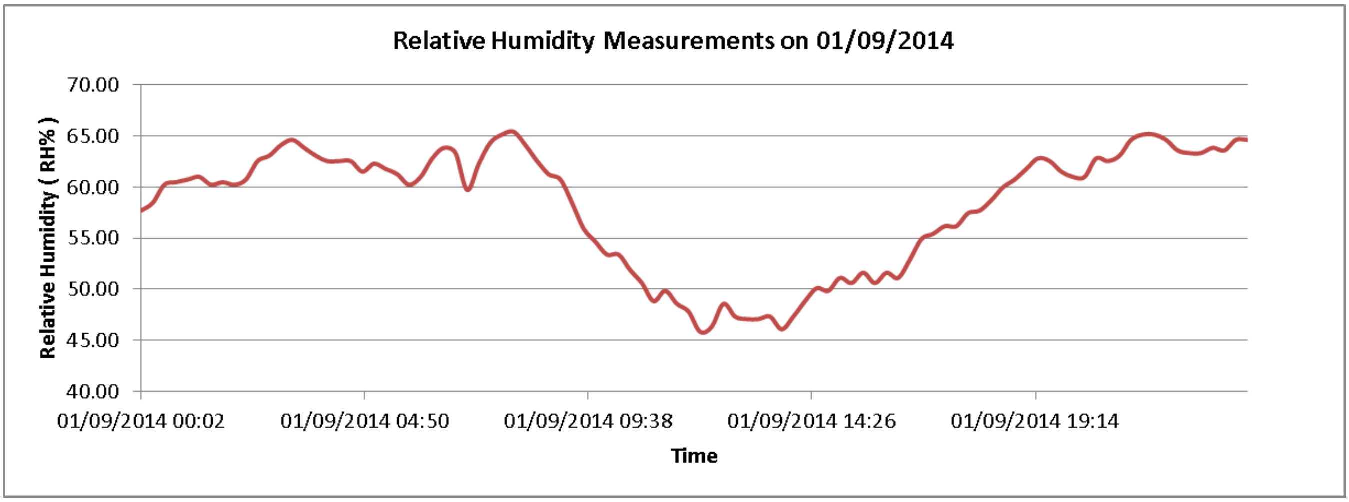

Figure 33 Relative Humidity Measurements on 01/09

5.2 MEASUREMENTS OF THE INDOOR ENVIRONMENTAL CONDITIONS

5.2.1 MEASUREMENTS OF THE 2ND FLOOR

The 2nd floor indoor measurements are depicted in the following figures.

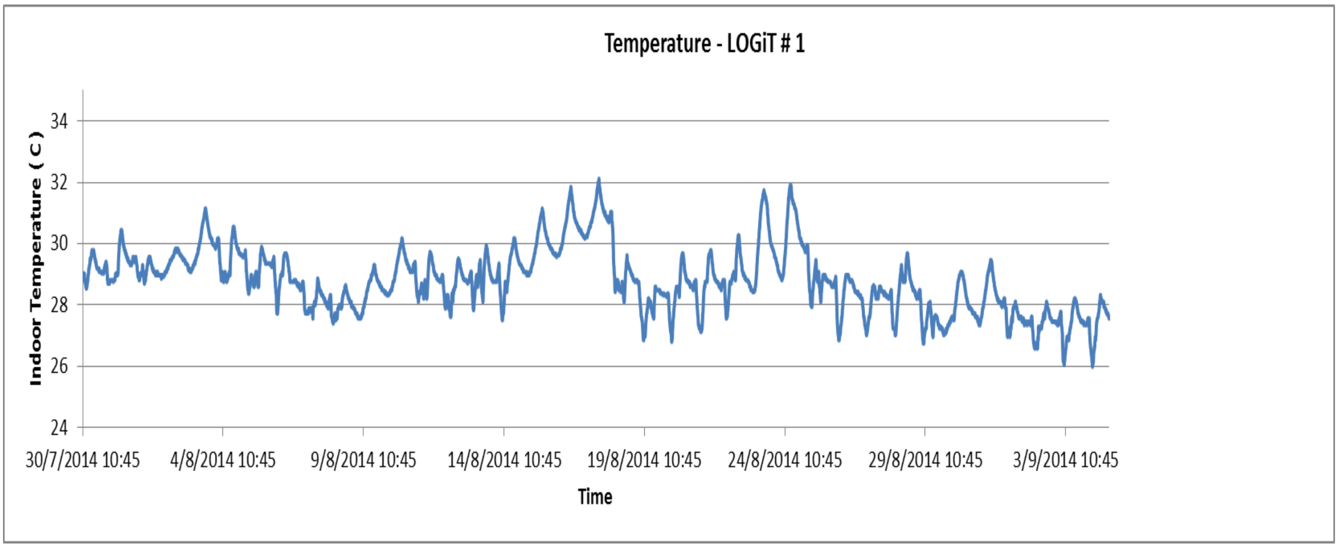

Figure 34 Indoor Temperature LOGiT#1

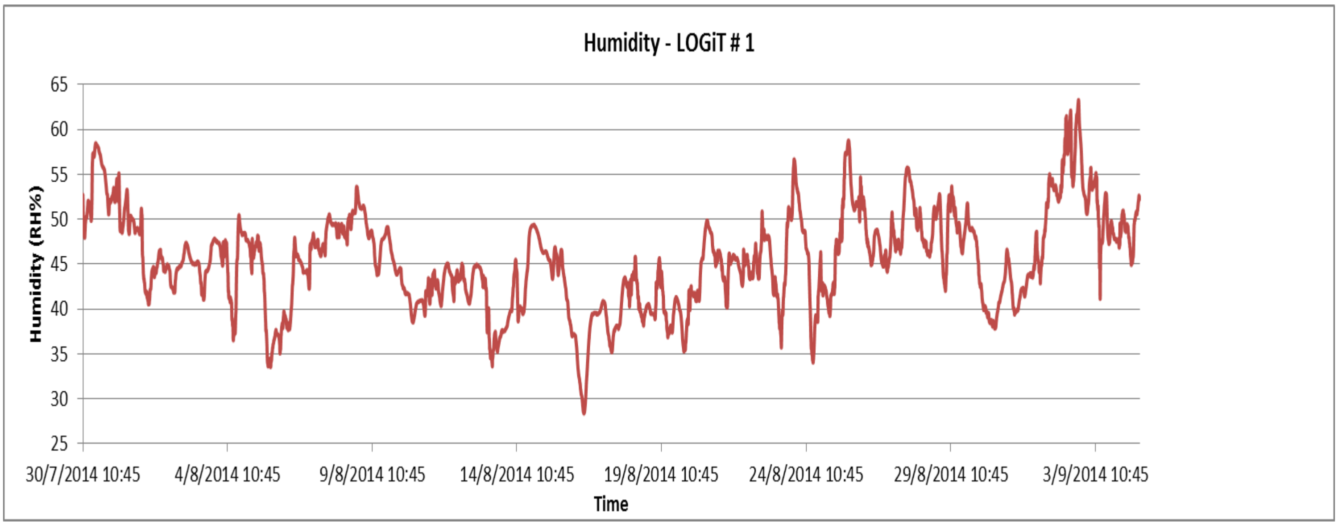

Figure 35 Indoor Humidity LOGiT#1

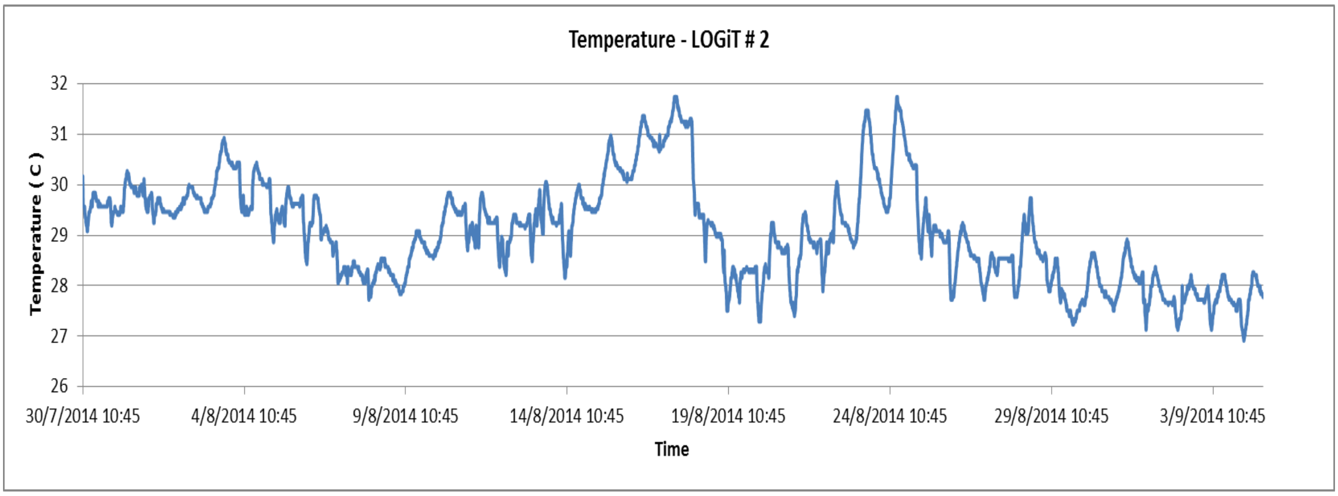

Figure 36 Indoor Temperature LOGiT#2

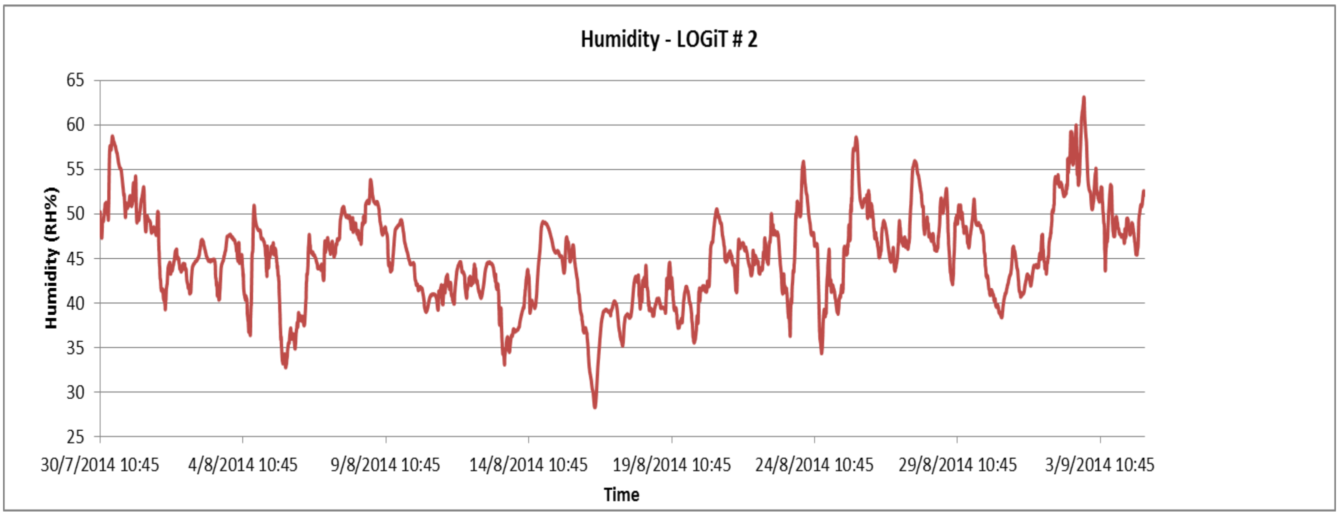

Figure 37 Indoor Humidity LOGiT#2

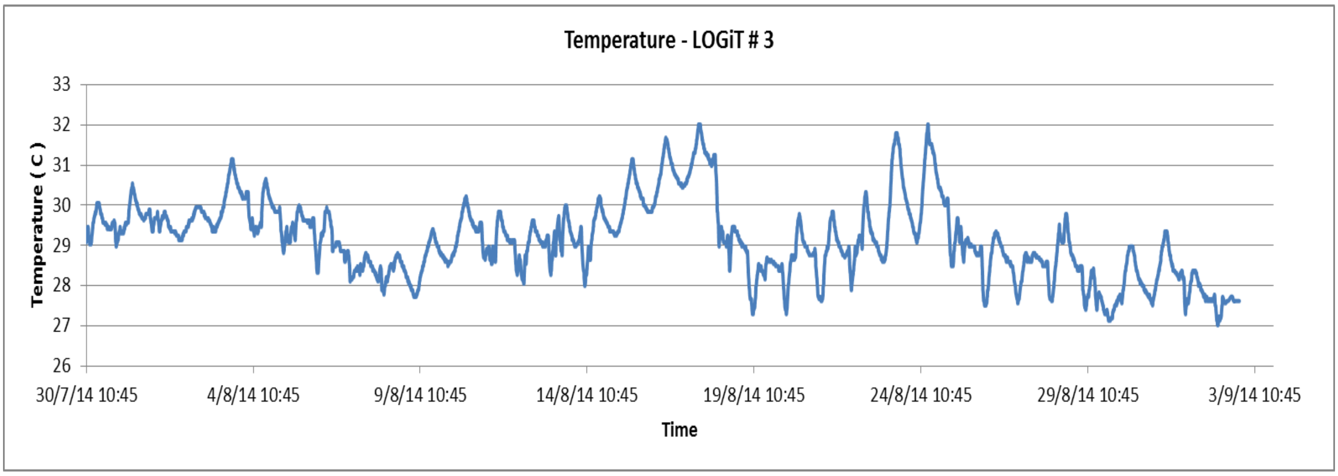

Figure 38 Indoor Temperature LOGiT#3

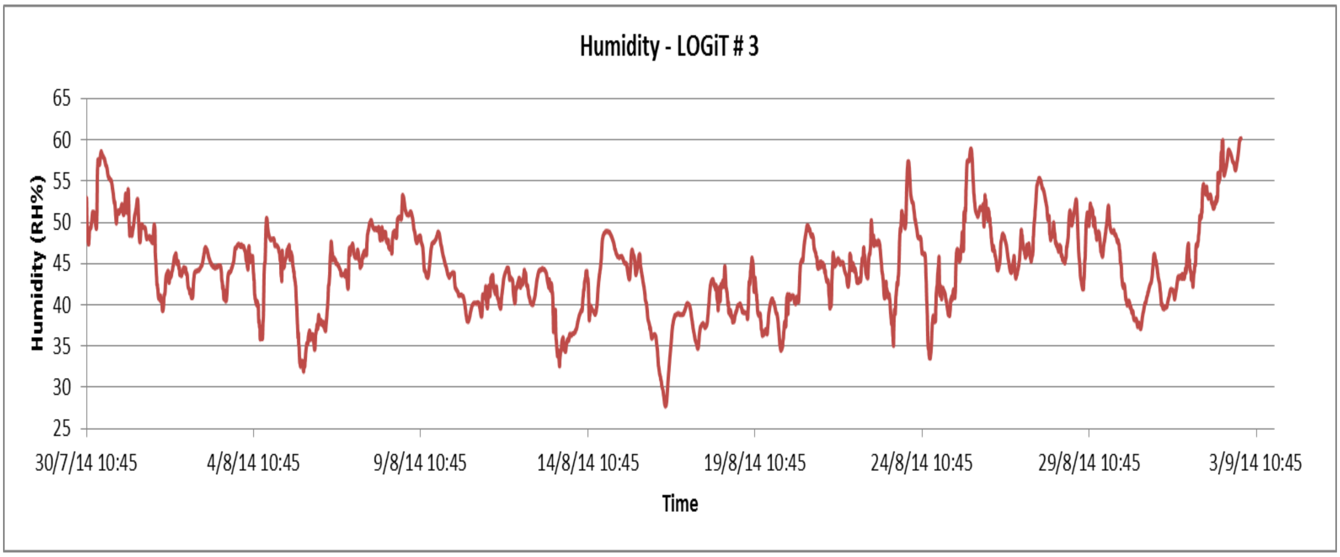

Figure 39 Indoor Humidity LOGiT#3

The indoor temperature extrcated by all data loggers fluctuates between 26-32◦C (See Figure 34, Figure 36, Figure 38). The maximum indoor temperatures occur for all cases during late afternon between 19:00-21:00 where there are no users while the minimum temperatures occur when the users are present and the air cconditioning is turned on.

Moreover it can be noticed that when the airconditioning systems are turned off, i.e. during weekends, the indoor temperature is about 2°C higher than the ones recorded during the weekdays.

The relative humitity levels are between 30-60% which corresponds to average comfort levels. The relative humidity is decreasing when the indoor temperature is increasing as expected. It should be underlined here that there is no humidity (humidification/dehumidification) control via the air conditioning system.

The daily temperature fluctuations are depicted in the following Figure 40, Figure 41 and Figure 42 for a typical day of July, August and September 2014. The differences between the three data loggers' measurements are in all cases lower than 0.5°C and it can be attributed to the fact that the Logit #2 and #3 are placed in higher level that the Logit#1 which is placed in desk level.

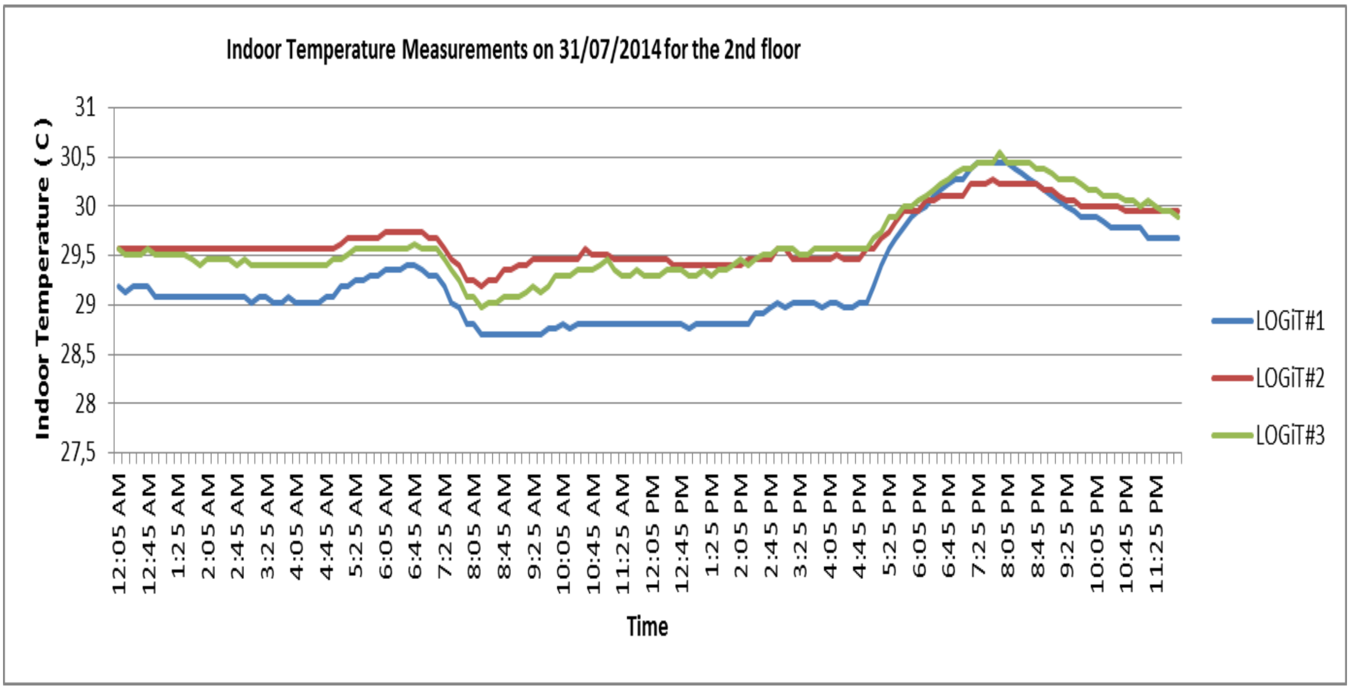

Figure 40 Indoor Temperature on 31/7 - 2nd floor

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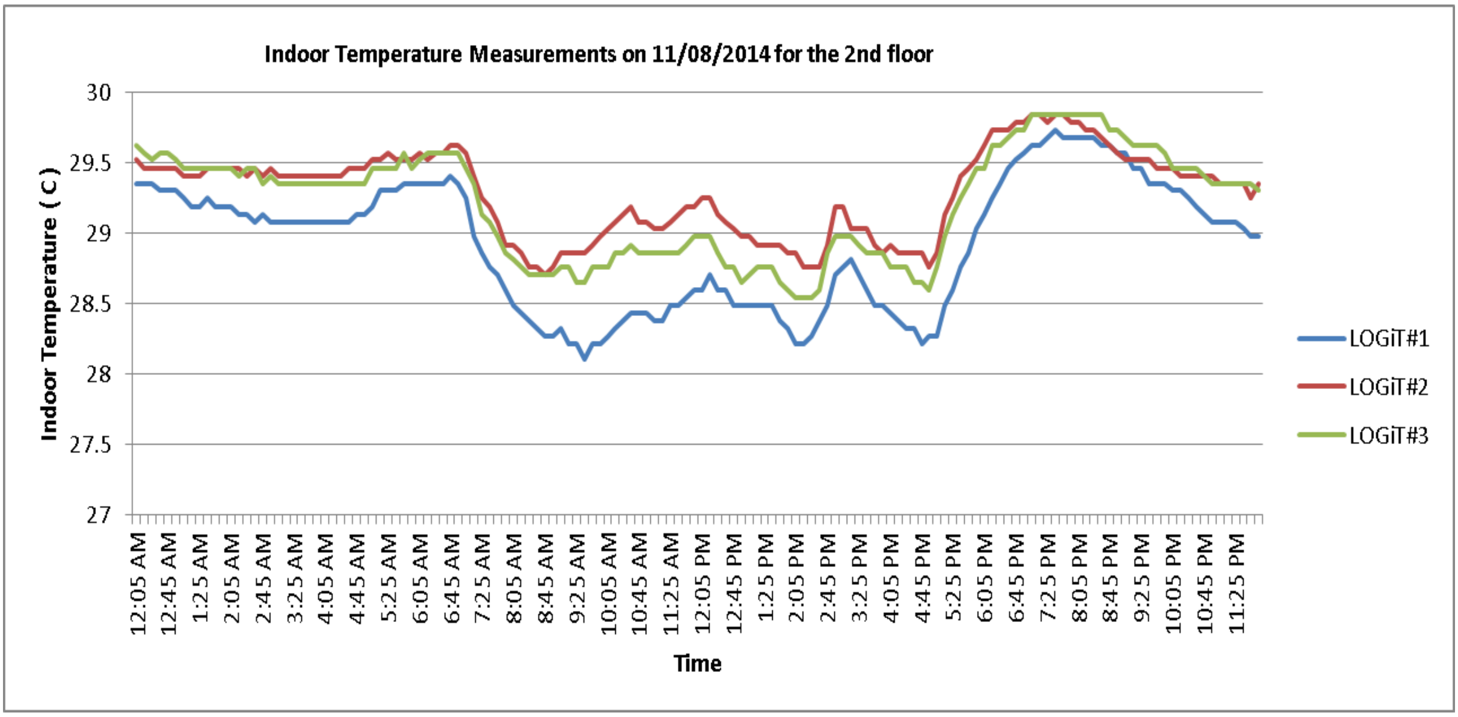

Figure 41 Indoor Temperature on 11/8 - 2nd floor

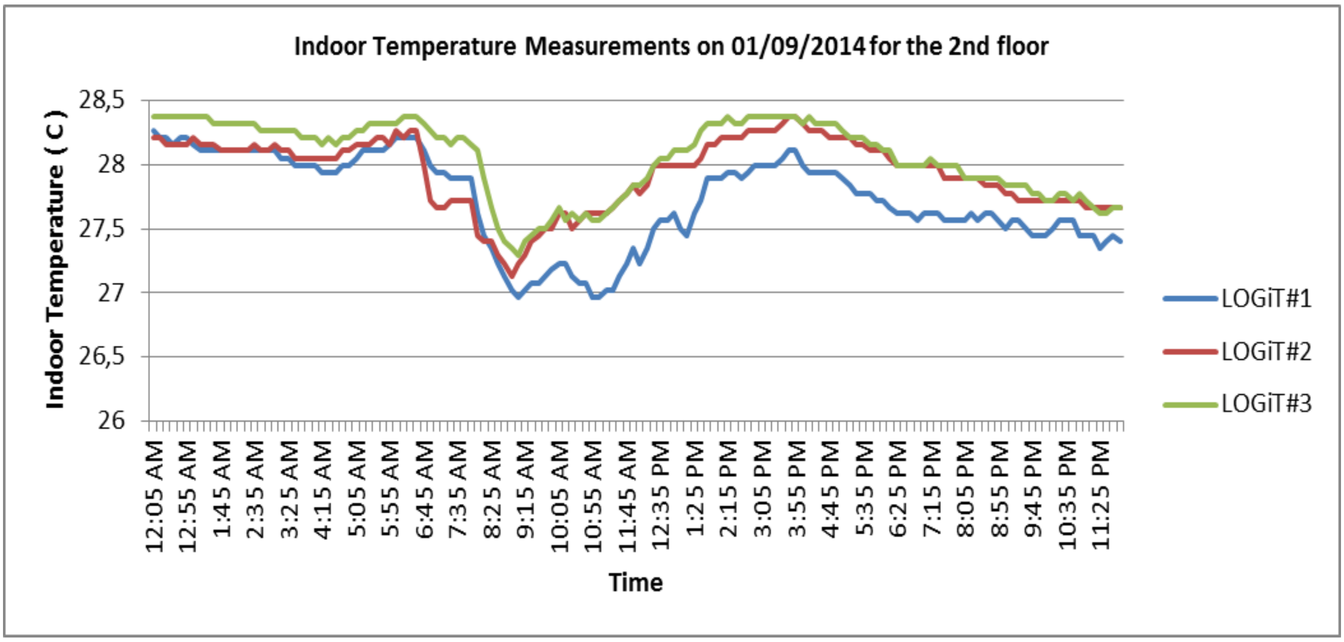

Figure 42 Indoor Temperature on 1/9 - 2nd floor

5.2.2 MEASUREMENTS OF THE 3RD FLOOR

The 3rd floor indoor measurements are depicted in the following figures. (See Figure 43, Figure 44)

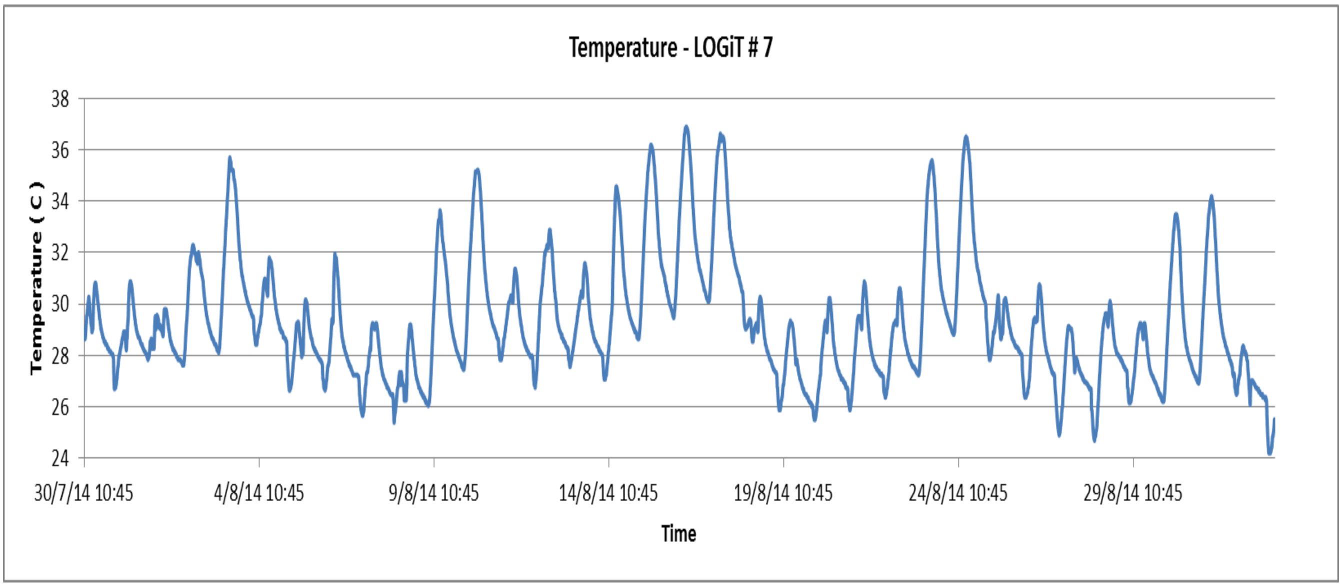

Figure 43 Indoor Temperature LOGiT#7

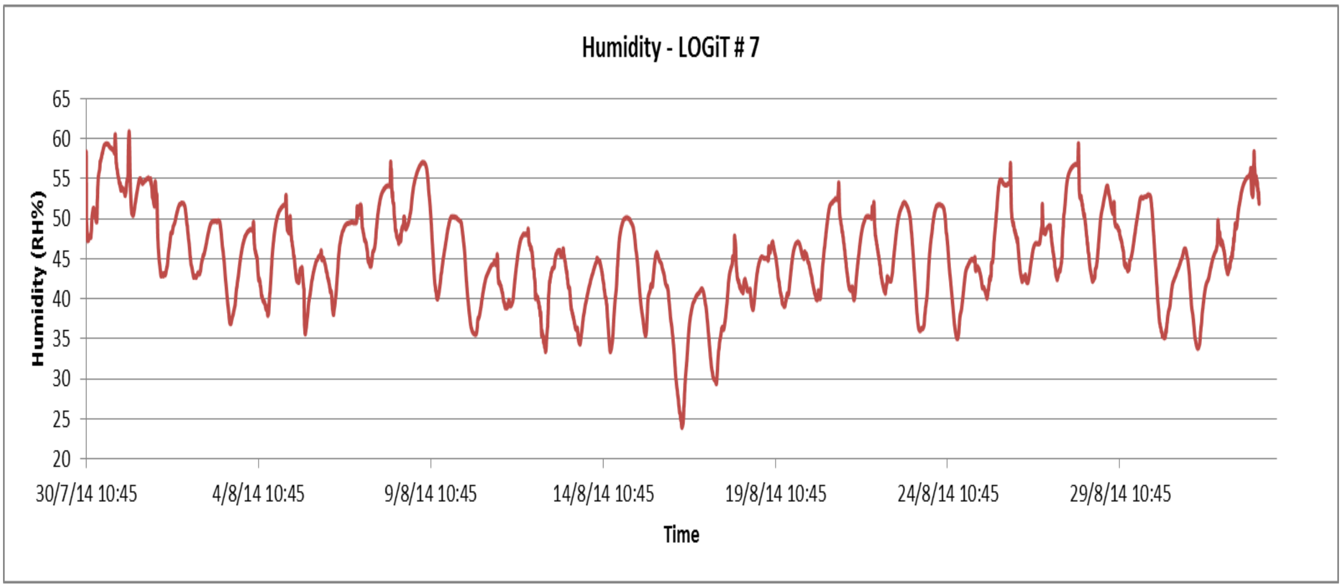

Figure 44 Indoor Humidity LOGiT#7

In the total diagrams of the indoor temperature and humidity during August we can observe that when airconditioning systems is turned off during weekends the level of temperature is about 2°C higher than during the week. As we can see above at 03/08, 17/08, 23/08, 24/08 we have “peaks” the indoor temperature and these dates are Saturdays and Sundays. (See Figure 43) As far as the humidity is concerned, it is reasonable to see lower levels of relative humidity when the indoor space is unoccupied (Weekends). (See Figure 44)

In the following diagrams we can see the daily temperature fluctuation on a typical working day of July, August and September. These days are Thursday for 31/07 and Monday for 11/08 and 01/09 as it was selected for the 2nd floor.

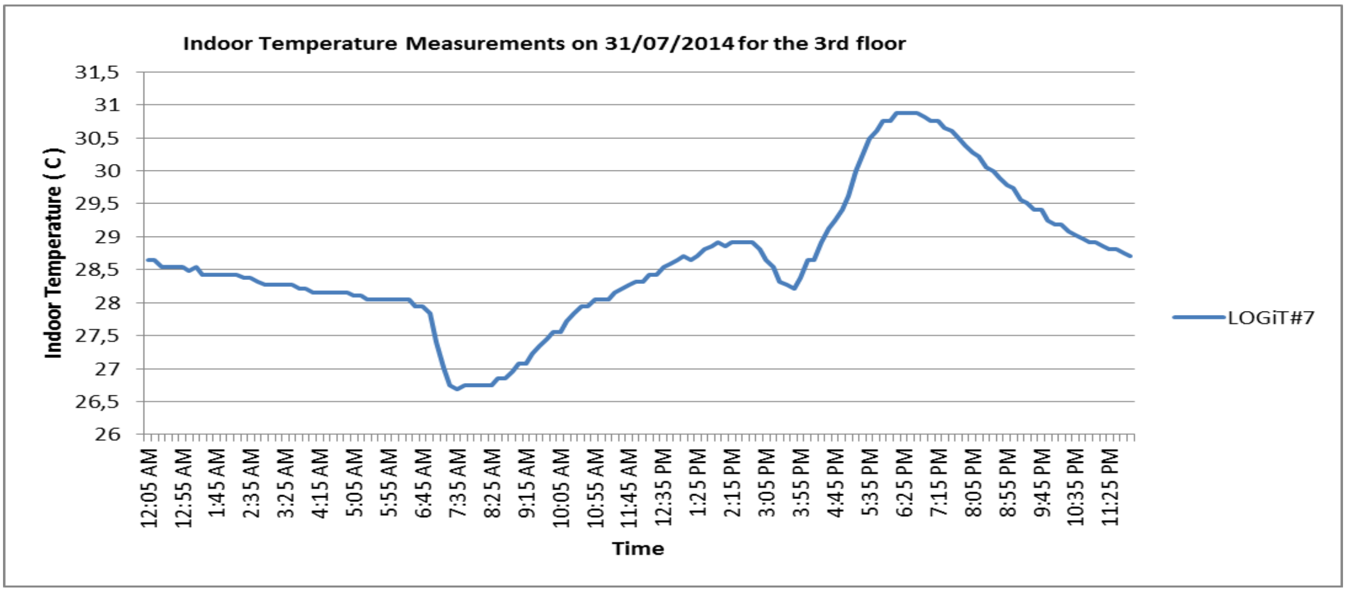

Figure 45 Indoor Temperature on 31/7 - 3rd floor

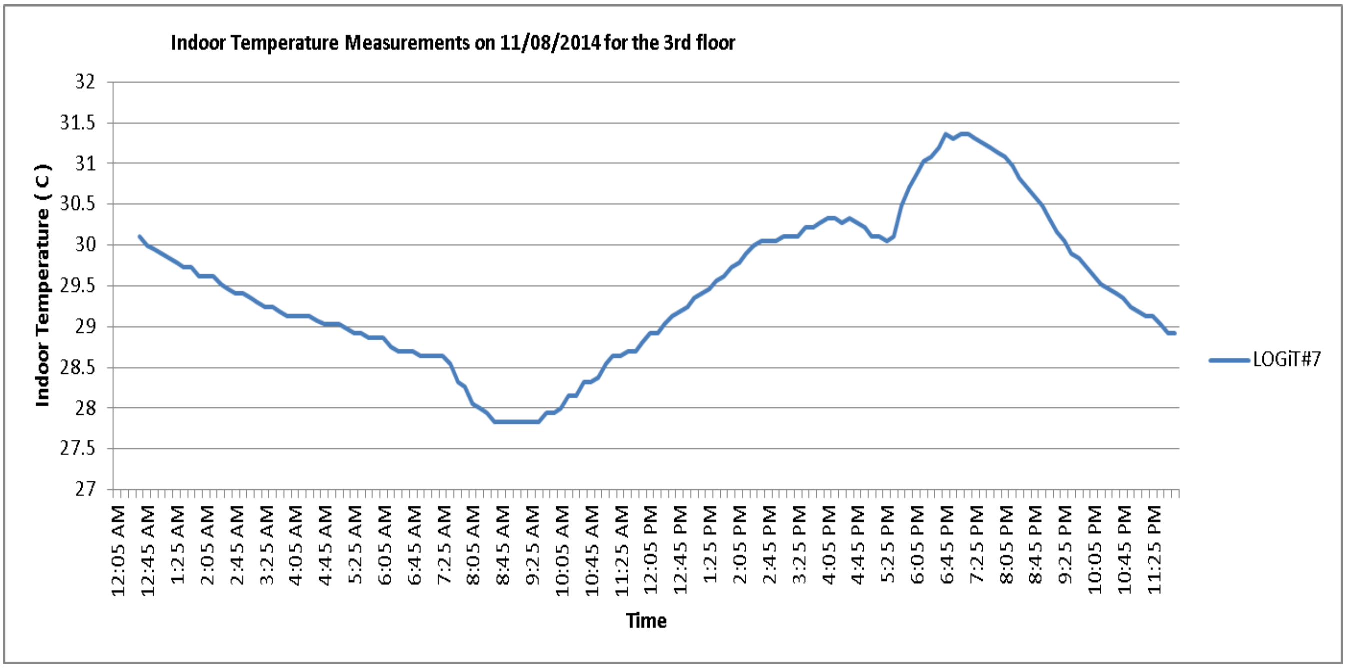

Figure 46 Indoor Temperature on 11/8 - 3rd floor

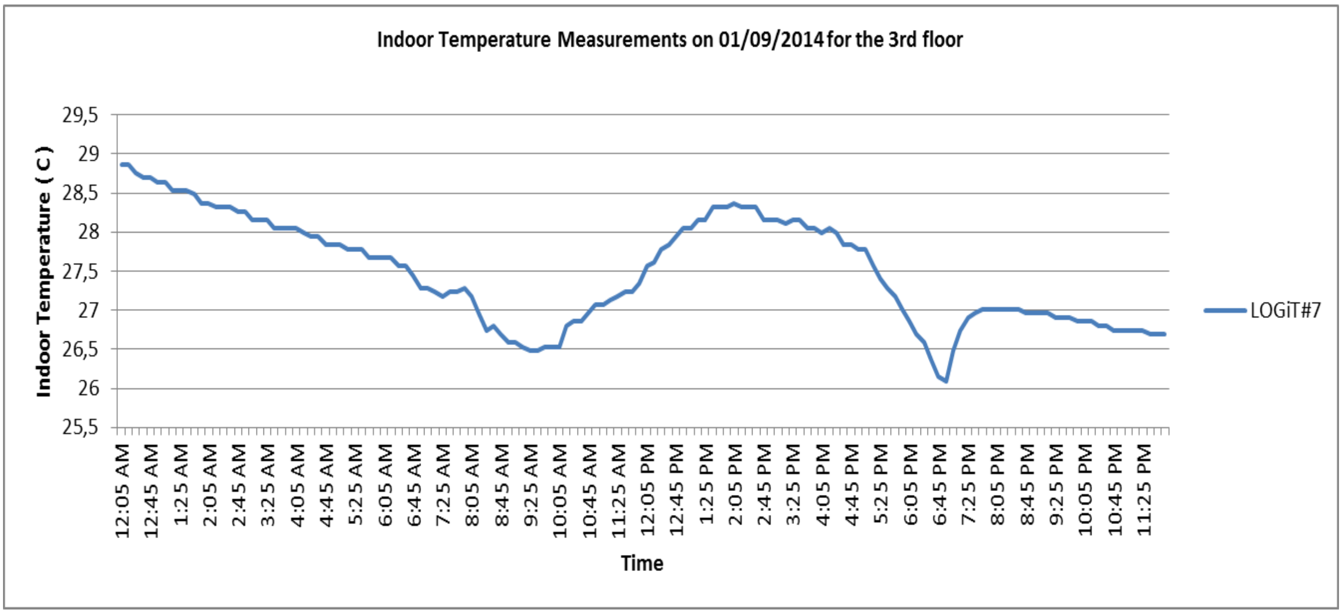

Figure 47 Indoor Temperature on 1/9 - 3rd floor

5.3 INFRARED THERMOGRAPHY

5.3.1 INFRARED THERMOGRAPHY – 2ND FLOOR

The following photos (See Figure 48, Figure 49 and Figure 50) show the various parts of thermography outdoors (terrace) on the 2nd floor along with their correlation with the visual photos. The photos were taken on 4/9/2014, 10:15pm.

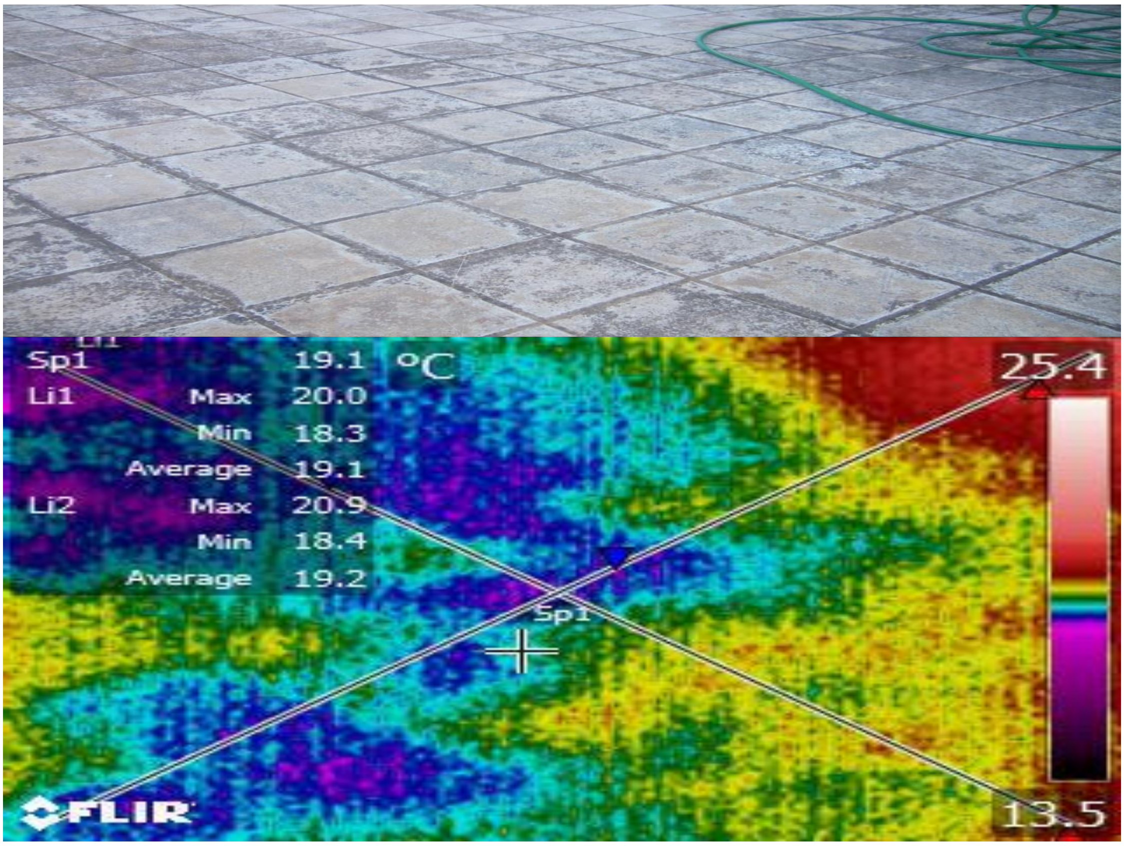

Figure 48 Thermal and visual photo of 2nd floor's roof tiles

From Figure 48 we can see that there are considerable surface temperature differences in the roof tiles. In Line 1 (Li1) the difference between the minimum and maximum temperatures is almost 2 °C while for Li2 the difference is almost 3°C.

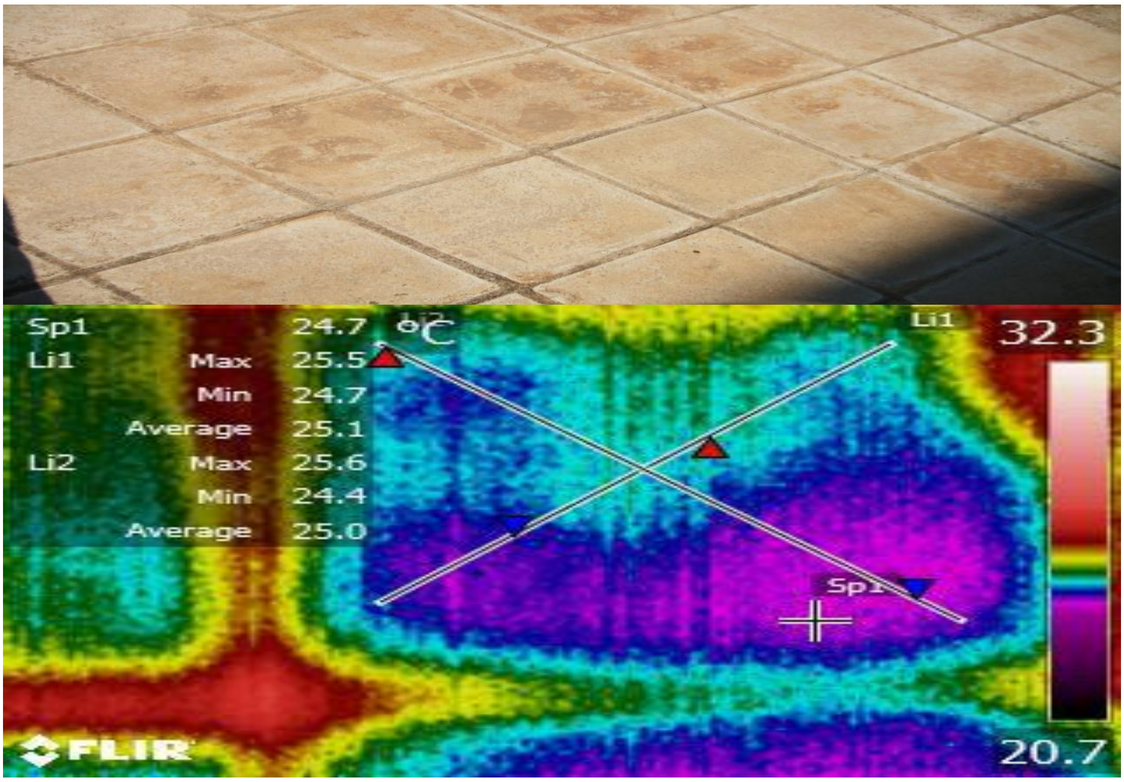

Figure 49 Thermal and visual photo of 2nd floor's roof tiles

In the visual photo above (See Figure 49) it is clearly obvious that we have some type of deterioration in the tiles. This translates to 1°C – 2°C difference in temperature between two nearby points.

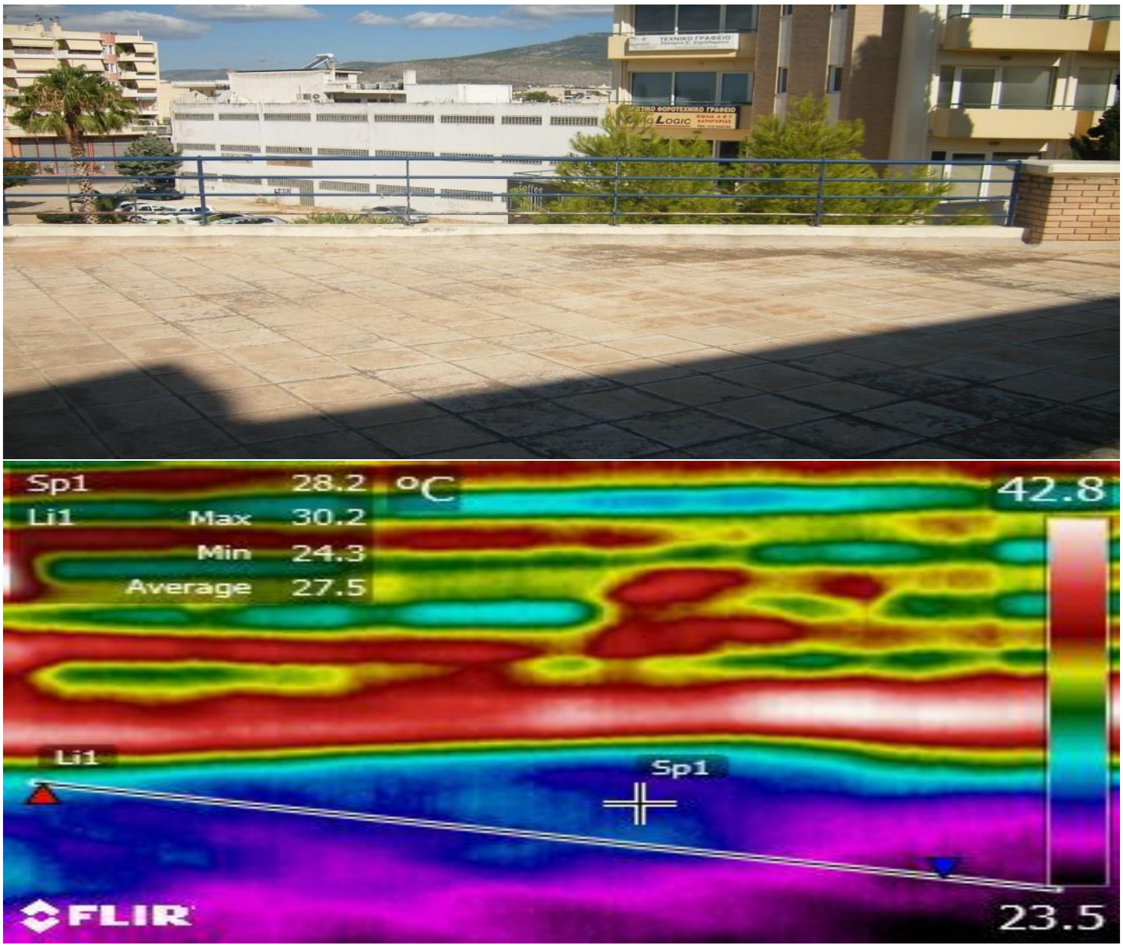

Figure 50 Thermal and visual photo of 2nd floor's roof tiles

The same results can be extracted by Figure 50. Furthermore we could say that the insolation and shading make significant difference in surface temperature of the tiles.

Based on the above, some maintenance should be performed in the roof to improve its performance.

5.3.2 INFRARED THERMOGRAPHY – 3^{RD} FLOOR

Respectively, 3^{rd} floor thermography is shown at different points in the exterior space (terrace) and their correlation with the shared photos. The photos were taken at 09:45pm, 04.09.2014.(See Figure 51,Figure 52,Figure 53,Figure 54,Figure 55 and Figure 56)

The following photos present fairly significant temperature difference in specific spots as shown by thermal camera. This temperature "gap" is might due to substandard in construction, difference in the type or the quality of materials (cement welding – tiles), old technique materials or the most simple due to shading or insolation.

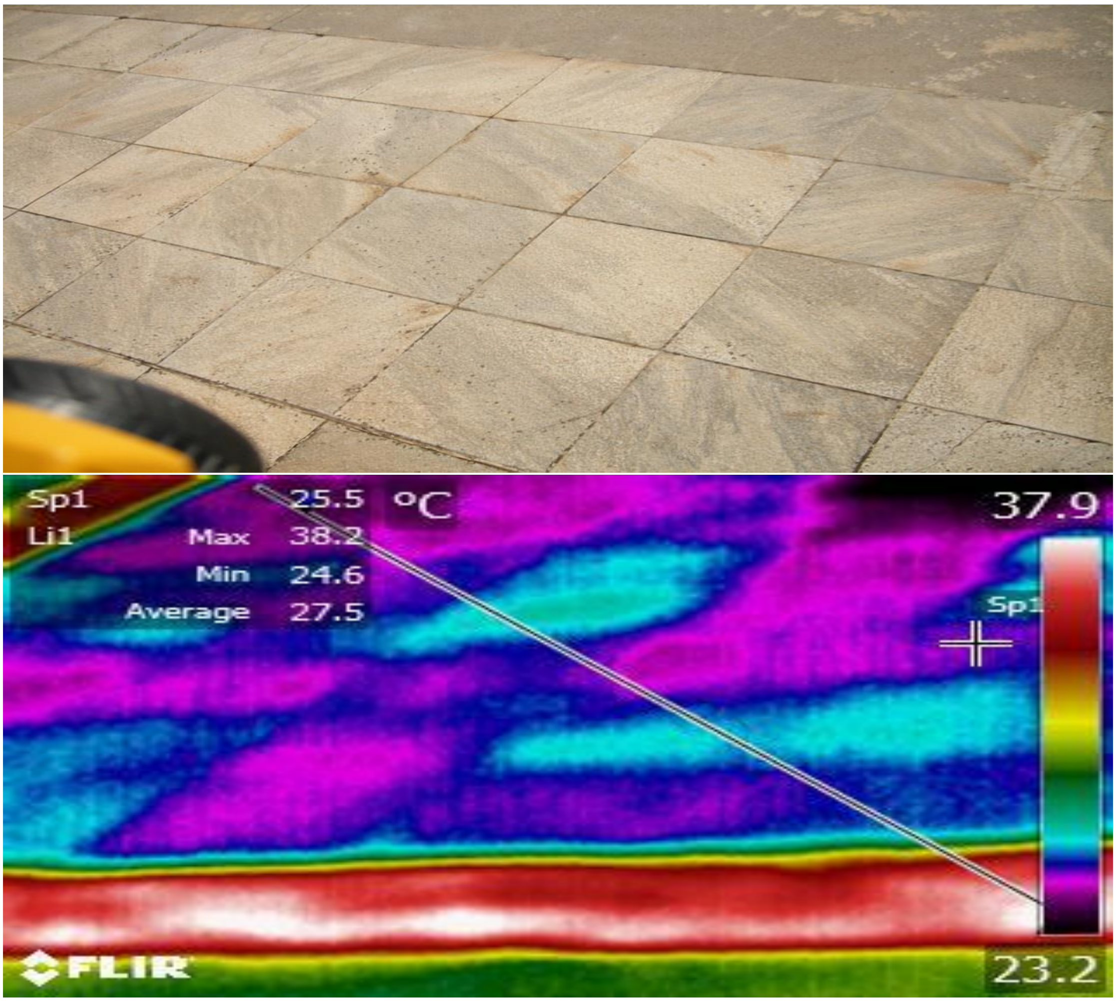

Figure 51 Thermal and visual photo of 3^{rd} floor's roof tiles

In the picture above (See Figure 51) we can observe temperature fluctuation that is more than 13°C in less than 4m^2 surface. This is obviously due to the difference in construction materials. The same we can say for the following picture with temperature fluctuation at 5°C.

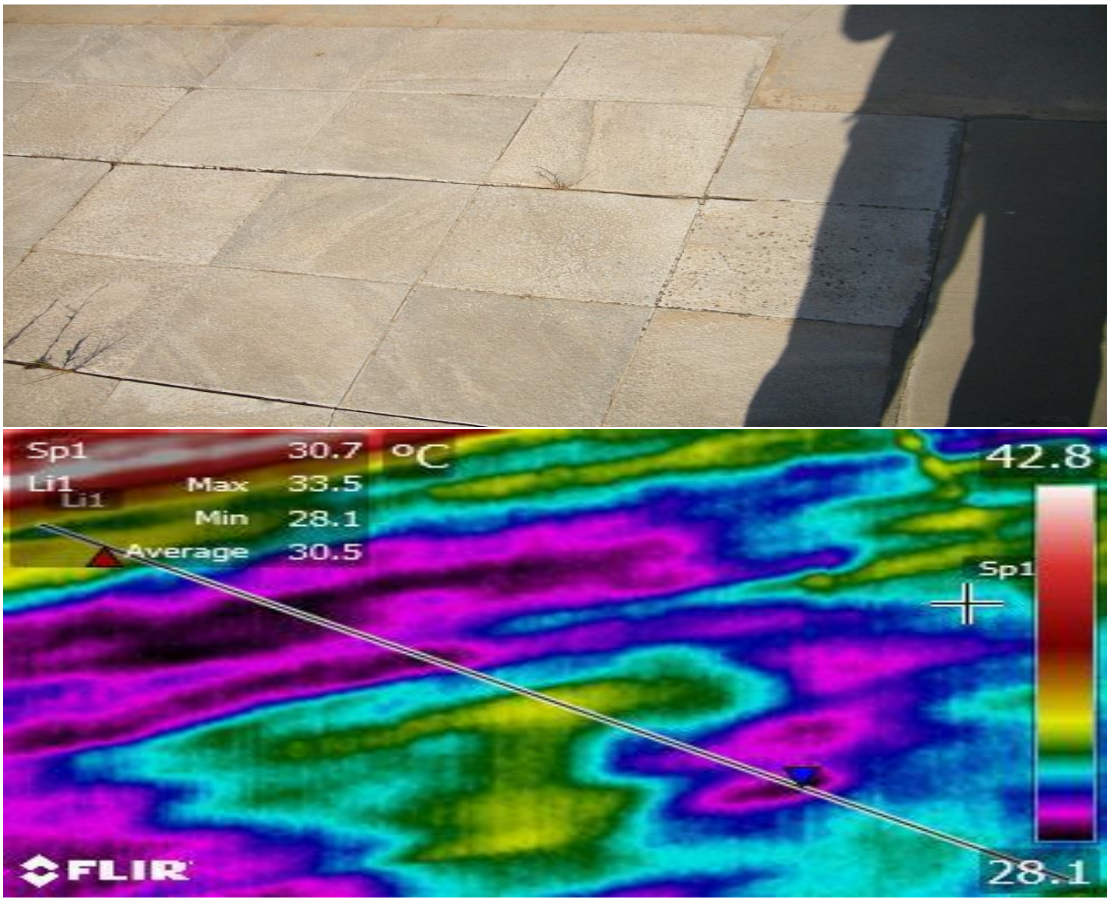

Figure 52 Thermal and visual photo of 3rd floor's roof tiles

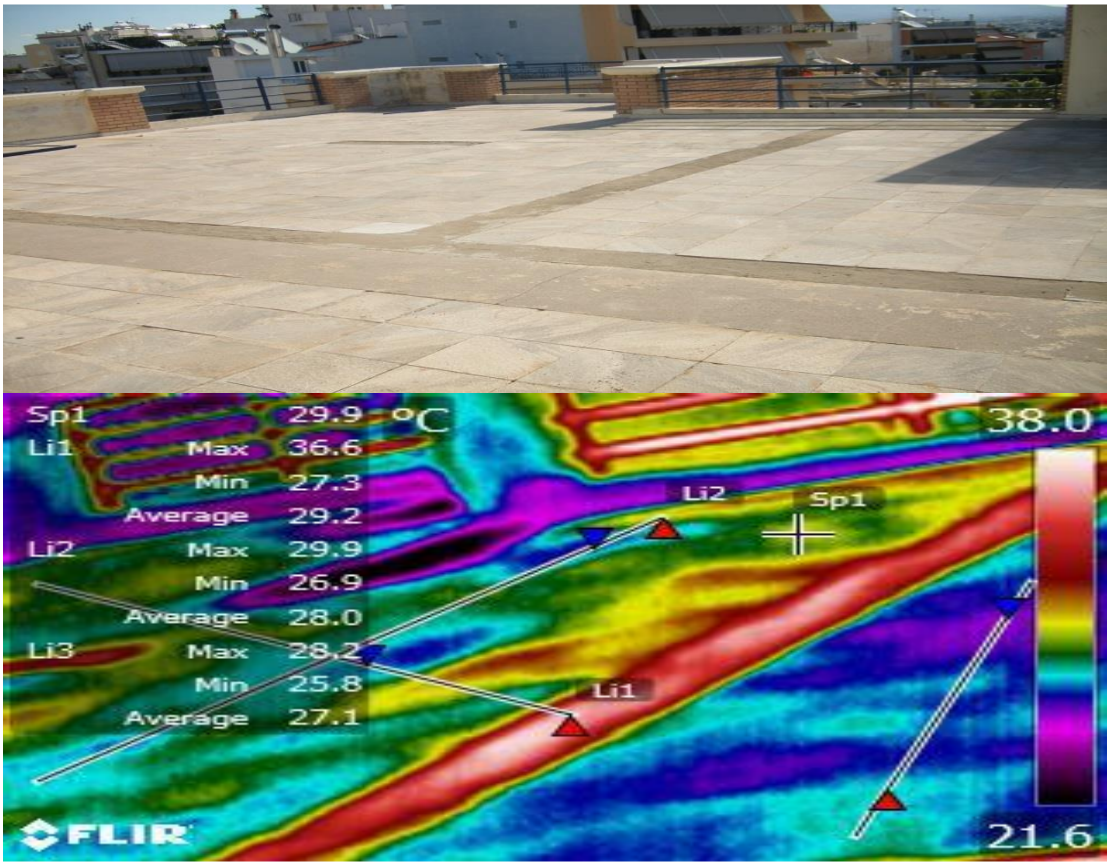

Figure 53 Thermal and visual photo of 3rd floor's roof tiles

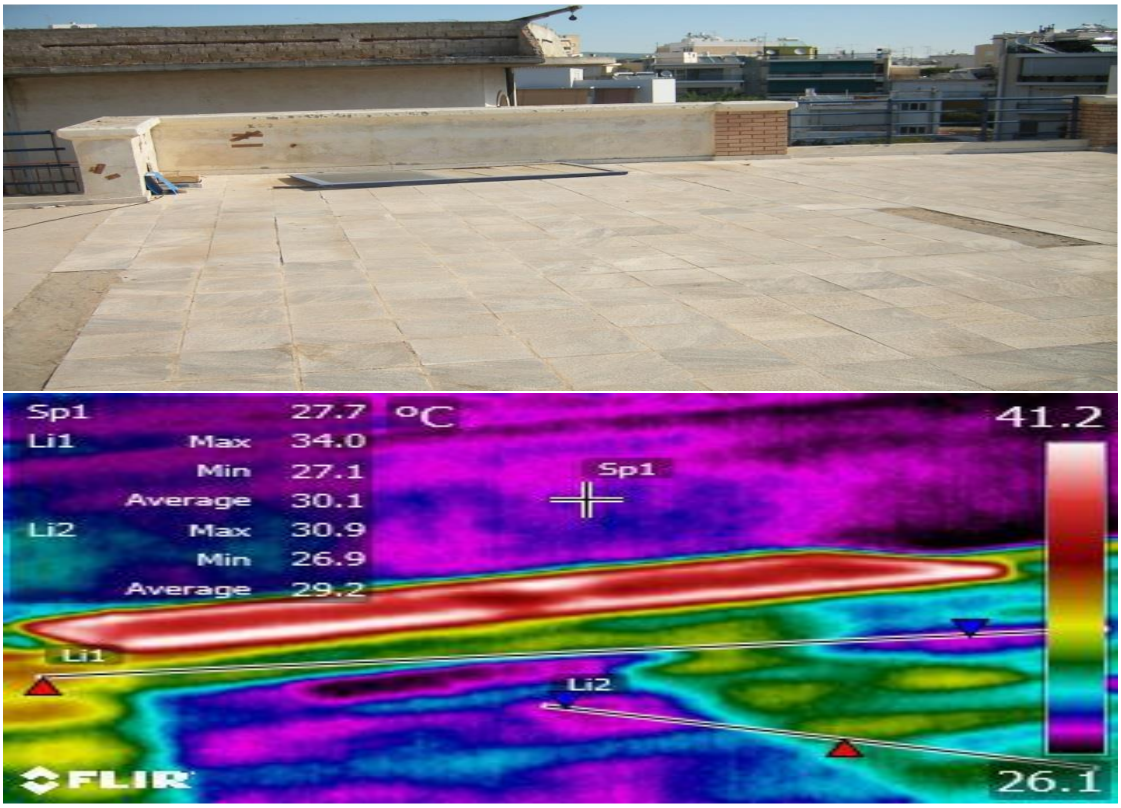

Figure 54 Thermal and visual photo of 3rd floor's roof tiles

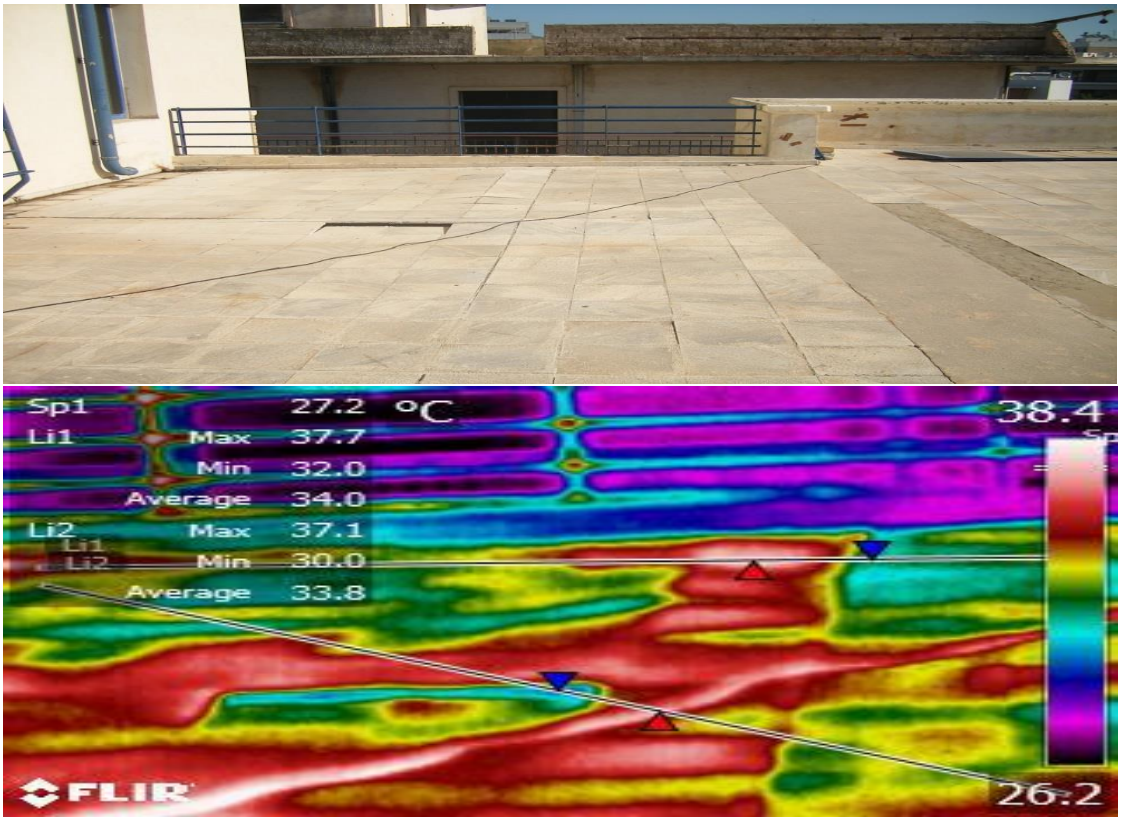

Figure 55 Thermal and visual photo of 3rd floor's roof tiles

It is clearly obvious in the visual photo (See Figure 55) that there is a significant distortion in our tiles. The temperature fluctuation is up to 6°C in the selected lines from the infrared camera.

5.4 MEASUREMENTS OF THE TWO ROOFS' SURFACE TEMPERATURE

The following graphs show the temperature's variation of the outdoors place on the roof. These measurements are taken by the thermometer which is placed next to the door.

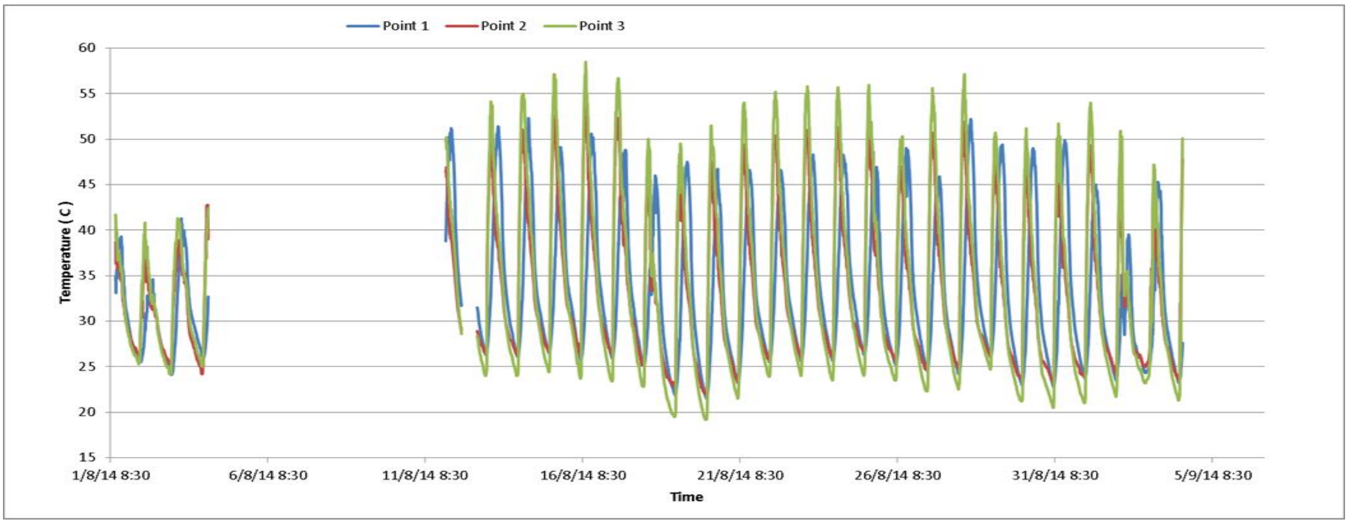

Figure 56 Aggregated Surface Temperature Measurements - 1_{st} thermometer - 3^{rd} floor

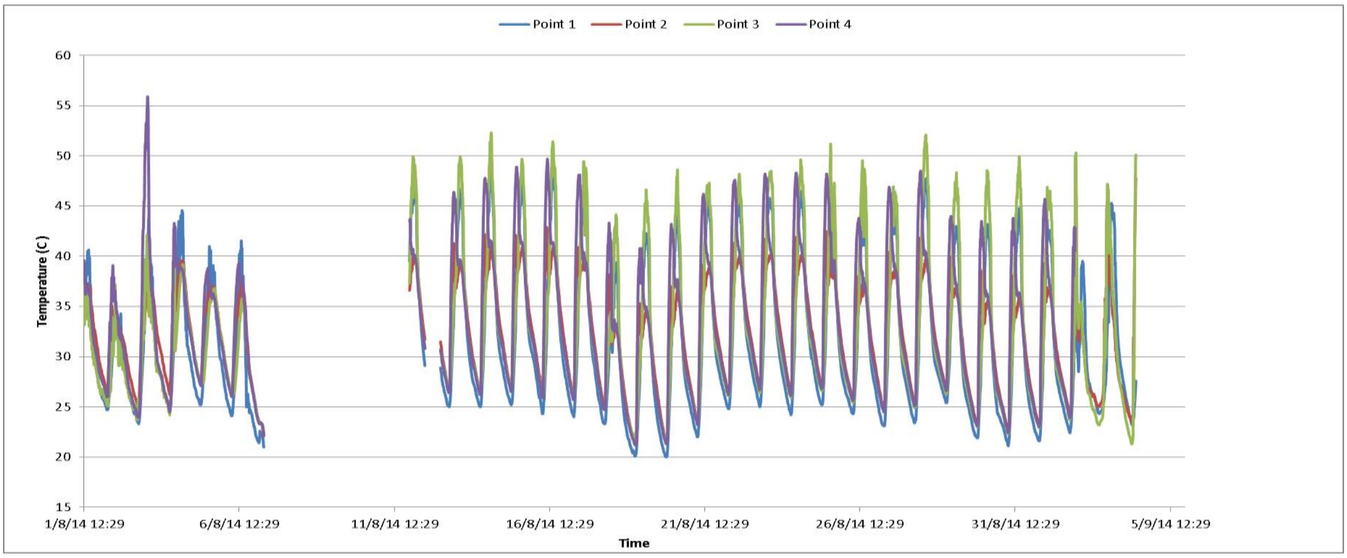

Figure 57 Aggregated Surface Temperature Measurements - 2_{nd} thermometer - 3^{rd} floor

Specifically, in the following diagram (Figure 58) we can see temperatures at the three points we have chosen between 25-50°C. This diagram shows the temperature's fluctuation on 04/09 during morning hours.

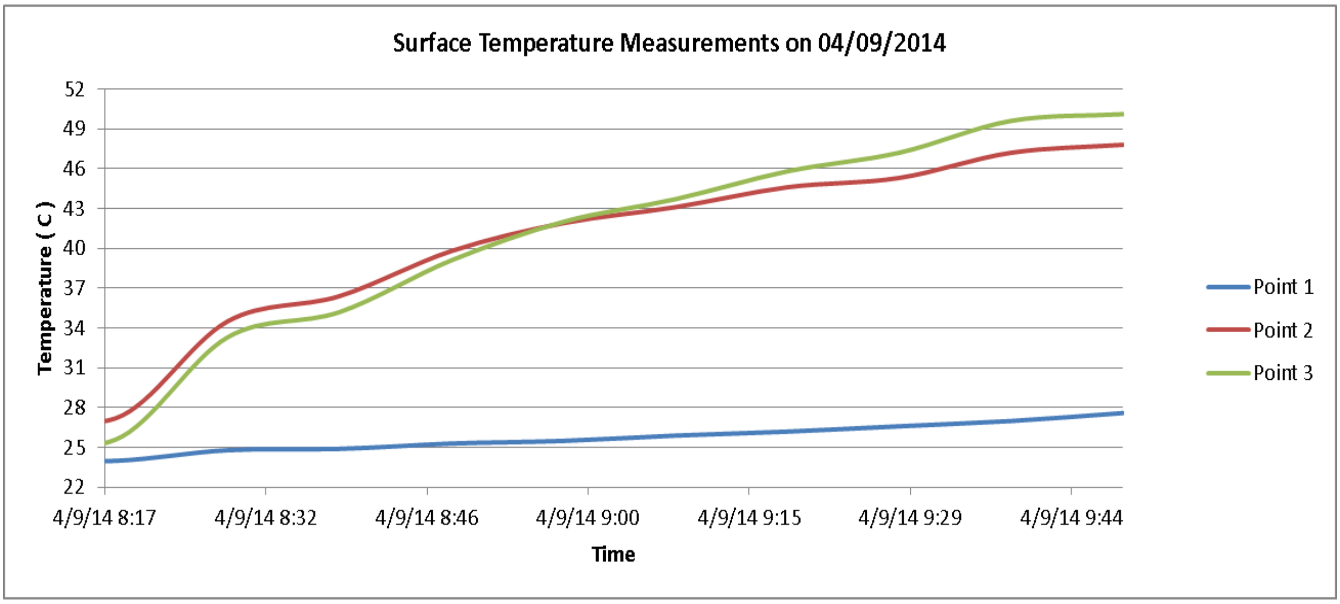

Figure 58 Surface Temperature Measurements on 4/9 - 1_{st} thermometer - 3^{rd} floor

Comparing the diagram with the photos taken by the thermal camera at 04/09 we can note compatibility in the recorded temperatures. In the following thermal photos we can observe the same temperatures. (See Figure 59, Figure 60, Figure 61 and Figure 62)

The following photos were taken at 9:45am 04/09/2014.

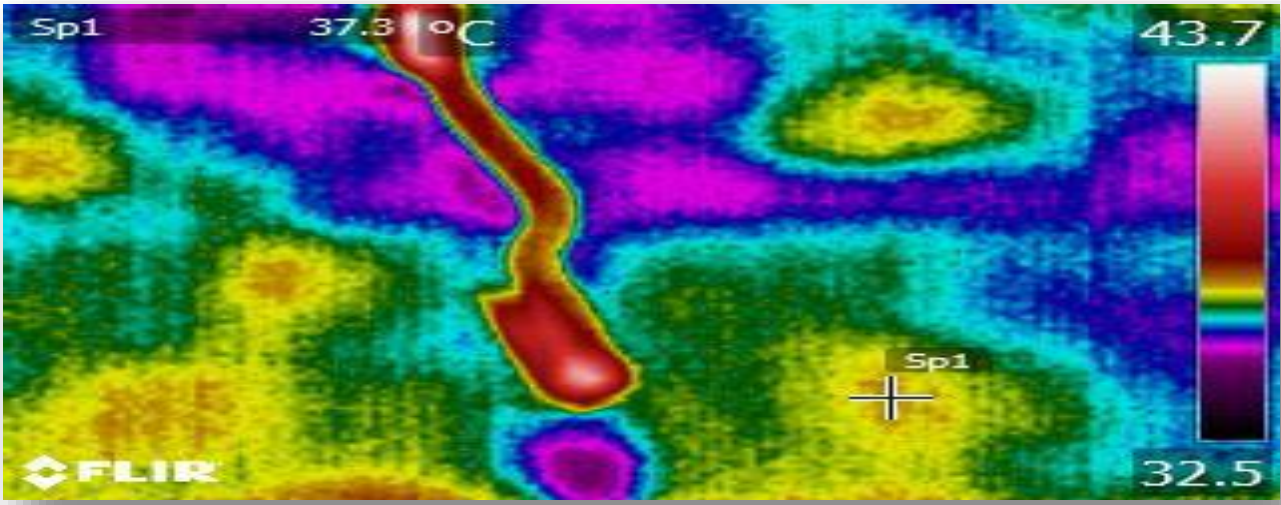

Figure 59 Thermal photo at Point 2

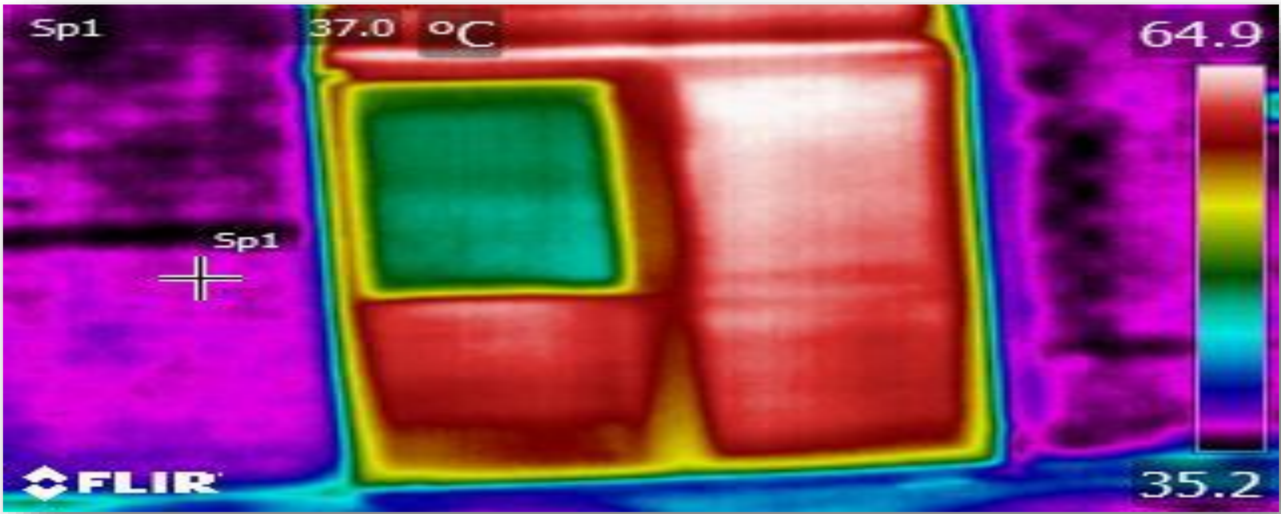

Figure 60 Thermal photo at Point 2

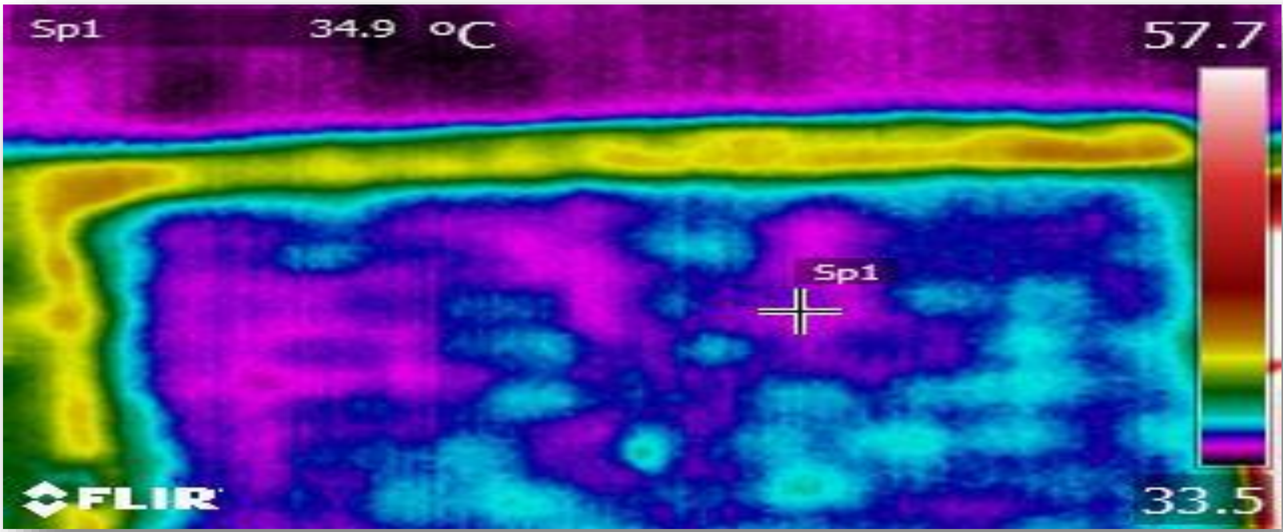

Figure 61 Thermal photo close to Point 3

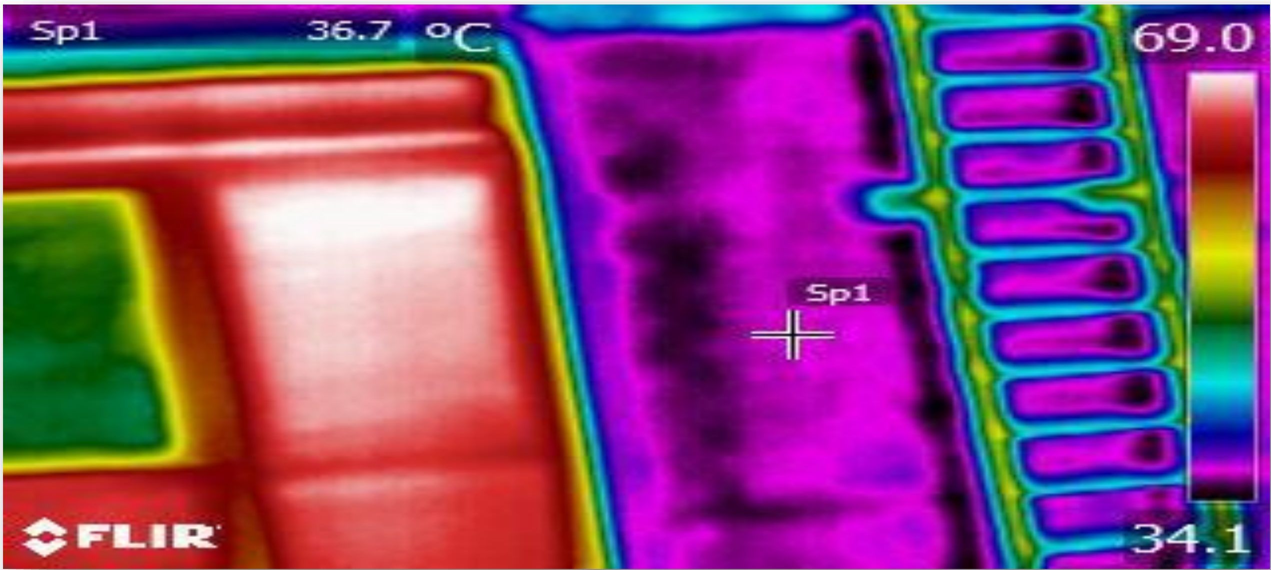

Figure 62 Thermal photo close to Point 3

5.5 CONCLUSIONS

The measurements which carried out during the last days of July, August and in early September showed the following below:

- Large temperature differences on the exterior surfaces of the roofs. Differences in temperature which were observed in some cases reaches 10°C. The highest fluctuations were observed in the terrace of the third floor due to its unfavourable view.
- The construction materials of the roofs (tiles, binding cement) require reconstrution or replacement.
- Significant many hours of operating the airconditioning systems to achieve thermal comfort in the working spaces. This means uncontrolled energy consumption which leads to unrestrained waste of money and undoubtely in environmental damage.

6 THERMAL MODEL DEVELOPMENT & CALIBRATION

Cool materials reduce the solar gains of the building through the envelope, hence minimizing the cooling energy and peak power demand during the summer. On the contrary cool roofs may induce higher heating energy demand in winter which is counterbalance given the sun's lower position with respect to the horizon and the reduced daytime period and sun radiation compared to summer time (Kolokotsa et al., 2011).

Several studies have demonstrated that a number of variables need to be taken into account for a comprehensive assessment of the cool materials technology. Such variables include:

- Climatic conditions
- Building use
- Building insulation level
- Building geometry and construction technology

It is acknowledged that data based on numerical analyses can provide satisfactory results with respect to the technology potential but only a very limited number of data is available for real building applications. This experimental work addresses this issue by assessing the application of cool materials at the exterior of the building envelope under real operating conditions.

Energy Plus one of the most advanced, publicly-available building energy simulation programs, whose development begun in 1996 with funding from the U.S. Department of Energy is used for this purpose (Clarke, 2001). While the program borrows what was effective from BLAST and DOE-2, it contains a number of innovative features, including sub-hourly time steps, user-configurable modular HVAC systems integrated with a heat and mass balance-based zone simulation, as well as input and output data structures that can facilitate third party module and interface development. Graphical user interface has recently been developed and released for EnergyPlus under the umbrella of OpenStudio, a software kit developed to simplify the construction of simulation models. Results from EnergyPlus are included hereafter as they enclose robust and valuable information for the evaluation of the actual building energy performance data. In Figures 62 and 63 the 3D model of the building which was developed in Google SketchUp is presented.

Figure 63 Front view of the Municipality building

Figure 64 Back view of the Municipality building

6.1 APPLICATION OF COOL MATERIALS

The actions which were implemented in the building are briefly described below:

- Removal of existing tiles and recycling
- Cleaning of surfaces
- Maintenance of uncovered layers where necessary
- Application of cool materials with laboratory certified characteristics (see Table 5 and Table 6). The reflectivity versus wavelength is illustrated in Figure 65.

Table 5: Values of reflectivity (%)

Product Description	Photo of sample	SR (%)	SRuv (%)	SRvis (%)	SRnir(%)
Grey tile		**66**	7	69	66

Table 6: Emissivity factor

Product Description	Emissivity factor (e) (error ± 0.02)
Grey tile	**0.89**

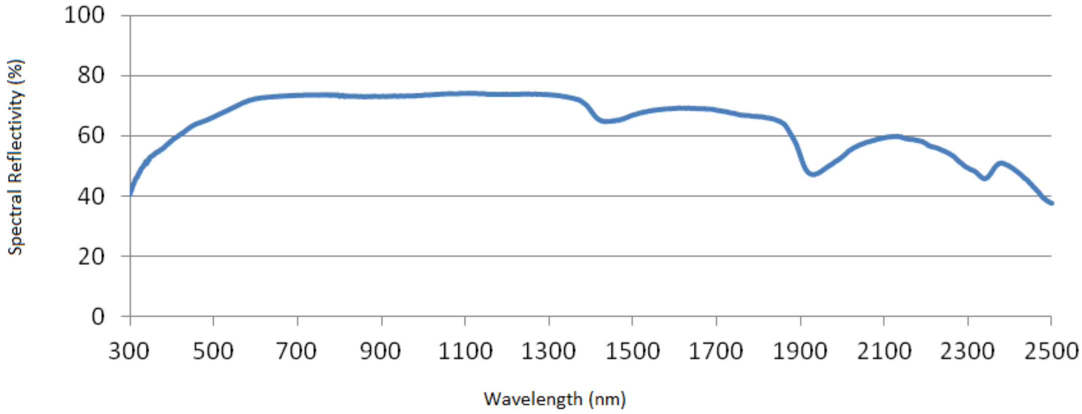

Figure 65 Cool material spectral reflectivity (%) vs wavelength (nm)

Figure 66 indicates the thermal zones and their numbers on top of which the cool materials were applied. Those are zones 1, 15, 16, 17, 18, 36, 42, 43 and 44.

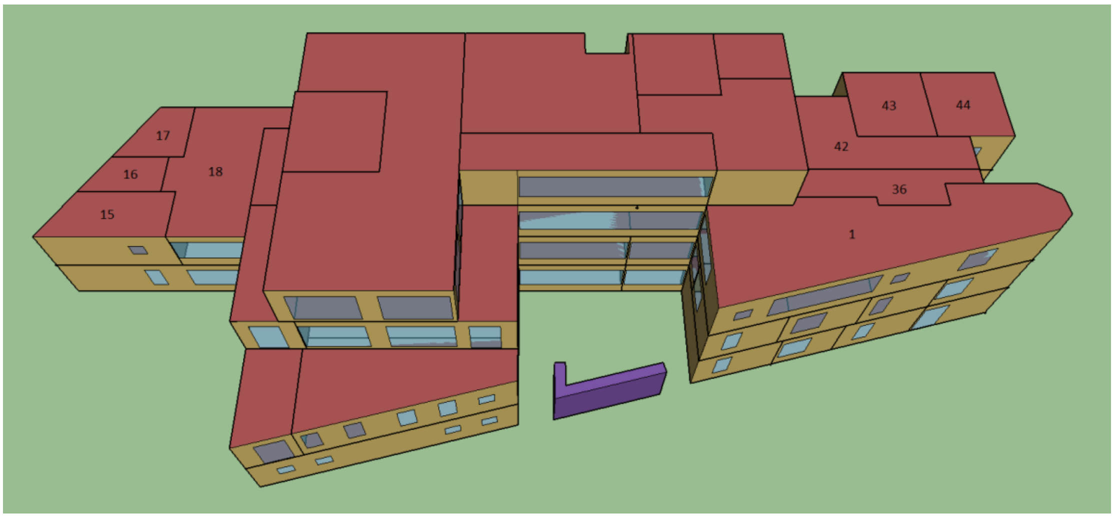

Figure 66 Thermal zones with cool materials applied

6.2 MODEL VALIDATION

Validation of the model was performed with the aid of measurements of indoor and ambient temperature which were performed during June 2015. In Figure 67 predicted and measured values of indoor temperature are shown for 8/6/15-9/6/15. In Figure 68 the results of the R^2 tests, indicate strong correlation between measured and predicted data.

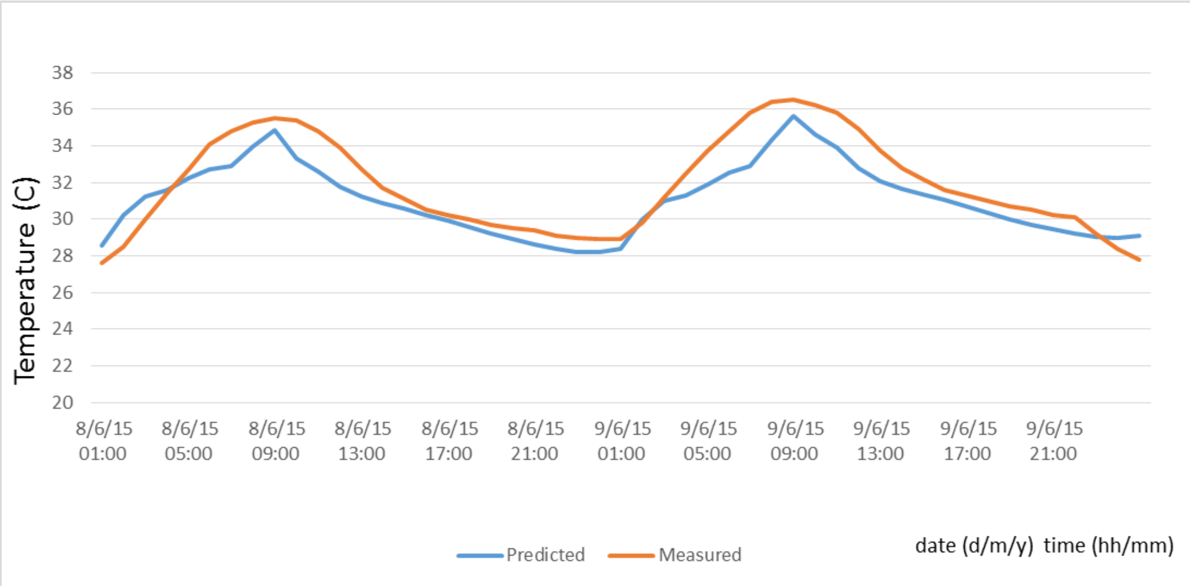

Figure 67 Model validation based on predicted and measured indoor temperature for 8/6/15-9/6/15

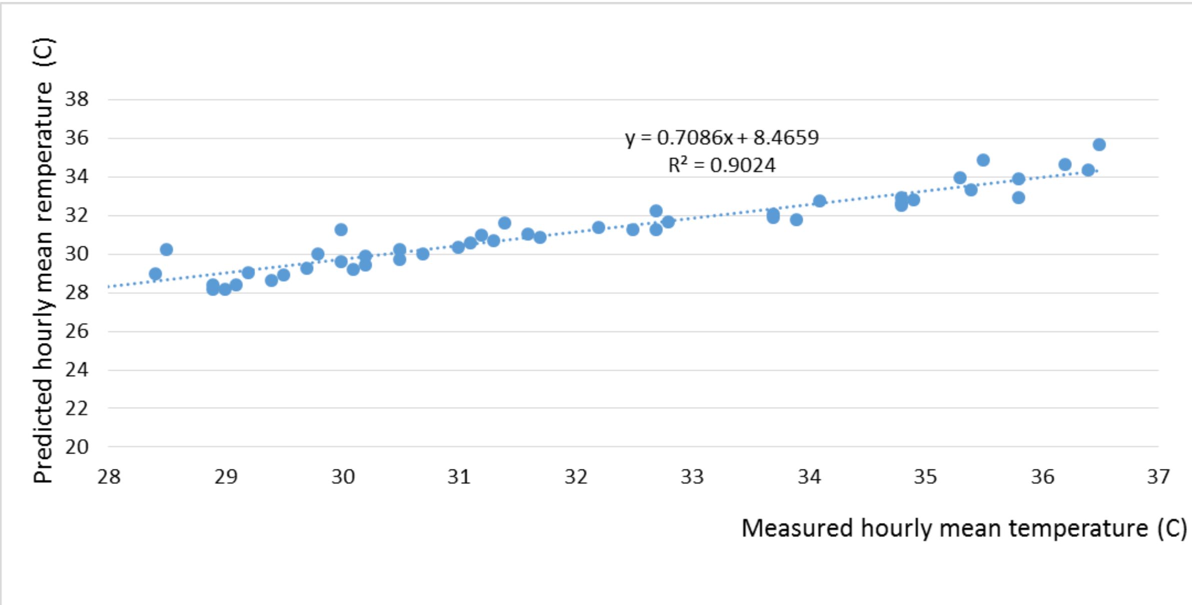

Figure 68 R2 correlation for 8/6/15-9/6/15 indoor predicted and measured hourly mean temperatures

In addition a snapshot of the data set used for validation purposes is presented in Figure 69. In Figure 70 the correlation of the predicted and measured hourly mean temperatures is presented for the time period between 15/6/15 and 17/6/15.

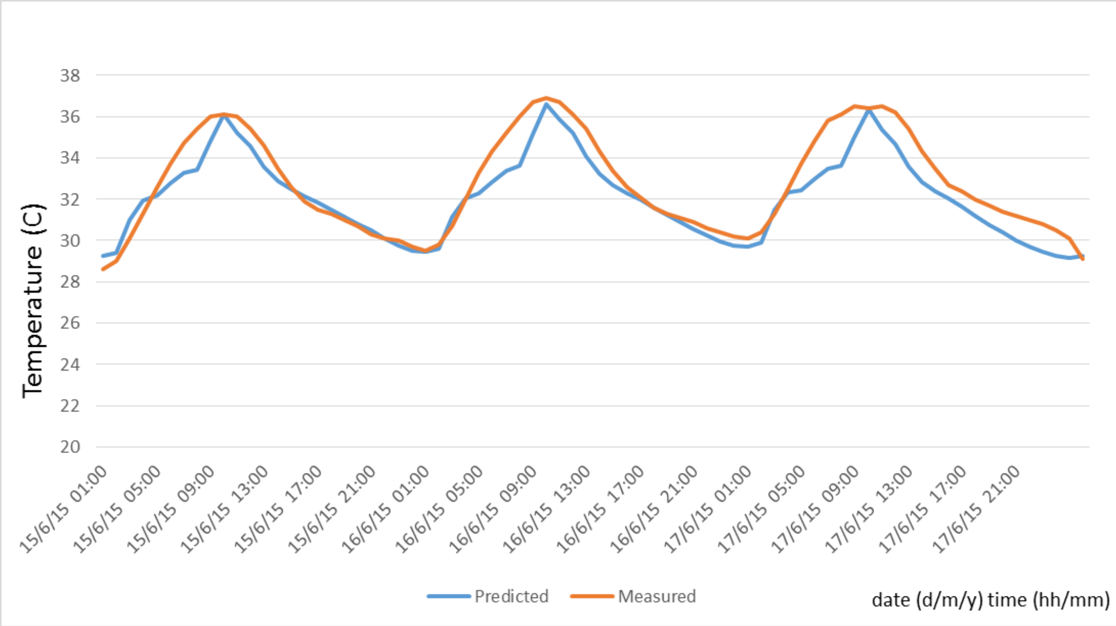

Figure 69 Model validation based on predicted and measured indoor temperature for 15/6/15-17/6/15

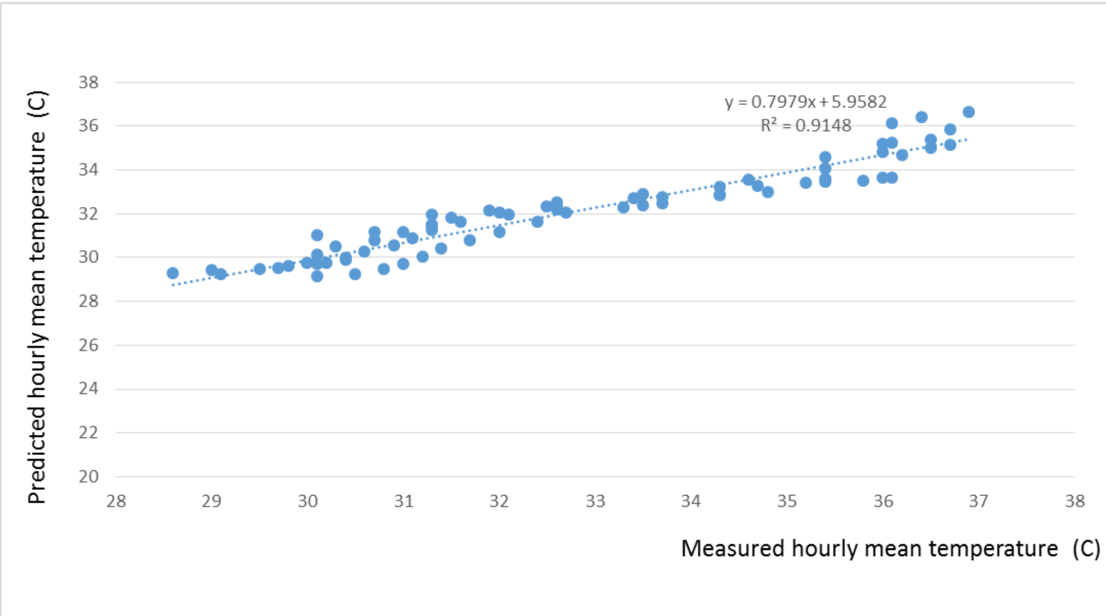

Figure 70 R2 correlation for 15/6/15-17/6/15 indoor predicted and measured hourly mean temperatures

6.3 CALCULATION OF RESULTS & DISCUSSION

In the following section the results of the simulation for a test reference meteorological data are displayed in the form of the temperature profiles of each thermal zone before and after the application of the cool material on its top surface. Figure 71 shows the geometrical characteristics of thermal zone 15 followed the temperature profile of thermal zone 15 before and after the application of the cool material (Figure 72).

The average difference of the predicted hourly mean temperatures before the application of the cool material compared to the predicted hourly mean temperatures after application is 3.87% which corresponds to 1.27K.

Differences in predicted hour mean temperatures before the application of the cool material compared to the predicted hour mean temperatures after application lie between [3.23%, 4.28%] which corresponds to temperature differences in the range [1.12K, +1.39K].

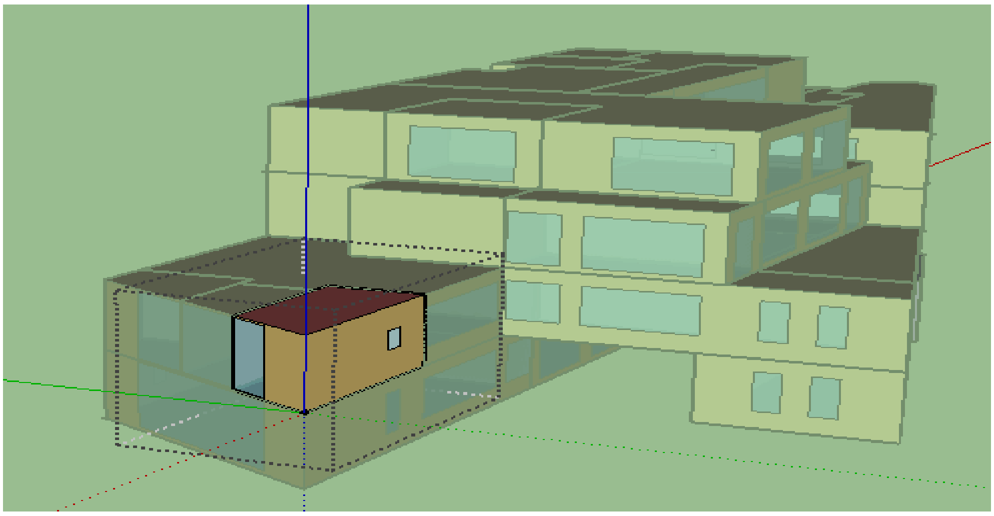

Figure 71 Thermal zone 15

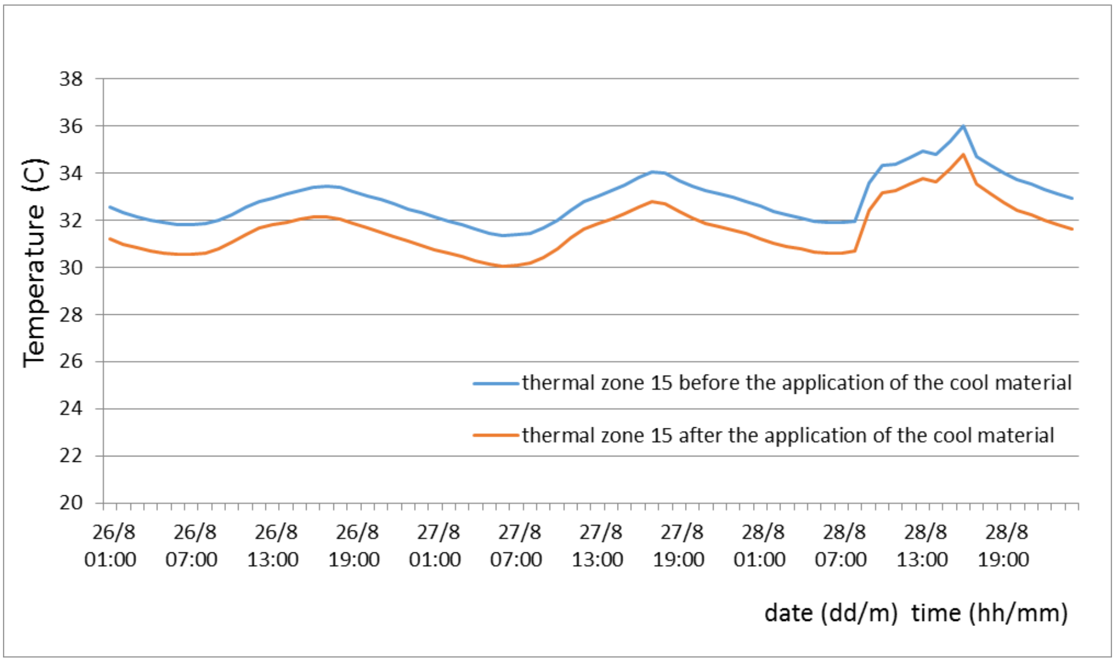

Figure 72 Air temperature profile of thermal zone 15 before and after the application of the cool material for test reference year meteorological data

Figure 73 contains a 3D image of thermal zone 16 followed by Figure 74 which illustrates the temperature profile of the same zone before and after the application of the cool material.

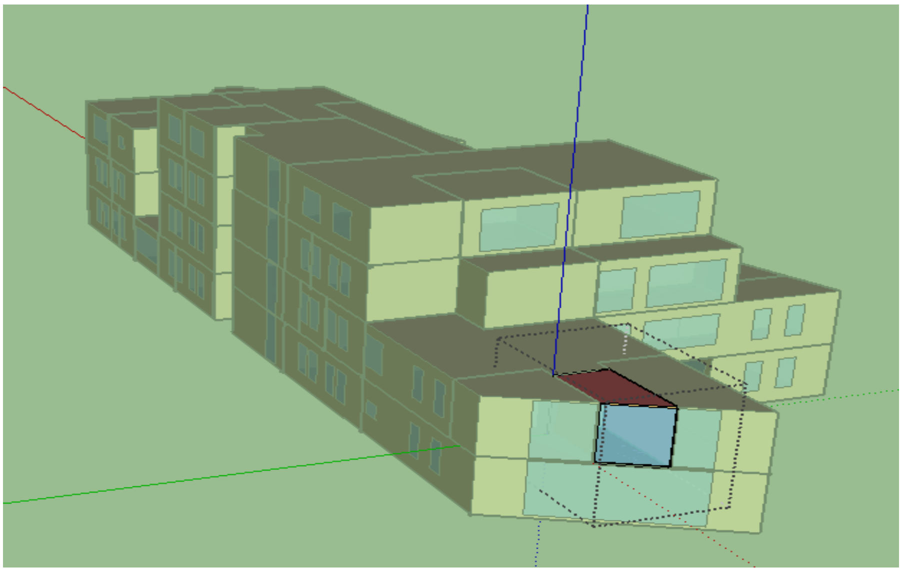

Figure 73 Thermal zone 16

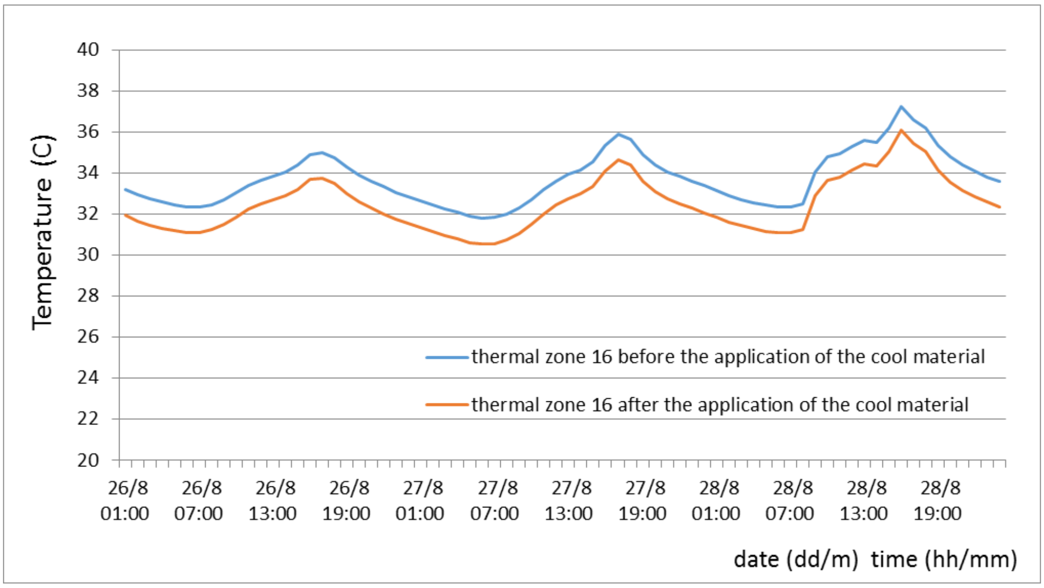

Figure 74 Air temperature profile of thermal zone 16 before and after the application of the cool material for test reference year meteorological data

The average difference of the predicted hourly mean temperatures before the application of the cool material in zone 16 compared to the predicted hourly mean temperatures after application is 3.66% which corresponds to 1.23K.

Differences in predicted hour mean temperatures before the application of the cool material compared to the predicted hour mean temperatures after application lie between [3.12%, 4.02%] which corresponds to temperature differences in the range [1.22K, +1.32K].

In Figure 75, thermal zone 17 is shown followed by the respective temperature profile before and after the application of the cool material (Figure 76).

The average difference of the predicted hourly mean temperatures before the application of the cool material in zone 17 compared to the predicted hourly mean temperatures after application is 3.76% which corresponds to 1.25K.

Differences in predicted hour mean temperatures before the application of the cool material compared to the predicted hour mean temperatures after application lie between [3.22%, 4.1%] which corresponds to temperature differences in the range [1.13K, +1.36K].

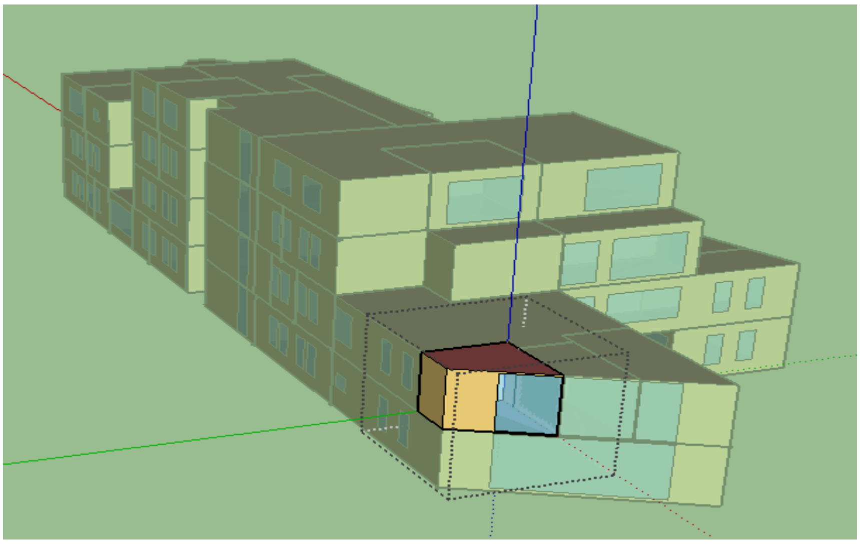

Figure 75 Thermal zone 17

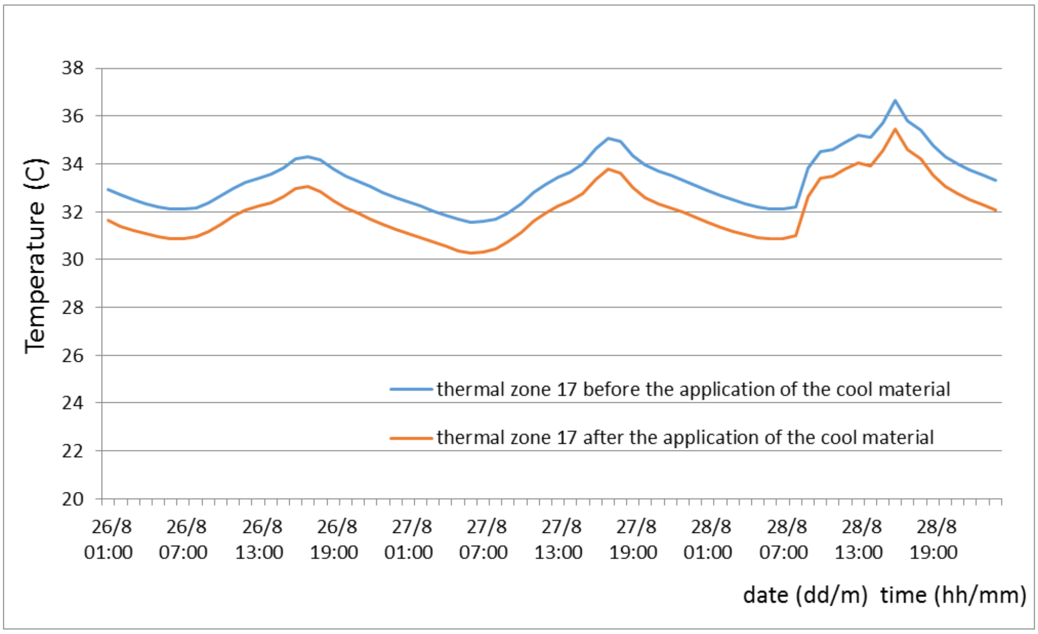

Figure 76 Air temperature profile of thermal zone 17 before and after the application of the cool material for test reference year meteorological data

Figure 77 presents the structure of thermal zone 18 in the building under study. The temperature profile of thermal zone 18 before and after the application of the cool material for the timeframe from 26-28/8/2014 is provided in Figure 78.

The average difference of the predicted hourly mean temperatures before the application of the cool material compared to the predicted hourly mean temperatures after application is 3.59% which corresponds to 1.23K.

Differences in predicted hour mean temperatures before the application of the cool material compared to the predicted hour mean temperatures after application lie between [2.93%, 4.03%] which corresponds to temperature differences in the range [1.02K, +1.25K].

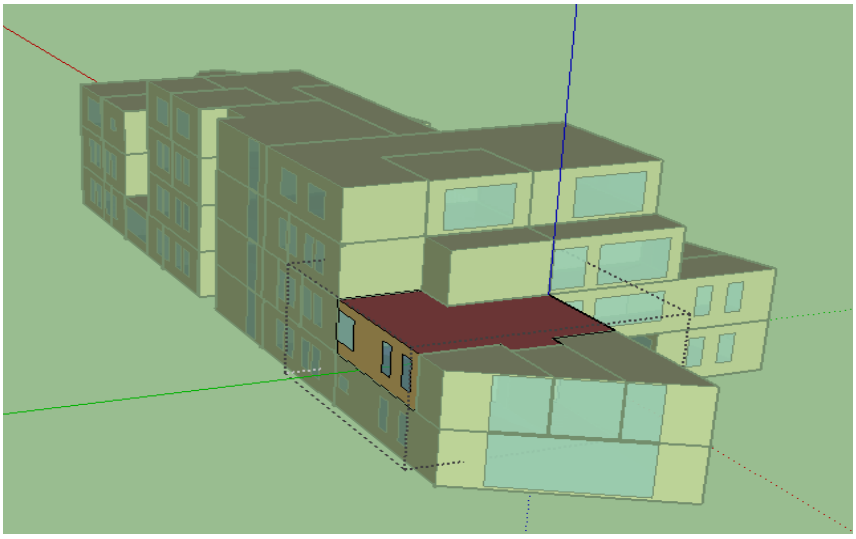

Figure 77 Thermal zone 18

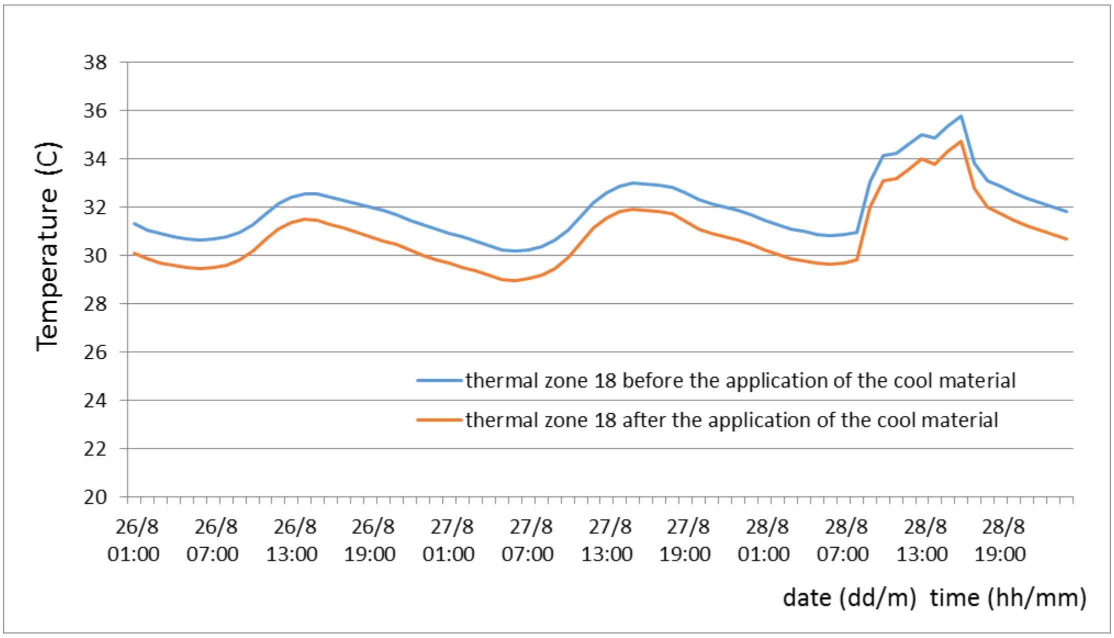

Figure 78 Air temperature profile of thermal zone 18 before and after the application of the cool material for test reference year meteorological data

In Figure 79 thermal zone 1 is highlighted. The temperature profile of thermal zone 1 before and after the application of the cool material is provided in Figure 80. The average difference of the predicted hourly mean temperatures before the application of the cool material compared to the predicted hourly mean temperatures after application is 3.35% which corresponds to 1.08K. Differences in predicted hour mean temperatures before the application of the cool material compared to the predicted hour mean temperatures after application lie between [2.70%, 3.79%] which corresponds to temperature differences in the range [0.94K, +1.2K].

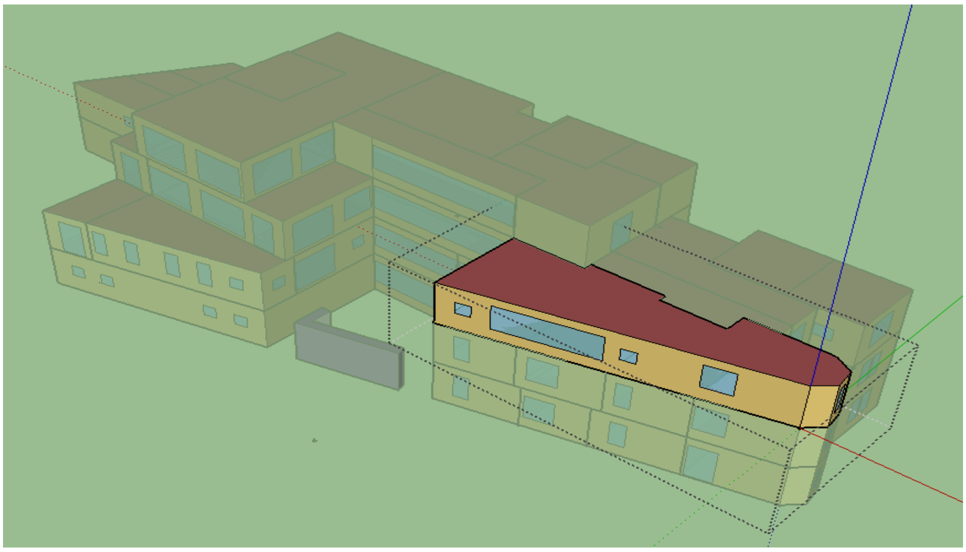

Figure 79 Thermal zone 1

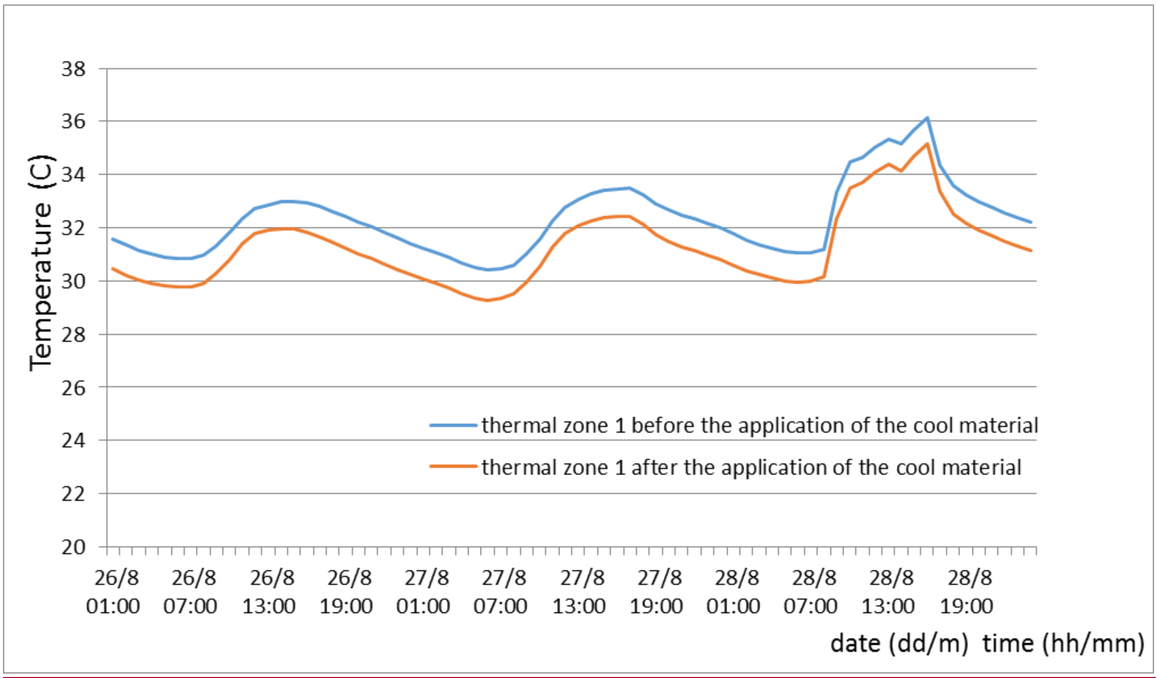

Figure 80 Air temperature profile of thermal zone 1 before and after the application of the cool material for test reference year meteorological data

Furthermore, thermal zone 36 is pictured in Figure 81. The temperature profile of thermal zone 36 before and after the application of the cool material is visualized in Figure 82. The average difference of the predicted hourly mean temperatures before the application of the cool material compared to the predicted hourly mean temperatures after application is 2.74% which corresponds to 0.86K. Differences in predicted hour mean temperatures before the application of the cool material compared to the predicted hour mean temperatures after application lie between [2.31%, 3.03%], which corresponds to temperature differences in the range [0.77K, 0.93K].

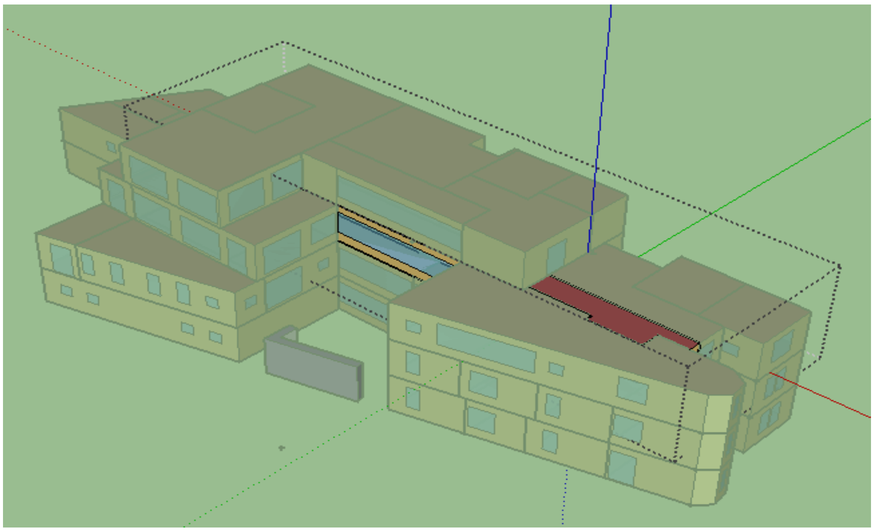

Figure 81 Thermal zone 36

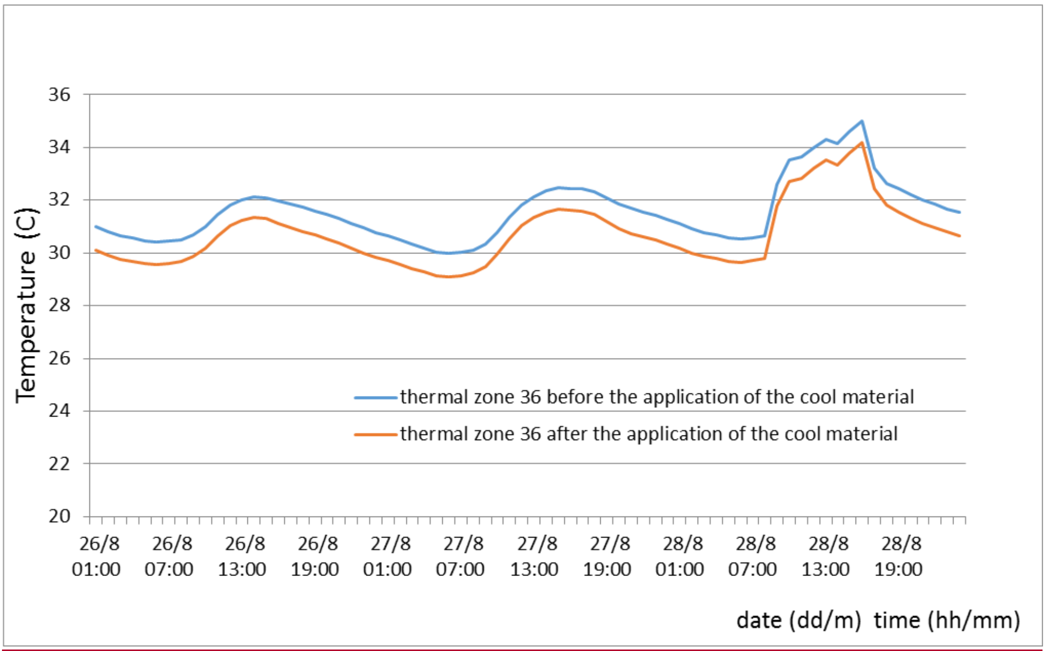

Figure 82 Air temperature profile of thermal zone 36 before and after the application of the cool material for test reference year meteorological data

Next, thermal zone 42 is presented in Figure 83 along with the equivalent temperature profiles before and after the application of the cool material (Figure 84). The average difference of the predicted hourly mean temperatures before the application of the cool material compared to the predicted hourly mean temperatures after application is 3.13% which corresponds to 0.98K. Differences in predicted hour mean temperatures before the application of the cool material compared to the predicted hour mean temperatures after application lie between

[2.67%, 3.48%], which corresponds to temperature differences in the range [0.87K, +1.06K].

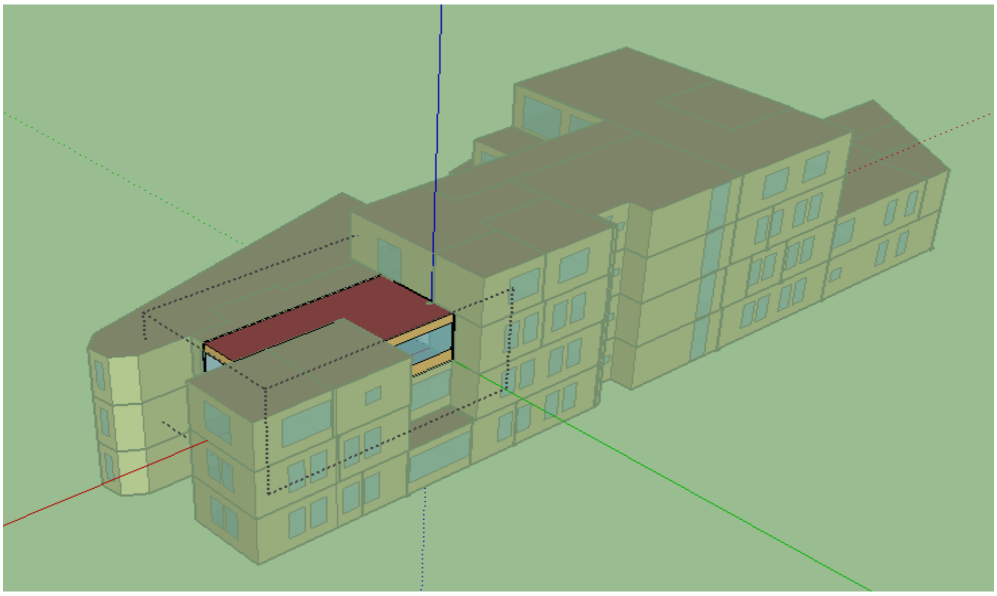

Figure 83 Thermal zone 42

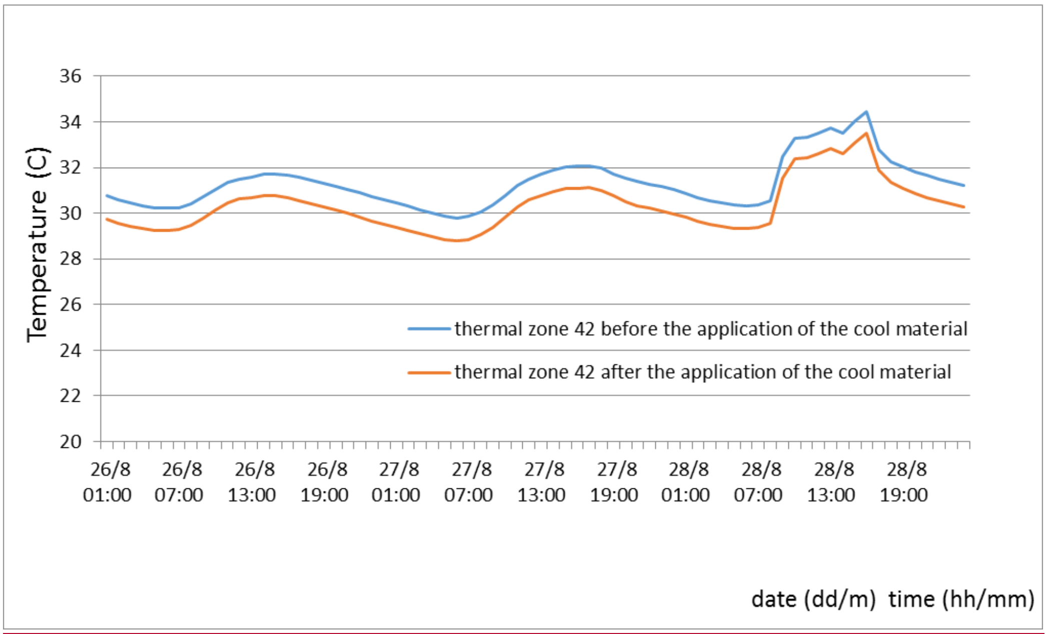

Figure 84 Air temperature profile of thermal zone 42 before and after the application of the cool material for test reference year meteorological data

Subsequently, the formation of thermal zone 43 is illustrated in Figure 85 below. Again, by comparing the temperature profiles before and after the application of the cool materials a significant improvement of indoor thermal conditions is justified (Figure 86). The average difference of the predicted hourly mean temperatures before the application of the cool material compared to the predicted hourly mean temperatures after application is 4.22% which corresponds to 1.31K.

Differences in predicted hour mean temperatures before the application of the cool material compared to the predicted hour mean temperatures after application lie between [3.61%, 4.68%] which corresponds to temperature differences in the range [1.17K, +1.43K].

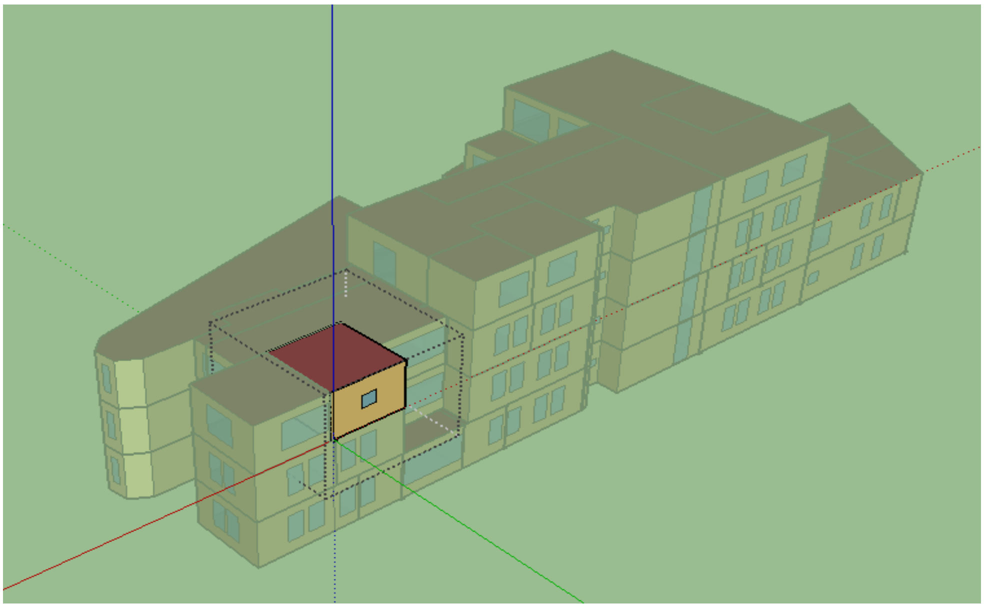

Figure 85 Thermal zone 43

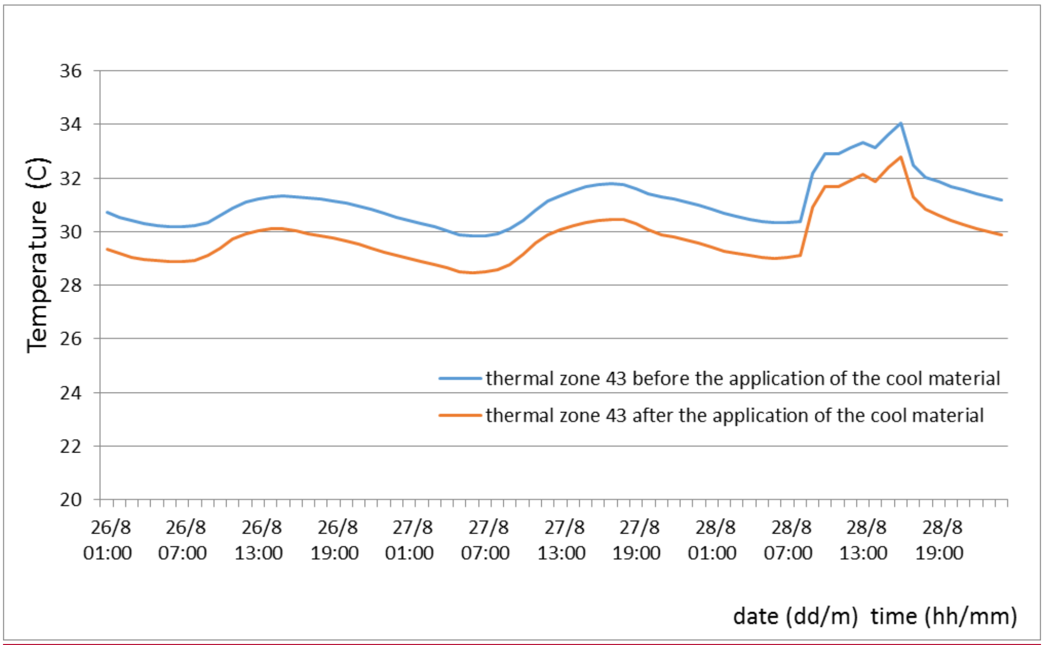

Figure 86 Air temperature profile of thermal zone 43 before and after the application of the cool material for test reference year meteorological data

Analogous results occur for thermal zone 44 (Figure 87) where a clear decrease of temperature values is observed after the application of the cool material (Figure 88).The average difference of the predicted hourly mean temperatures before the application of the cool material compared to the predicted hourly mean temperatures after application is 4.29%, which corresponds to 1.38K.

Differences in predicted hour mean temperatures before the application of the cool material compared to the predicted hour mean temperatures after application lie between [3.59%, 4.79%], which corresponds to temperature differences in the range [1.24K, +1.52K].

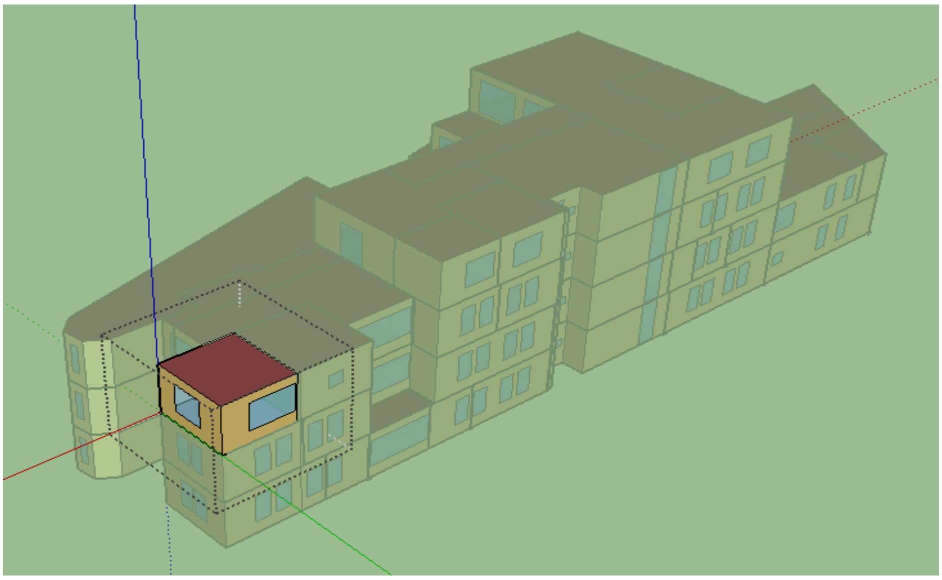

Figure 87 Thermal zone 44

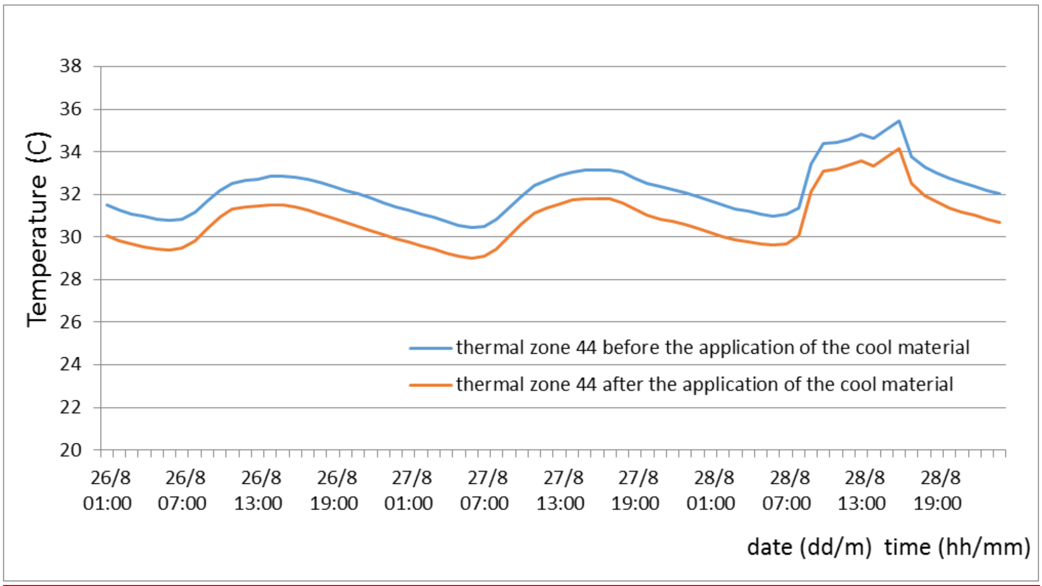

Figure 88 Air temperature profile of thermal zone 44 before and after the application of the cool material for test reference year meteorological data

In terms of energy demand Figure 89 indicates a slight increase during the heating period which is counterbalanced by a greater total decrease during the cooling period.

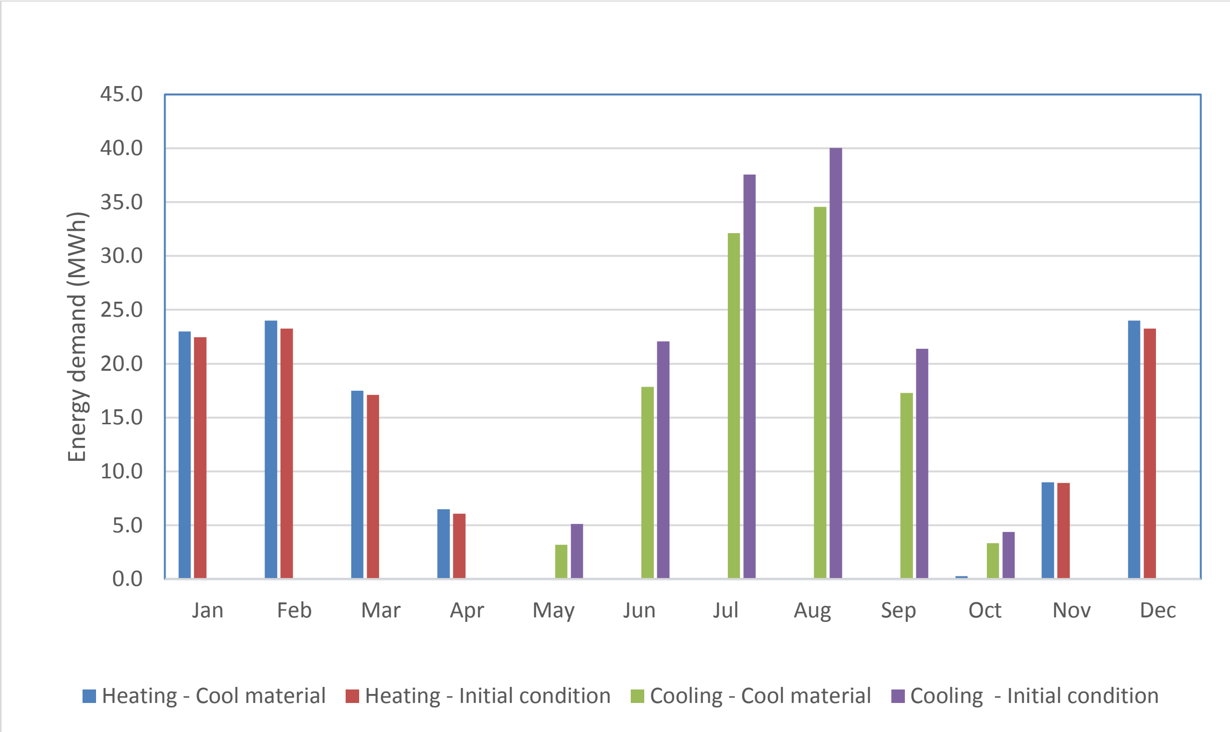

Figure 89 Monthly heating and cooling energy demand before and after the application of the cool material

The annual energy demand for cooling is decreased by 21% while the increase of the energy demand for heating is almost 3% for the overall period.

7 COOL PAVEMENTS APPLICATION

7.1 URBAN MODEL DEVELOPMENT & CALIBRATION

ENVI-met is a three-dimensional microclimate model designed to simulate the surface-plant-air interactions in urban environment with a typical resolution of 0.5 to 10m in space and 10sec in time which simulates even complicated geometric forms such as terraces, balconies or complex quarters. It is also a prognostic model based on the fundamental laws of fluid dynamics and thermo- dynamics. Its high spatial resolution allows a fine analysis of the microclimate at street level and the possibility of representing complex geometries including galleries and horizontal overhangs as well as various vegetation covers. Typical areas of application are Urban Climatology, Architecture, Building Design or Environmental Planning. Envimet is used to calculate the microclimate and air quality in urban structure and open space. ENVI-met model is capable of predicting the microclimate changes within urban environments in terms of different variables with good accuracy(Michael Bruse & Team, 2010; Tsilini et al., 2015).

The model includes the simulation of:

1. Flow around and between buildings
2. Exchange processes of heat and vapour at the ground surface and at walls
3. Turbulence
4. Exchange at vegetation and vegetation parameters
5. Bioclimatology
6. Pollutant dispersion

The simulation of the above mentioned parameters is grouped in four main systems:

1. Soil
2. Vegetation
3. Atmosphere
4. Building

The soil from the surface to 2m depth is divided into multiple layers with the vertical spacings. Different soil profiles and patches of surfaces can be modelled by allocating various natural soils or artificial materials for each grid cell. For natural soils, the heat and water vapour transfers are taken into account while merely heat transfer is considered for sealed materials. The ground surface temperature is calculated from the net radiative fluxes, the turbulent fluxes of heat and vapour and the heat conduction into the ground at the surface. The albedo of natural soil is determined by the model itself, as a function of solar incident angle and water content of top soil layer.

ENVI-met is a freeware program (not open source) based on different scientific research projects and is therefore under constant development. It comes along with a number of additional software ranging from editors up to graphical visualization tools for the model results. The model combines the calculation of fluid dynamics parameters such as wind flow or turbulence with the thermodynamic processes taking place at the ground surface, at walls and roofs or at plants.

An inaccuracy consists in the fact that its high complexity makes the model very slow. In order to succeed sufficient results in a specific time period one has either to limits the calculated timespan or the model resolution or the size of the area of interest. However the limitation to the resolution leads to inaccuracy. Due to the low horizontal grids resolution all objects become cuboids. While lager objects are composed by several cuboids, smaller objects can't be included in the calculations at all. Furthermore, the low horizontal resolution leads to inaccuracy in the calculation of radiation and air flow.

7.2 APPLICATION OF COOL PAVEMENTS

The cool pavements were applied in the side walk in the front of a school building in the Municipality of Acharnes (Figure 90).

Figure 90 The cool pavement application area

The activities involving the cool material application were the following:

• Remove of old paving slabs in the specific area,

• Cleaning of the surface from loose materials, etc.

• Placement of the cool pavements, in a layer of lime-cement plaster with a thickness of 2.5 – 3.0cm (consisting of one part lime, five parts clean sand and 180kg/m^3). The grouting of the cool pavements was made with a marble-cement plaster containing white cement in the ratio of 650kg/m^3.

The cool pavement materials were in line with the standards on solar reflectance ASTM E903 / ASTMG159 and emissivity ASTM C1371. In order to verify the cool pavements properties, the laboratory on the Department of Physics of the University of Athens, carried out reflectance measurements in the spectral range 300-2500nm as well emissivity measurements of the proposed pavement type. As a result the reflectance (SR) and emissivity (e) coefficients of the applied material are:

SR = 0.69

e=0.9

The cool material application spot, an area of the sidewalk in the specific urban region of the Municipality of Acharnes, is depicted in Figure 91.

Figure 91 Street view of the sidewalk with the cool material application

In Figure 92 we can see a thermal image representation of the cool and conventional pavement at 9:00 on 17 June 2015. Although the ambient temperature is still relatively low, the surface temperature difference between the conventional (AR03) and cool pavement (left square AR02) is almost 2K.

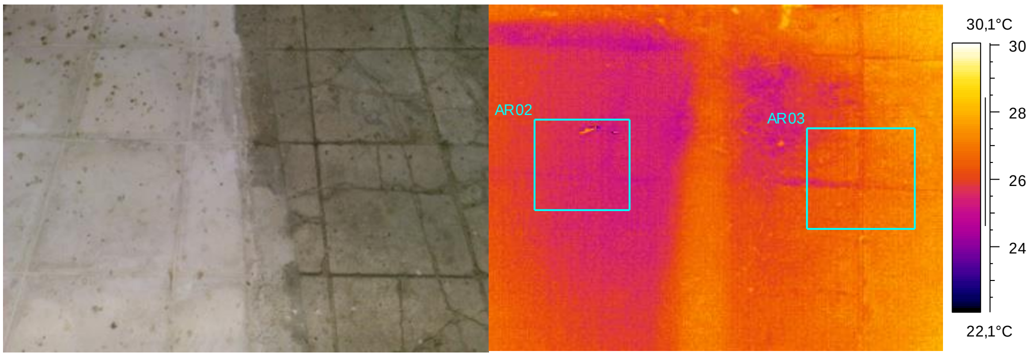

Figure 92 The Cool pavement application and its viewpoint through a thermal camera, at 9:00

At midday and during noon, while the ambient temperature increases, the surface temperature difference between cool pavement and the conventional sidewalk is more evident (Figure 93 and 94) and reaches 4-5K.

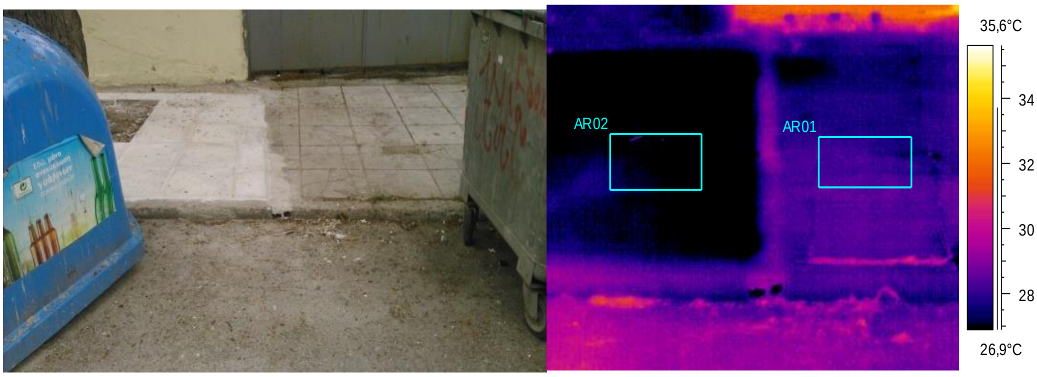

Figure 93 The Cool pavement application and its viewpoint through a thermal camera, at 12:00

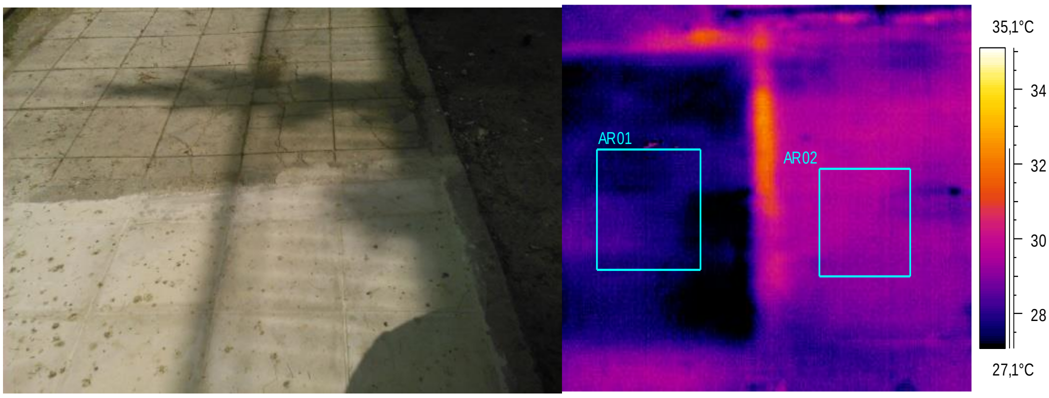

Figure 94 The Cool pavement application and its viewpoint through a thermal camera, at 18:00

7.3 CALCULATION RESULTS & DISCUSSION

As mentioned in Section 7.2, the urban model used for the surface and air temperature simulation was the ENVI-met software. The 3D model in Envi-met was developed using in-situ measurements of the urban layout, maps and photos. Two types of files were developed to support the Envi-met simulation:

- The input file
- The configuration file (Configuration File-CF)

The input files contain all the relevant information about the geometry of the simulated area and the neighbouring buildings. As it was observed during in situ visits, the area consists of asphalt roads, cement pavement and building blocks of maximum three floors. Furthermore, the vegetation of the study area was inserted (see green spots of Figure 35).

The study area was organized in a grid of 90x90x20 cells (x,y,z) with each grid sized 1.30m x 1.30m. The simulation height z was set at 16m. The format of the input file for the analysis of the current situation is presented in Figure 95.

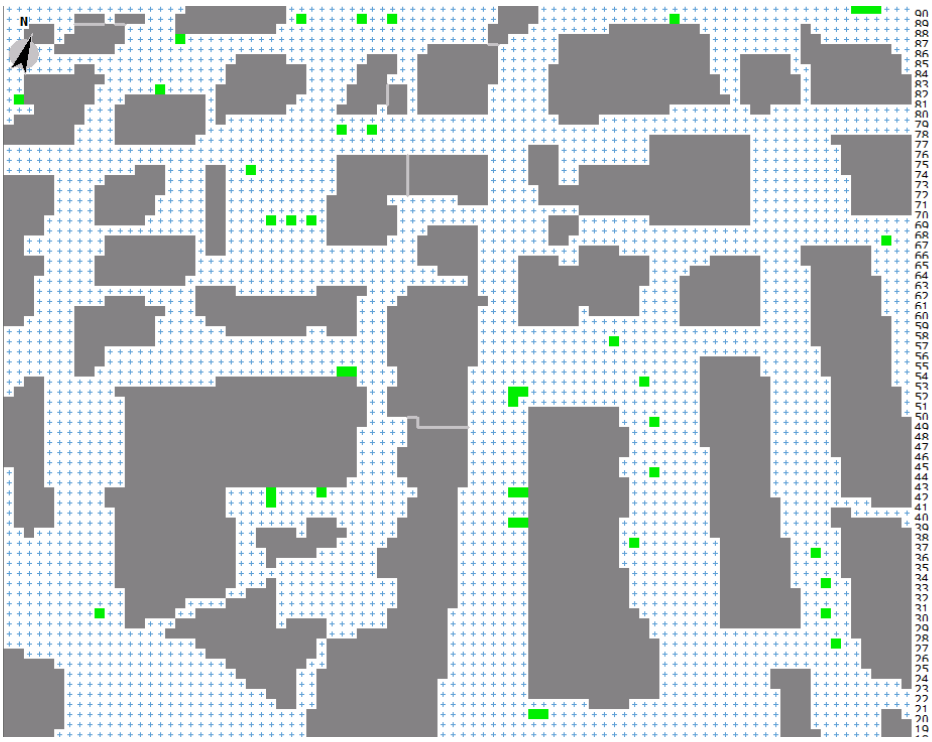

Figure 95 Image of the simulation area in Envi-met regarding the initial situation

In the configuration file, the total simulation time was set at 24hours. The initial conditions of the model are the average meteorological conditions extracted by the meteorological station that was installed in the Municipality of Acharnes. The simulation day was the 16th of June 2015. The initial conditions for the simulation are:

• Average temperature: 29° C

• Wind Speed 1.0m/s

• Wind direction WNW

• Relative Humidity 50%

The configuration file (Configuration File-CF) is depicted in Figure 96.

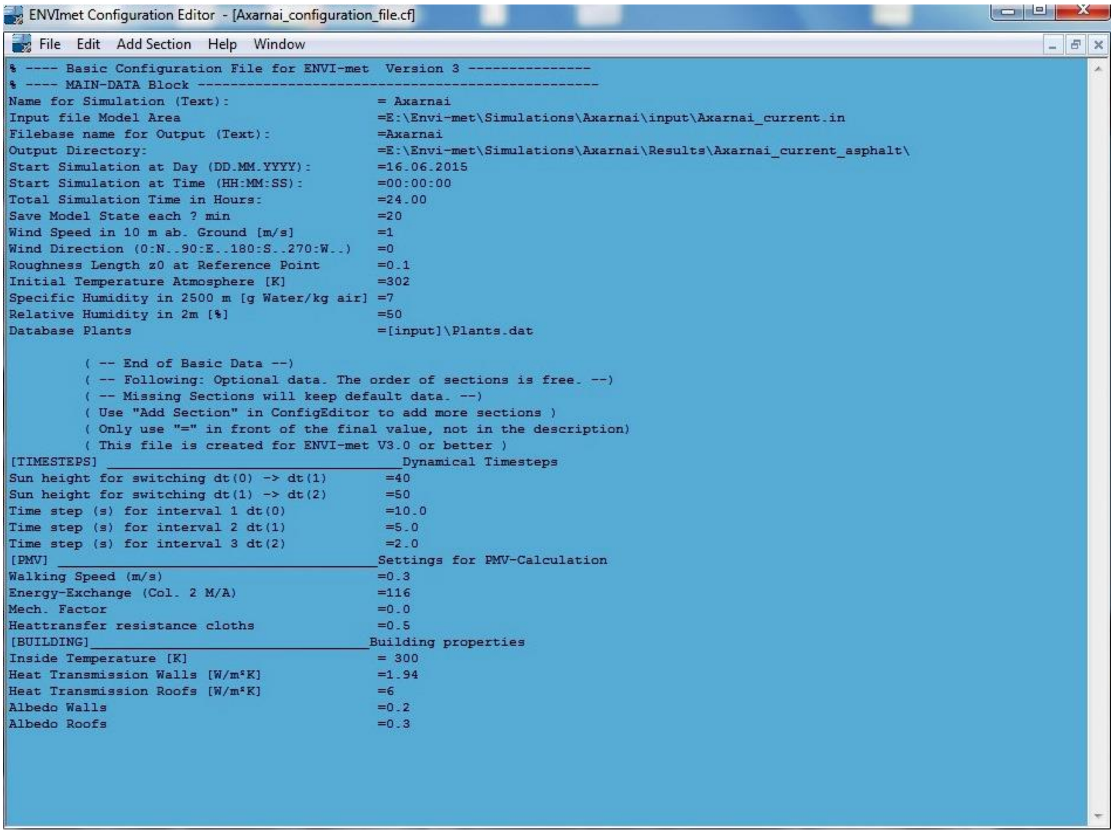

Figure 96 Envi-met configuration file

7.3.1 URBAN MODEL RESULTS BEFORE THE COOL PAVEMENT APPLICATION

The results of the Envi-met simulation for the surface temperature regarding the initial condition without the cool pavements, in a typical summer day of 16th of June are presented in the following three images for representative hours of the day, namely at 12:00 (Figure 97) at 15:00 (Figure 98) and at 18:00 (Figure 99).

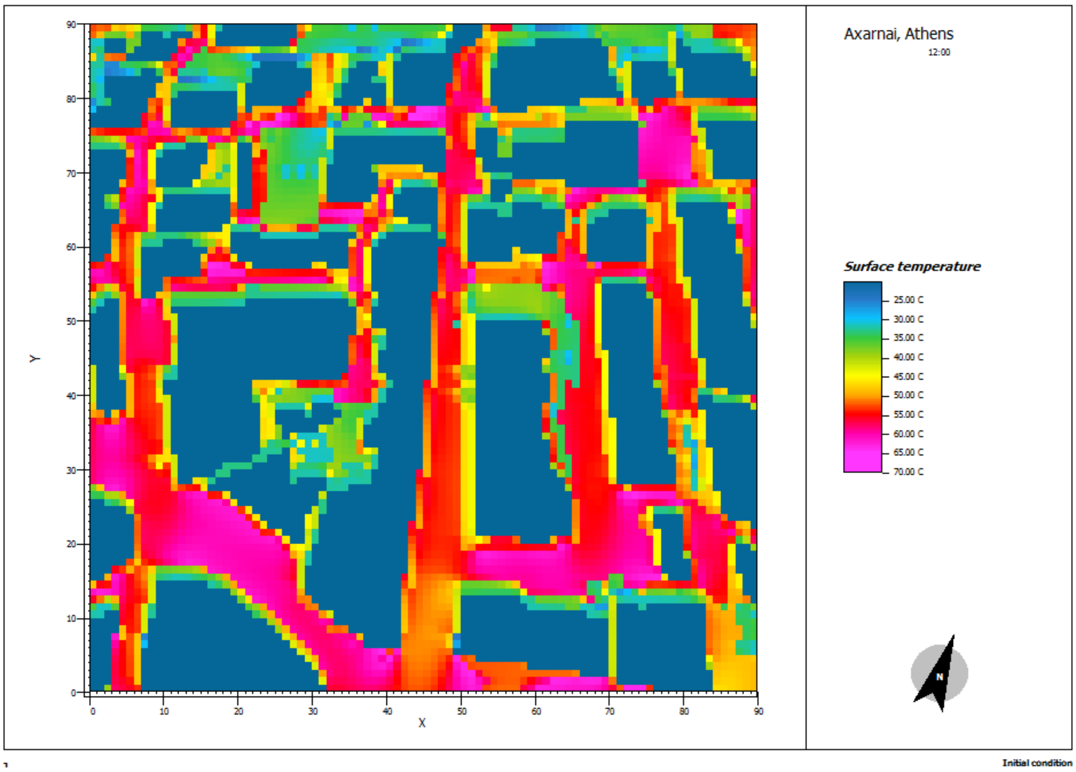

Figure 97 Spatial distribution of the surface temperature at 12:00 with the conventional pavements.

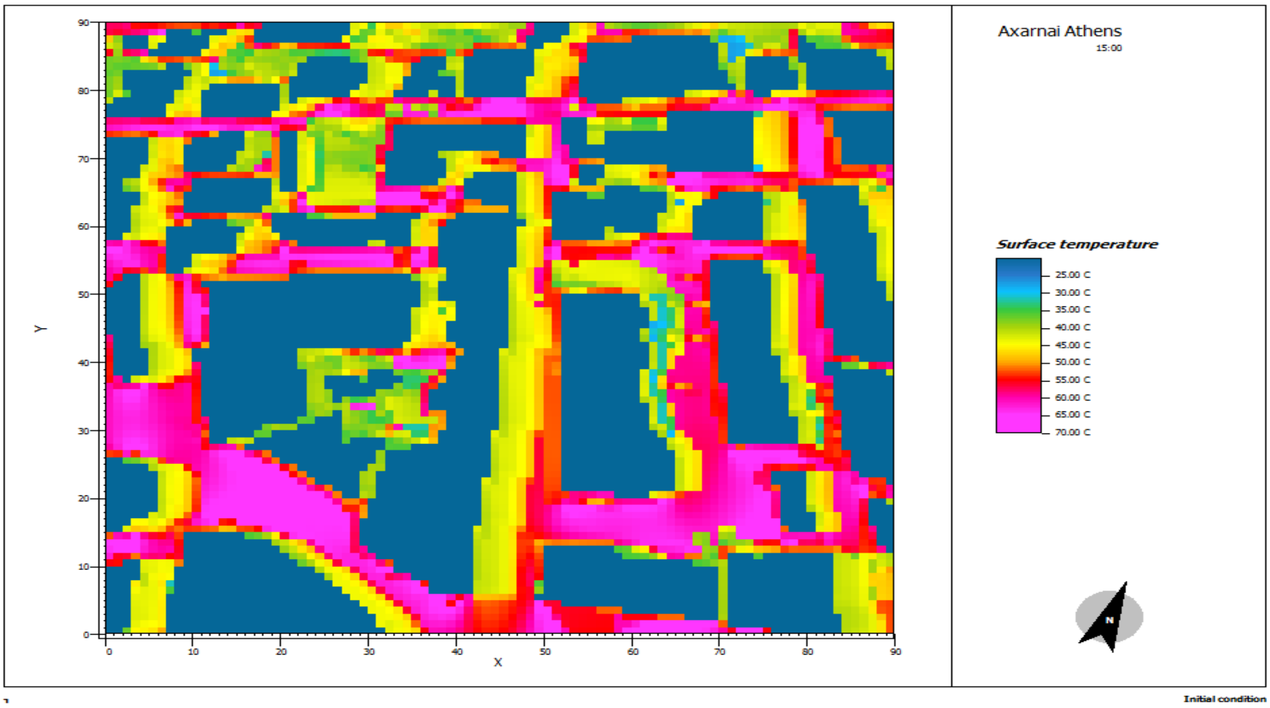

Figure 98 Spatial distribution of the surface temperature at 15:00 with the conventional pavements.

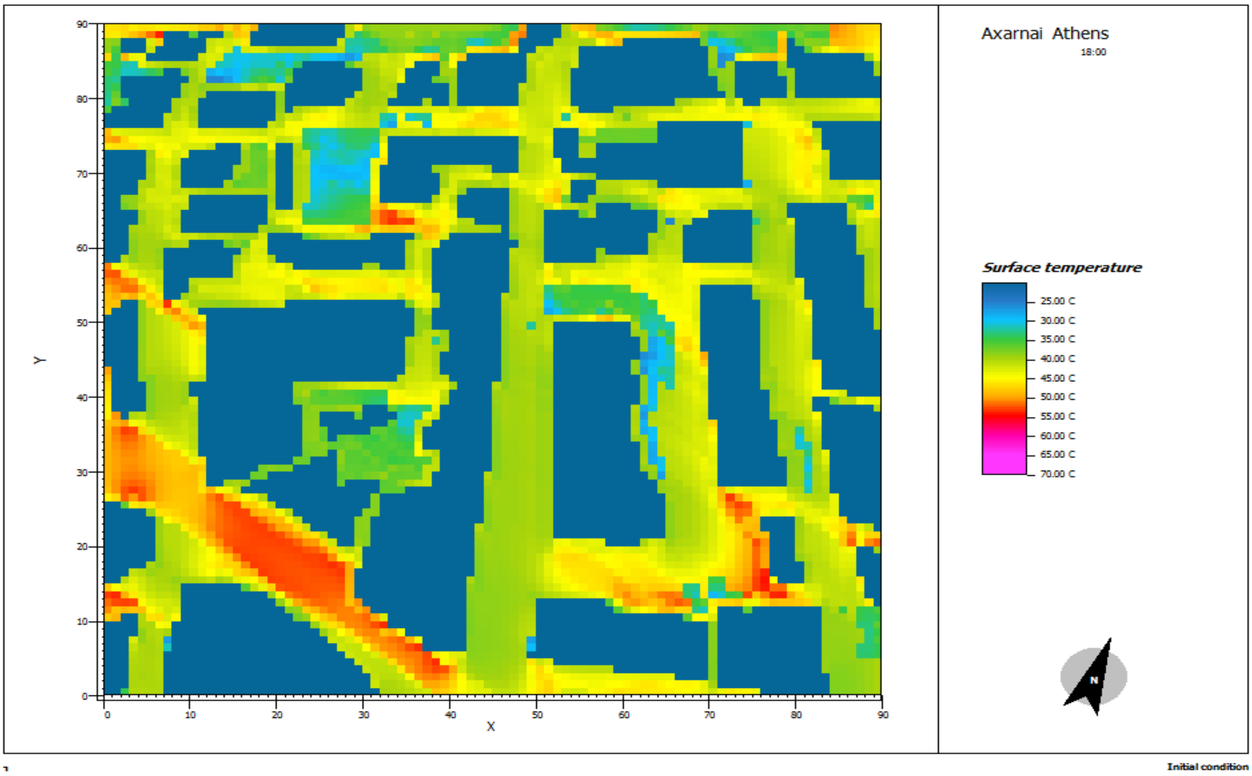

Figure 99 Spatial distribution of the surface temperature at 18:00 with the conventional pavements.

The air temperature at 1.8m height for the conventional pavements is depicted in Figure 100, 101 and 102 for 12:00, 15:00 and 18:00 respectively.

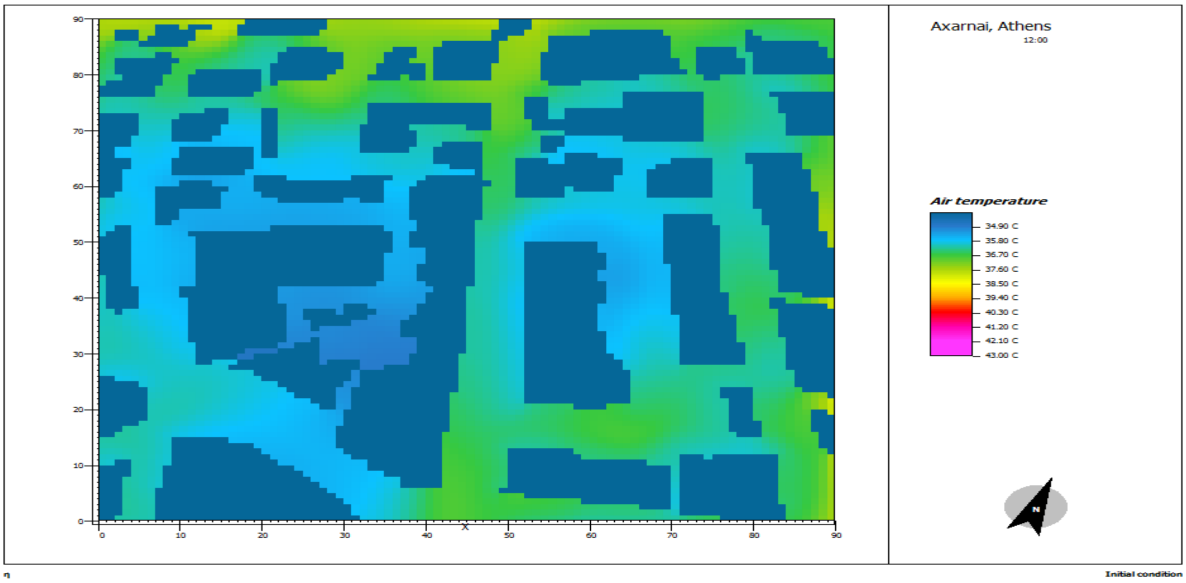

Figure 100 Spatial distribution of the air temperature at 12:00, z=1.8m with the conventional pavements.

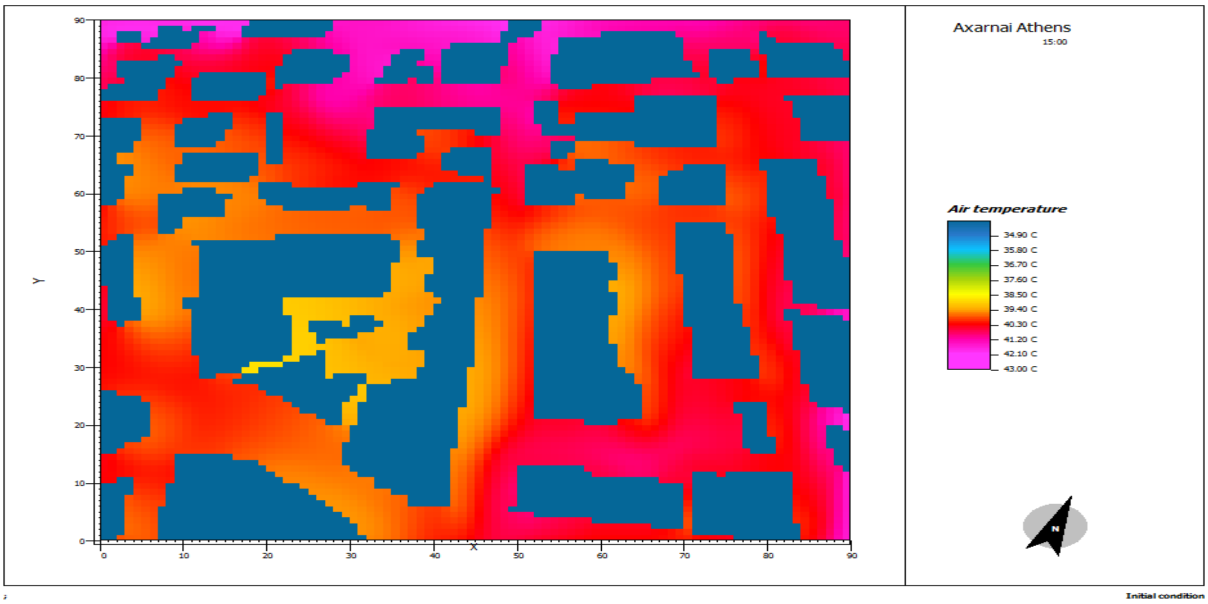

Figure 101 Spatial distribution of the air temperature at 15:00 z=1.8m with the conventional pavements.

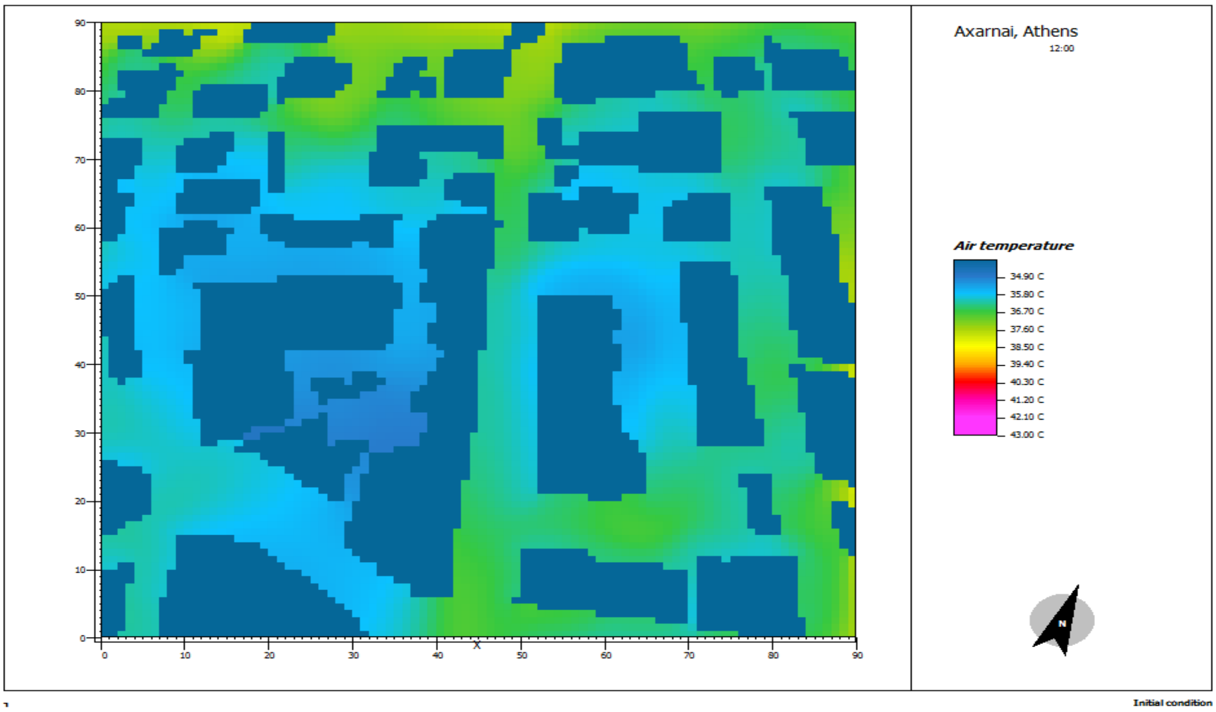

Figure 102 Spatial distribution of the air temperature at 18:00 z=1.8m with the conventional pavements.

7.3.2 URBAN MODEL RESULTS AFTER THE COOL PAVEMENT APPLICATION

Following the cool pavement application, the simulation of the urban microclimatic conditions was performed using Envi-met. The urban 3D model used is depicted in Figure 103. The cool pavement application is also illustrated in Figure 103.

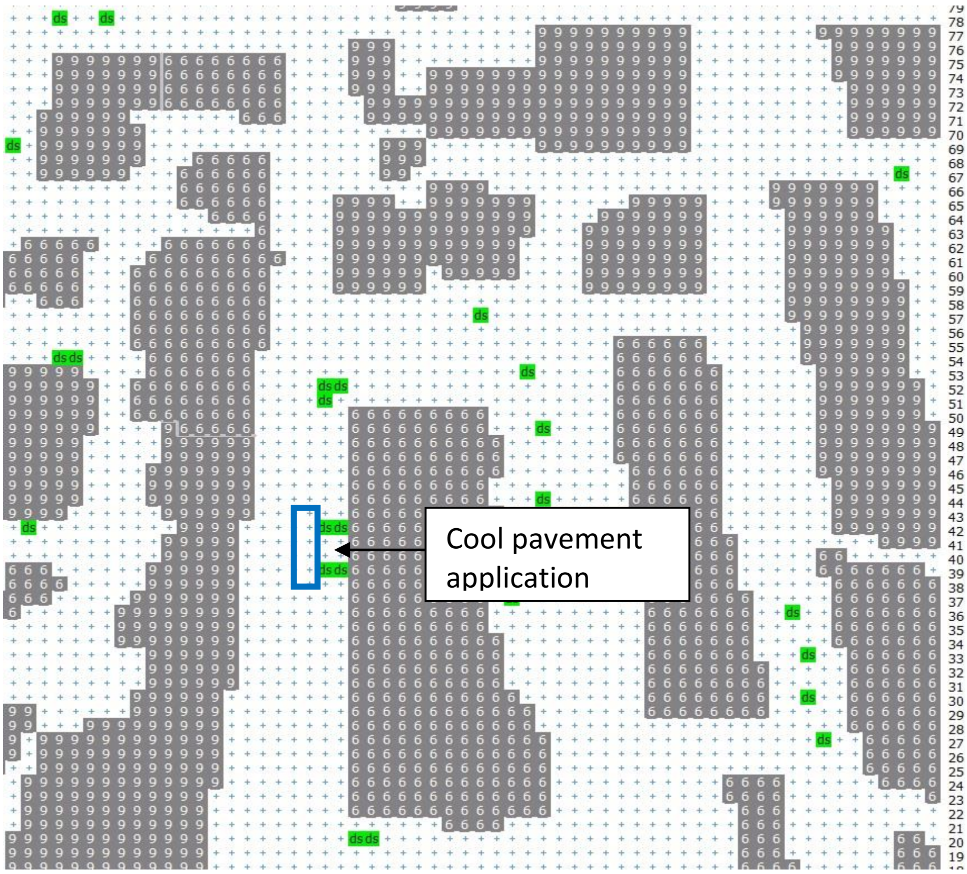

Figure 103 Image of the simulation area in Envi-met and the cool pavement application.

A second configuration file is created containing the cool pavement information.

The results of the Envi-met simulation for the surface temperature after the cool pavement application and for 12:00, and 18:00 are depicted in Figures 104, 105 and 106 respectively. The surface temperature difference is pinpointed with a circle.

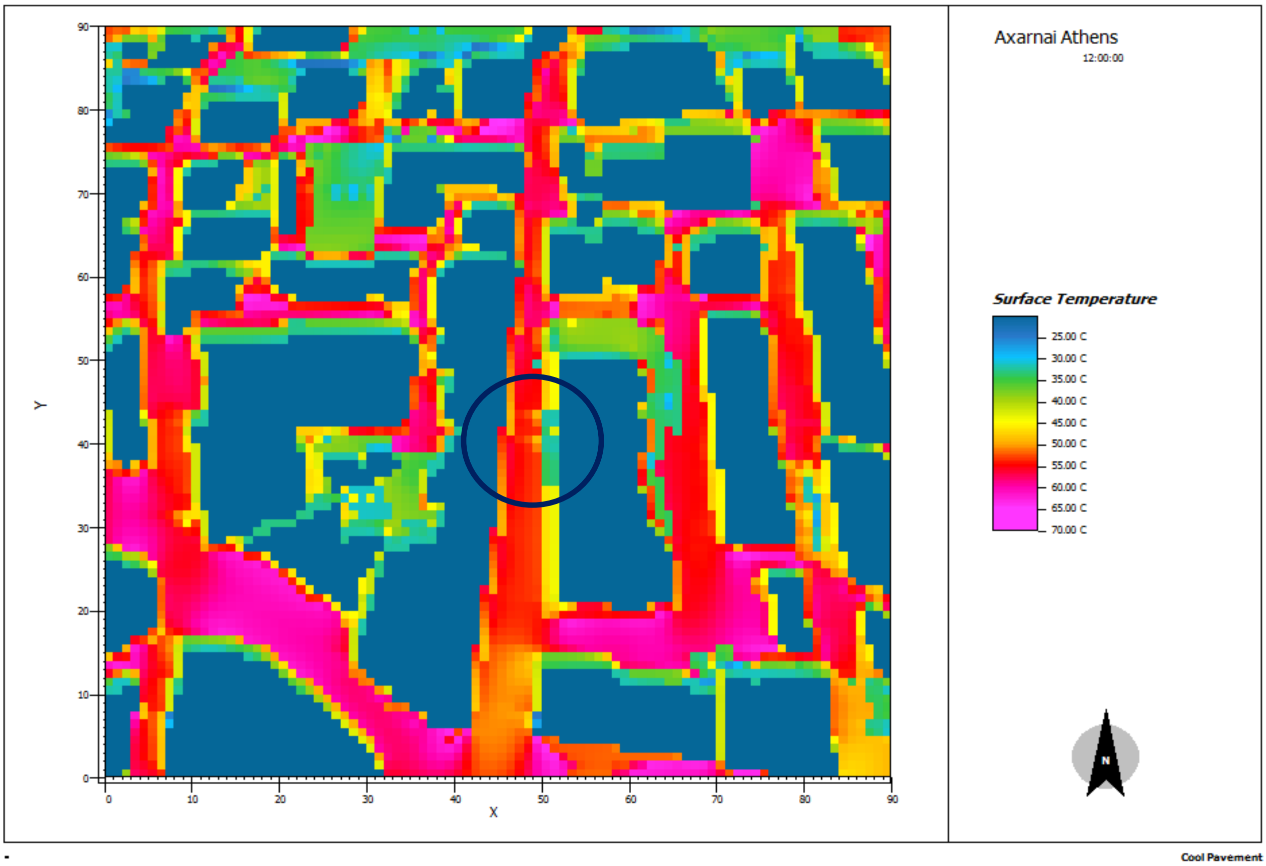

Figure 104 Spatial distribution of the surface temperature at 12:00, after the cool pavement application

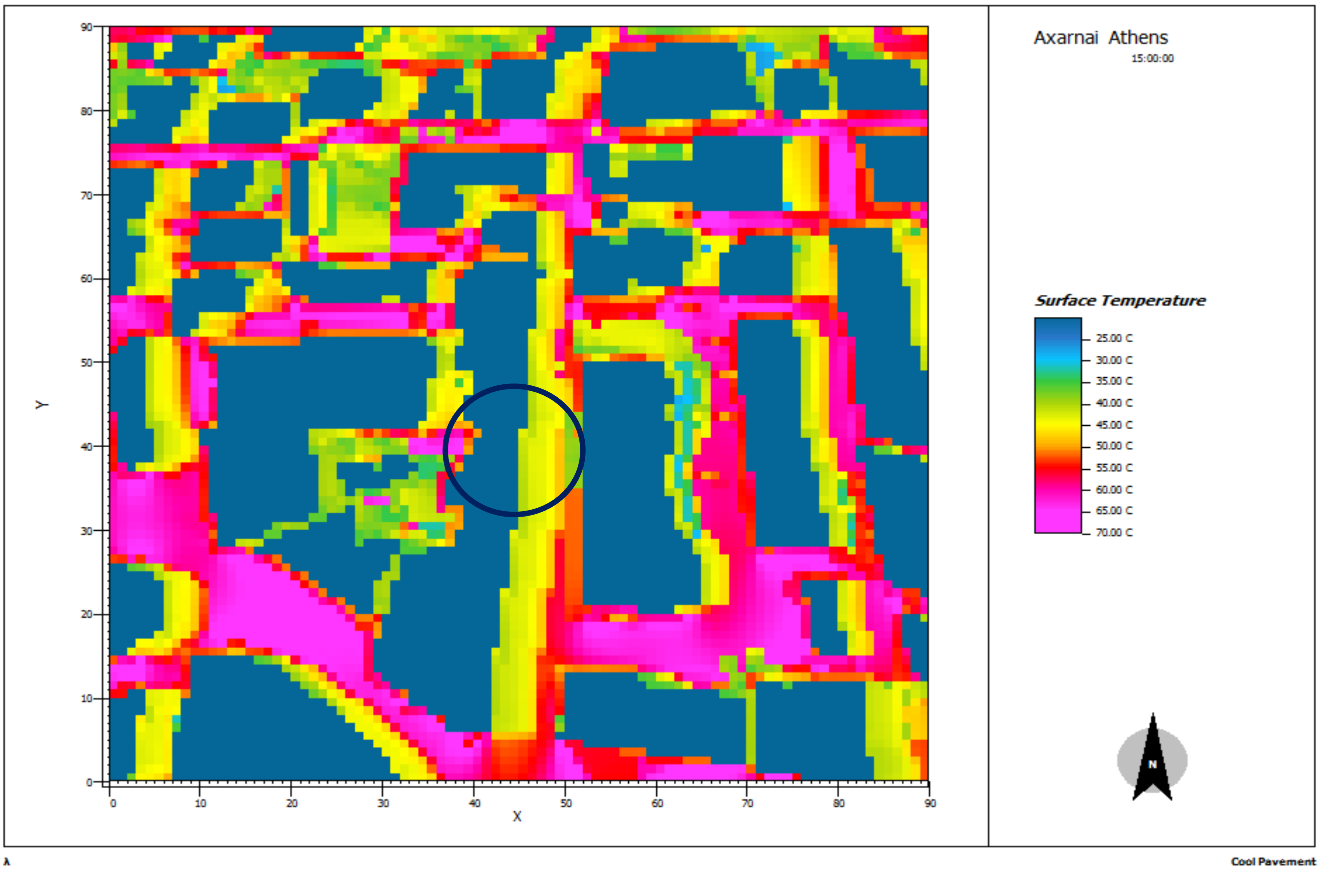

Figure 105 Spatial distribution of the surface temperature at 15:00, after the cool pavement application

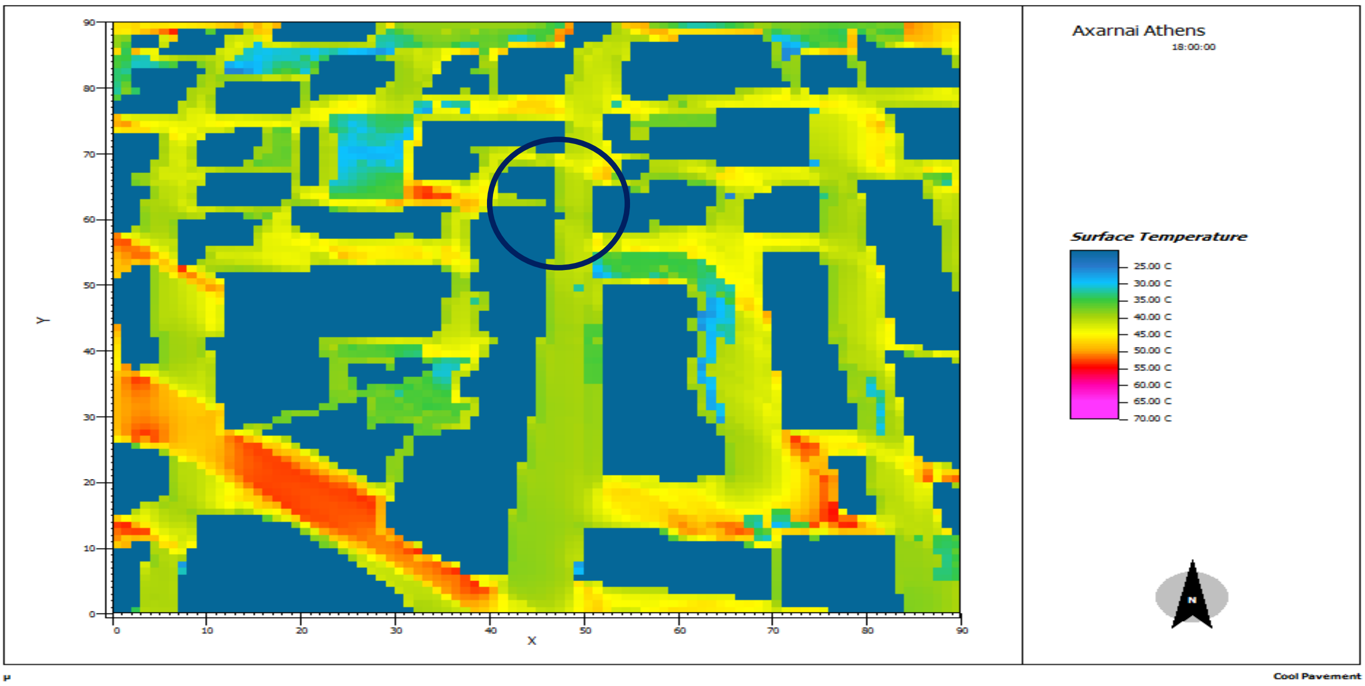

Figure 106 Spatial distribution of the surface temperature at 18:00, after the cool pavement application.

The air temperature at 1.8m height for the conventional pavements is depicted in Figure 107, 108 and 109 for 12:00, 15:00 and 18:00 respectively.

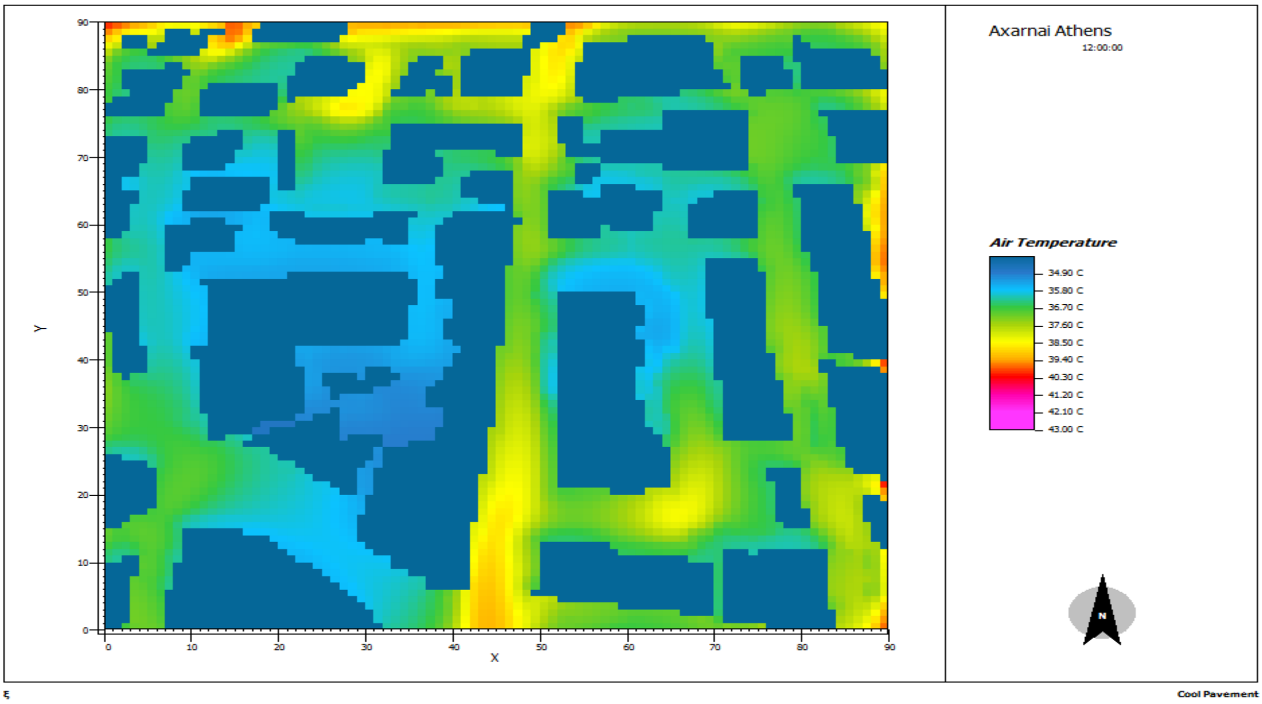

Figure 107 Spatial distribution of the air temperature at 12:00 and z=1.8m, after the cool pavement application

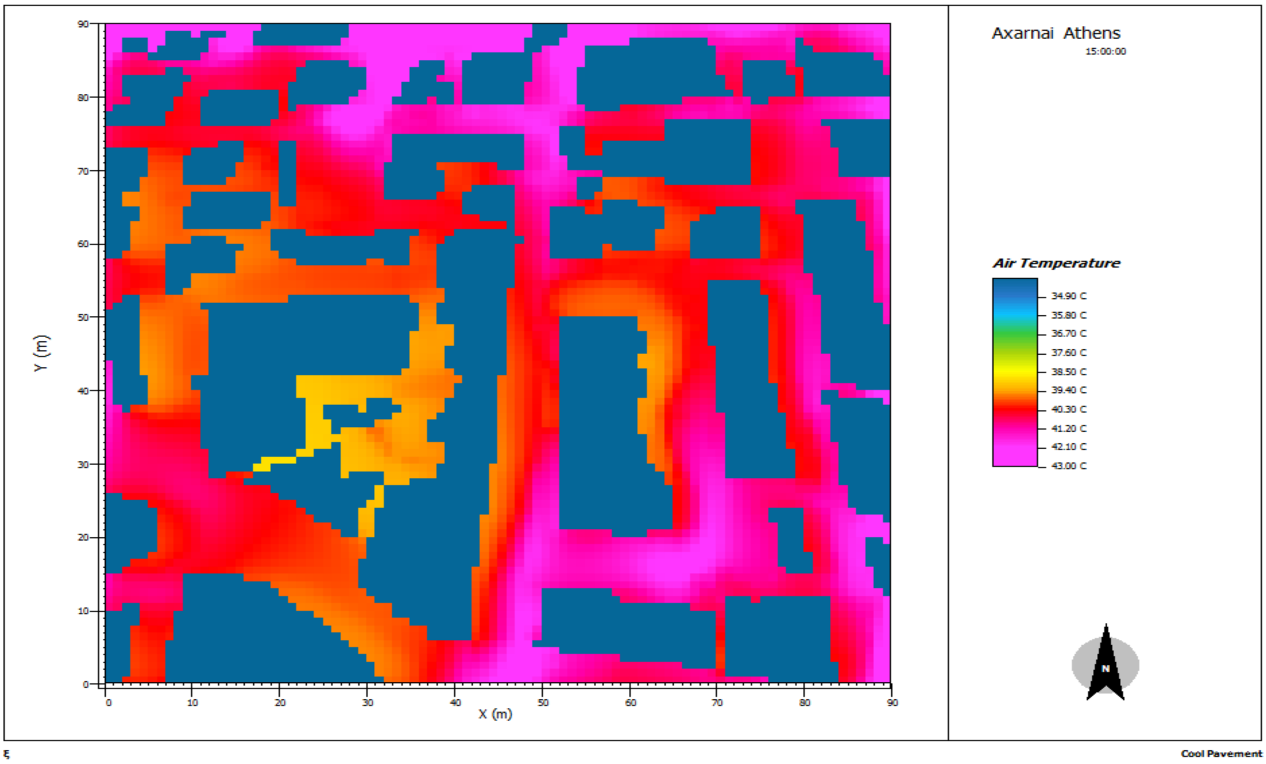

Figure 108 Spatial distribution of the air temperature at 15:00 and z=1.8m, after the cool pavement application

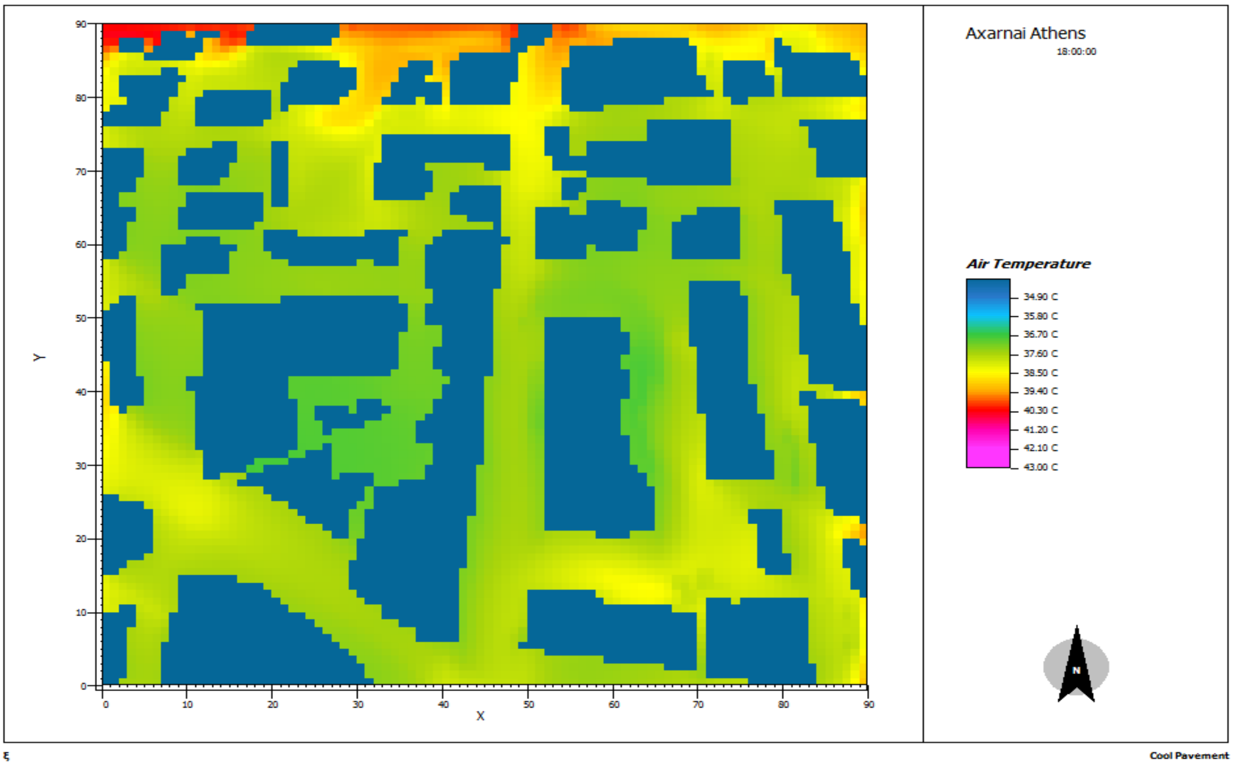

Figure 109 Spatial distribution of the air temperature at 18:00 and z=1.8m, after the cool pavement application

7.4 DISCUSSION - CONCLUSIONS

The application of cool pavements has the following results in the urban environment:

- The reduction in the average maximum summer ambient temperature in the cool pavement area at height 1.80m, at 12:00 is almost 0.3K (Figure 110).
- The reduction of the surface temperature in the area of the cool pavement application is almost 10K (Figure 111).

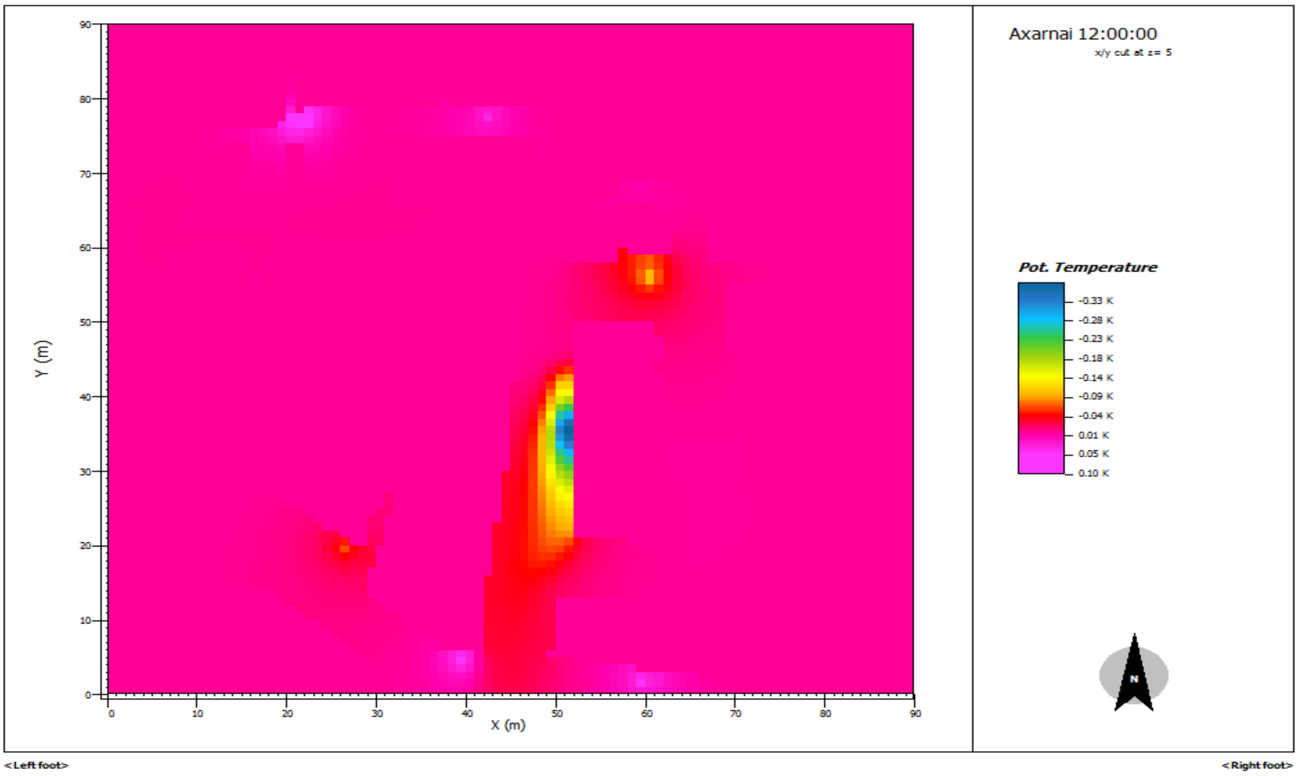

Figure 110 Air temperature difference before and after the cool pavement application at z=1.8m, 12:00.

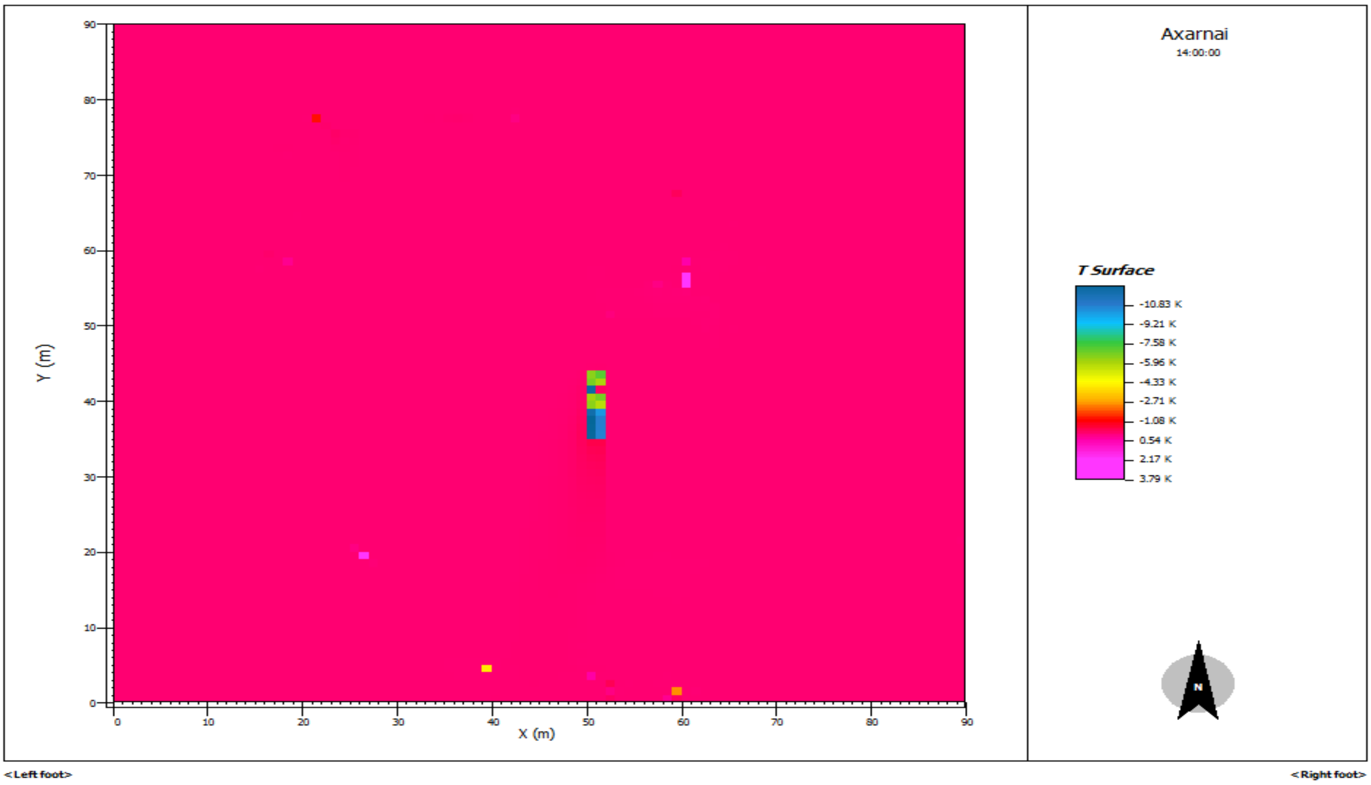

Figure 111 Surface temperature difference before and after the cool pavement application at 14:00.

Furthermore, in situ measurements were taken at the same day of the simulation, in sunlight and shaded spots of the cool pavement and of the conventional cement pavement boards. As it is observed in Table 7, the surface temperature reduction in a spot under the sunlight at 14:00 is about 10K which is in line with the extracted results of the Envi-met simulation.

Table 7 Measured surface temperature of cool and conventional pavement on 16/6/2015

Surface Temperature (˚C)				
Day Time	**Cool Pavement**		**Conventional pavement**	
9:00	27.9 (shaded by nearby buildings and trees)		28.1(shaded by nearby buildings and trees)	
10:00	31 (non-shaded)		33.3 (non-shaded)	
11:00	35.1 (non-shaded)	29 (shaded by nearby buildings and trees)	31.1 (shaded by nearby buildings and trees)	
12:00	37.4 (non-shaded)			
13:00	39.3(non-shaded)			
14:00	32.9 (non-shaded)	31.7 (shaded by nearby buildings and trees)	42.6 (non-shaded)	34.9 (shaded by nearby buildings and trees)
15:00	32 (shaded by nearby buildings and trees)	34.2 (non-shaded)	37.2 (non-shaded)	33.5 (shaded by nearby buildings and trees)
16:00	35.3 (non-shaded)	32.5 (shaded by nearby buildings and trees)	39.3 (non-shaded)	34.5 (shaded by nearby buildings and trees)
17:00	31.5 (non-shaded)		38.0 (non-shaded)	

The pilot application study cases consist of the cool material on the Municipality building and of the cool pavement area in the centre of Acharnes.

The cool roofs application contributes to a 17% reduction of the energy demand for cooling while the cool pavement has 10K reduction of surface temperature.

7.5 PROPOSAL OF ENVIRONMENTAL ENGINEERING DEPARTEMENT

The Department of Environmental Engineering, in the research framework of the program suggests the replacement of conventional paving slabs with cold tiles in the the town hall area shown below.

Figure 112 The propose modification area in cool pavements from Environmental Engineering department

In the configuration file, the total simulation time was set at 24hours and the simulation day was the 31th of July 2014. The initial conditions of the model which have been chosen are the following:

- Average temperature: 30° C
- Wind Speed 1.8 m/s
- Wind direction SE
- Relative Humidity 58%

Two configuration files were created. The first one includes conventional pavements and seconds the cool pavements. The results of the Envi-met simulation for the surface and air temperature before the cool pavement application are depicted in the following figures.

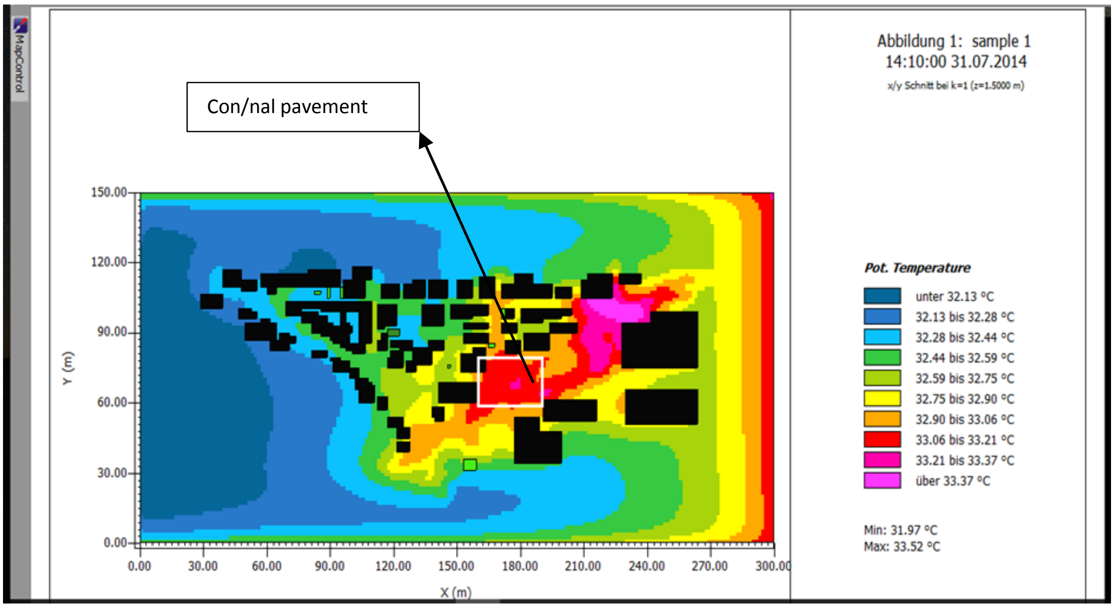

Figure 113 Air temperature with the conventional pavement

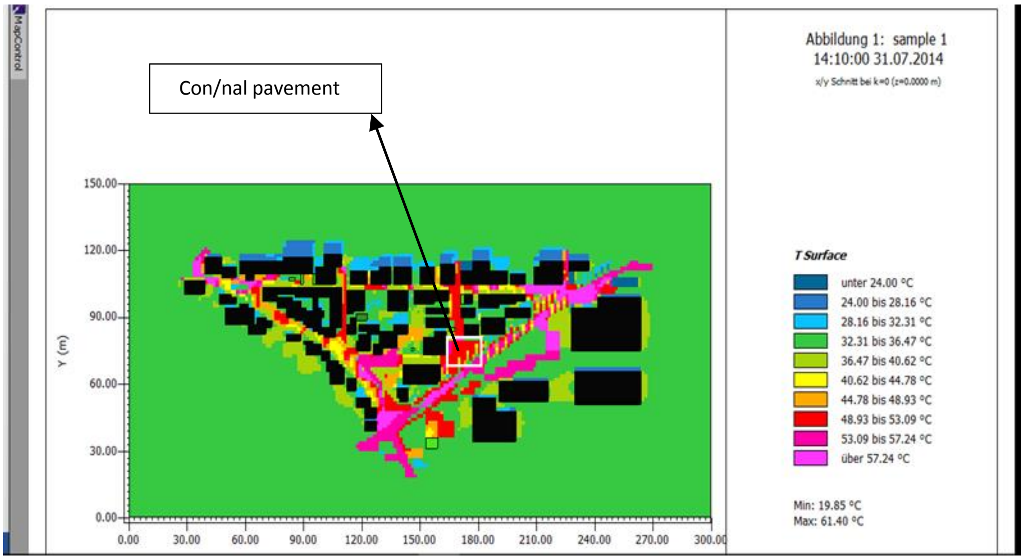

Figure 114 Surface temperature with the conventional pavement

A second configuration file was created containing the cool pavement information. The results of the Envi-met simulation for the surface and air temperature after the cool pavement application are depicted in the following figures.

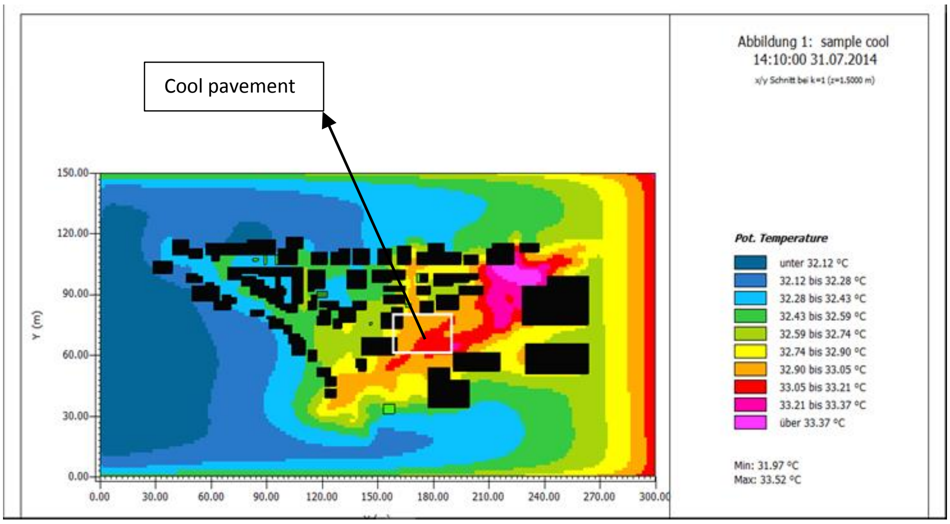

Figure 115 Air temperature after the cool pavement application

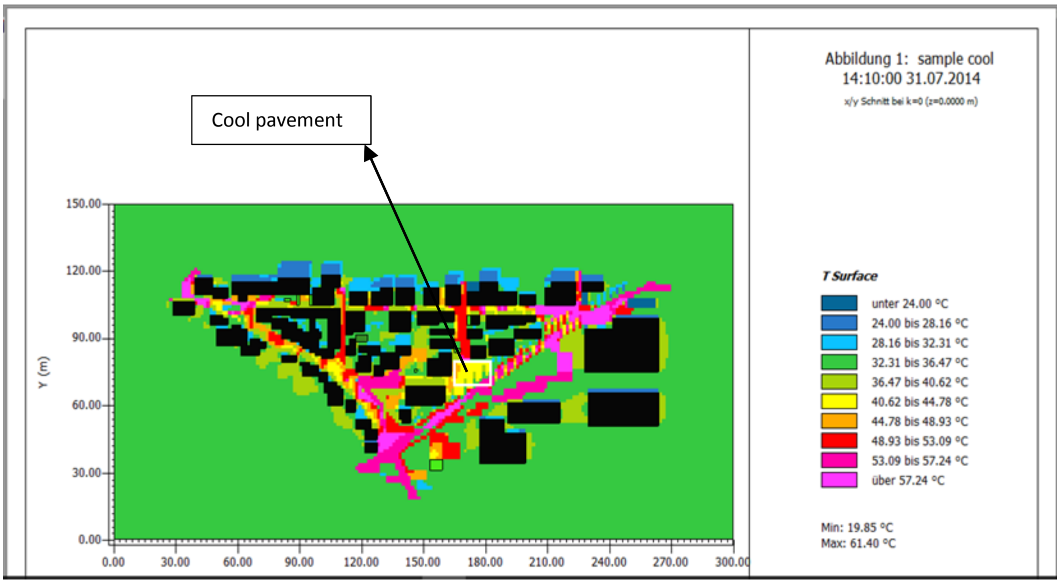

Figure 116 Surface temperature after the cool pavement application

The application of cool pavements in the specific area that Environmental Engineering Department proposes has the following results in the urban environment:

- The reduction in the average maximum summer ambient temperature in the cool pavement area is almost 0.20K.
- The reduction of the surface temperature in the area of the cool pavement application is almost 7K.

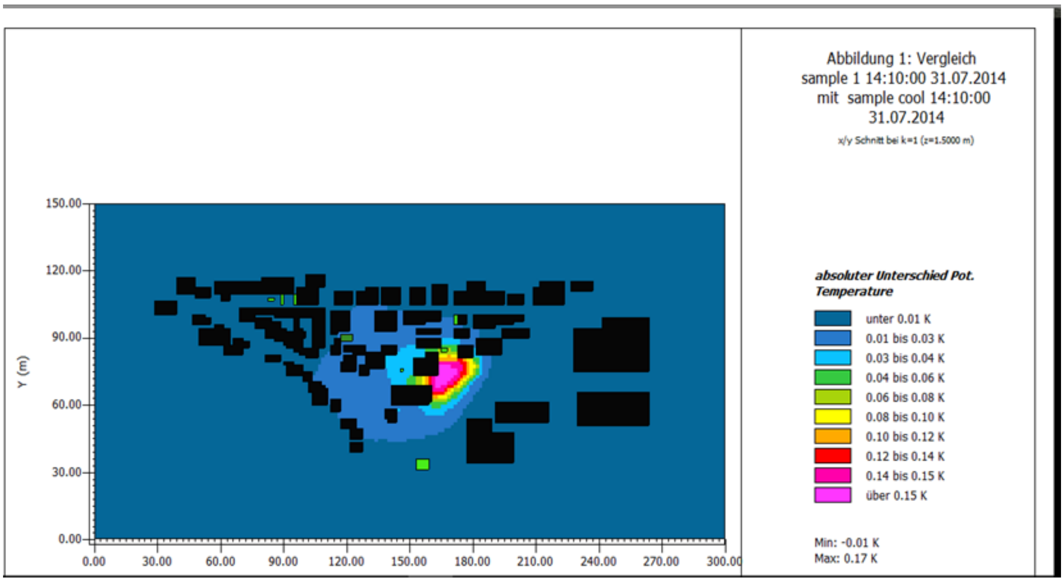

Figure 117 Air temperature difference before and after the cool pavement application

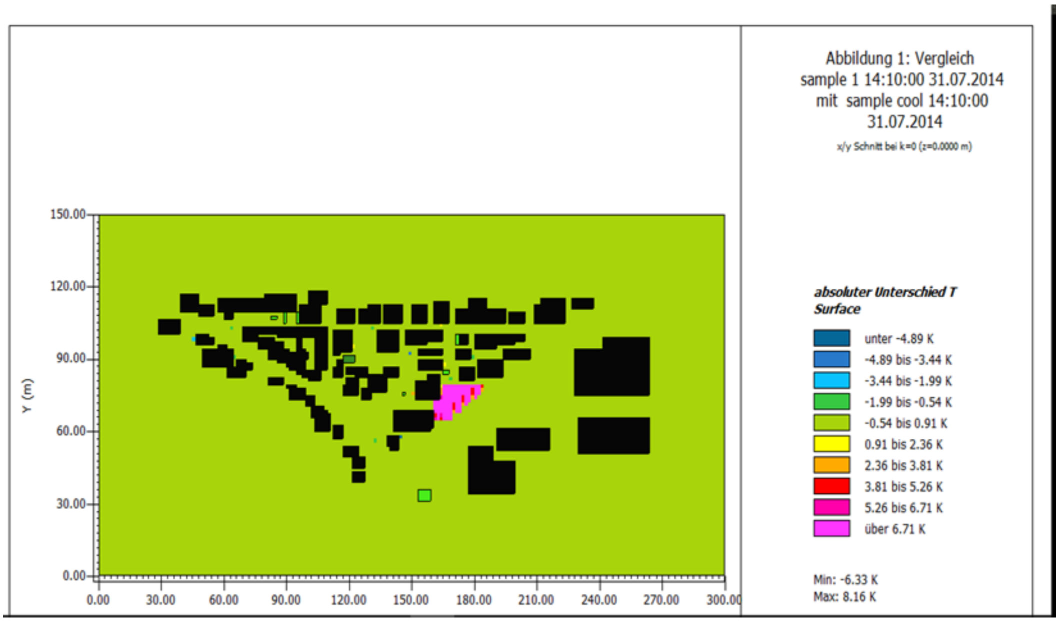

Figure 118 Surface temperature difference before and after the cool pavement application

8 CONCLUSIONS & FUTURE PROSPECTS

Urban Heat Island effect and local climate change increase the ambient temperature of the cities, resulting on a significant impact on the energy consumption of buildings and adverse effects on vulnerable low income population, indoor and outdoor thermal comfort and health conditions. To counterbalance the effect, a large scale implementation of cool concrete pavements in the town hall of Acharnes, has been designed and applied resulting on one of the largest urban mitigation projects.

An efficient monitoring strategy was conducted in the area during the entirety of the summer period (June-September). It was found that cool materials demonstrated lower surface temperatures compared to the conventional and the amount of reduction reached 7.5^{o}C and 6.1^{o}C respectively in the summer period.

Uncontestably, the whole bioclimatic rehabilitation project established that cool materials, as an application in open spaces, can reduce effectively the intensity of urban heat island effect and contribute to protect in a more effective way the local vulnerable population.

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