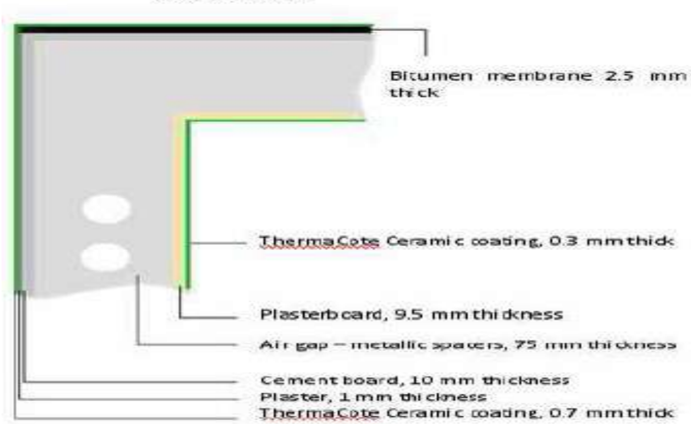
38% Energy saving with ThermaCote :

Norme: EU ISO-9869	Reduced energy consumption of 38%	$R_{\text{Valeur jusqu'à}}$ 1,87 m^2K/W	$U_{\text{Valeur jusqu'à}}$ 0,53 W/m^2K

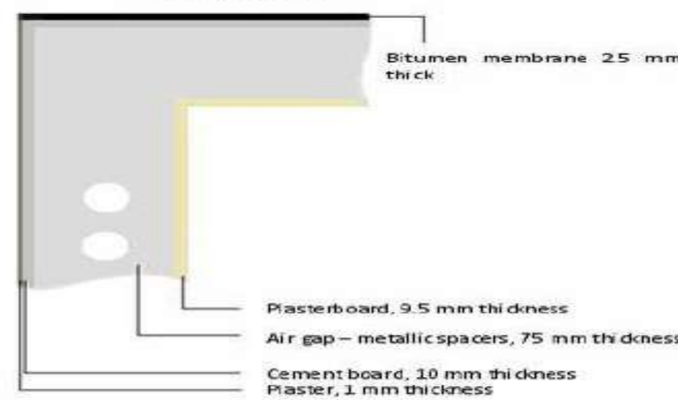
Test according to standard: **EU ISO 9869**: Thermal insulation - Building elements - In situ measurement of thermal resistance and thermal transmittance. The method consists of isolating in a different way identical, calibrated and measured buildings, and then comparing the energy consumption required to maintain these buildings at an identical and constant indoor temperature, regardless of the external climatic conditions. This measurement protocol, study and test was carried out in **Europe** by **CRES** (Center for Renewable Energy Sources and Saving), equivalent in Greece of **ADEME**, during the summer of 2015 in a Mediterranean climate..

КАПЕ
CRES

Test Room 1



Test Room 2



With ThermaCote

Climatisation= 35,9 kWh

Save to 38 %

Without coating

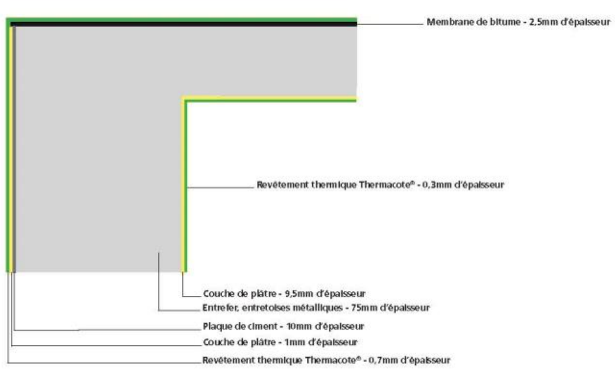
Climatisation= 57,8 kWh

Norme ISO 9869 : Isolation thermique -- Éléments de construction -- Mesurage in situ de la résistance thermique et du coefficient de transmission thermique

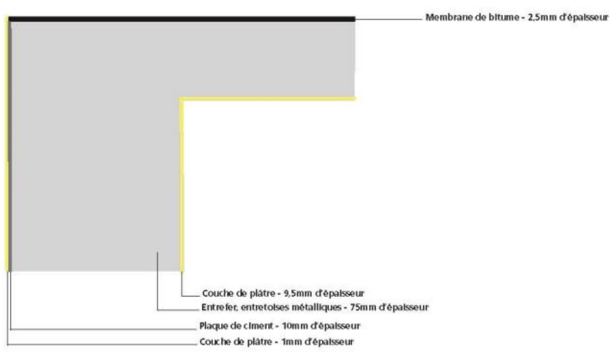
La méthode consiste à isoler de manière différente des bâtiments identiques, calibrés et à mesurer, puis comparer les consommations d'énergie nécessaires pour maintenir ces bâtiments à une température intérieure identique et constante, quelles que soient les conditions climatiques extérieures. Ce protocole de mesure, étude et test a été réalisé en Europe par le **CRES**, équivalent Grecque de **l'ADEME** en France, durant l'été 2015 dans un climat méditerranéen.

Méthode de test :

Chambre d'essai n°1



Chambre d'essai n°2



Avec ThermaCote	Sans revêtement
Climatisation= 35,9 kWh	Climatisation= 57,8 kWh
Economie de 38 %	

Mesures réalisés:

	NORME	RESULTATS
Mesurage in situ de la consommation d'énergie	EU ISO 9869	Consommation d'énergie **réduite de 38%**
Mesurage in situ de la résistance thermique : R	EU ISO 9869	**R** Valeur jusqu'à **1,87m²K/W**
Mesurage in situ du coefficient de transmission thermique : U	EU ISO 9869	**U** Valeur jusqu'à **0,53W/m²K**

CRES - CENTRE POUR LES ENERGIES RENOUVELABLES ET LES ECONOMIES D'ENERGIE - GRECE

Le Centre pour les énergies renouvelables et économie d'énergie (**CRES**) est un organisme public supervisé par le ministère de l'environnement, de l'énergie et les changements climatiques. Il a une indépendance financière et administrative.

CRES est actif dans les domaines de **sources d'énergie renouvelables** (SER), **l'utilisation rationnelle de l'énergie** (URE) et des **économies d'énergie** (ES). Son objectif principal est de promouvoir les applications technologiques dans les domaines mentionnés ci-dessus à la fois **au niveau national et international**.

MEDENER est l'association méditerranéenne des agences nationales de maîtrise de l'énergie. Elle fédère les agences du pourtour méditerranéen chargées de l'efficacité énergétique et de la promotion des énergies renouvelables, deux conditions clés pour la réussite de la transition énergétique.

Convaincus de la nécessité d'une coopération renforcée pour la promotion de l'efficacité énergétique et des énergies renouvelables en région Méditerranée, **MEDENER** a été créé en 1997 à Tunis, sous la forme d'une association internationale à but non lucratif. Elle réunit aujourd'hui 12 organisations nationales des deux rives Nord et Sud de la Méditerranée.

The Centre for Renewable Energy Sources and Saving (CRES) is a government agency supervised by the Ministry of the Environment, Energy and Climate Change. It is financially and administratively independent.

CRES is active in the areas of **sources of renewable energy** (SRE), **rational use of energy** (RUE) and **energy savings** (ES). Its main goal is to promote technological applications in the areas mentioned above both at **national and international level**.

MEDENER is the Mediterranean Association of the National Agencies for Energy Conservation It brings together agencies in the Mediterranean region in charge of energy efficiency and the promotion of renewable energy sources, two key conditions for the success of the energy transition.

In 1997, due to the need for stronger cooperation for the promotion of energy efficiency and renewable energy in the Mediterranean region, **MEDENER** was created in Tunis in the form of an international non-profit organization. Today, it brings together 12 national agencies from the northern and southern banks of the Mediterranean.

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3) **IDAE-Espagne**
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5) **ENEA-Italie**
6) **ADEREE-Maroc**
7) **ANME-Tunisie**
8) **APRUE-Algérie**
9) **ALMEE-Liban**
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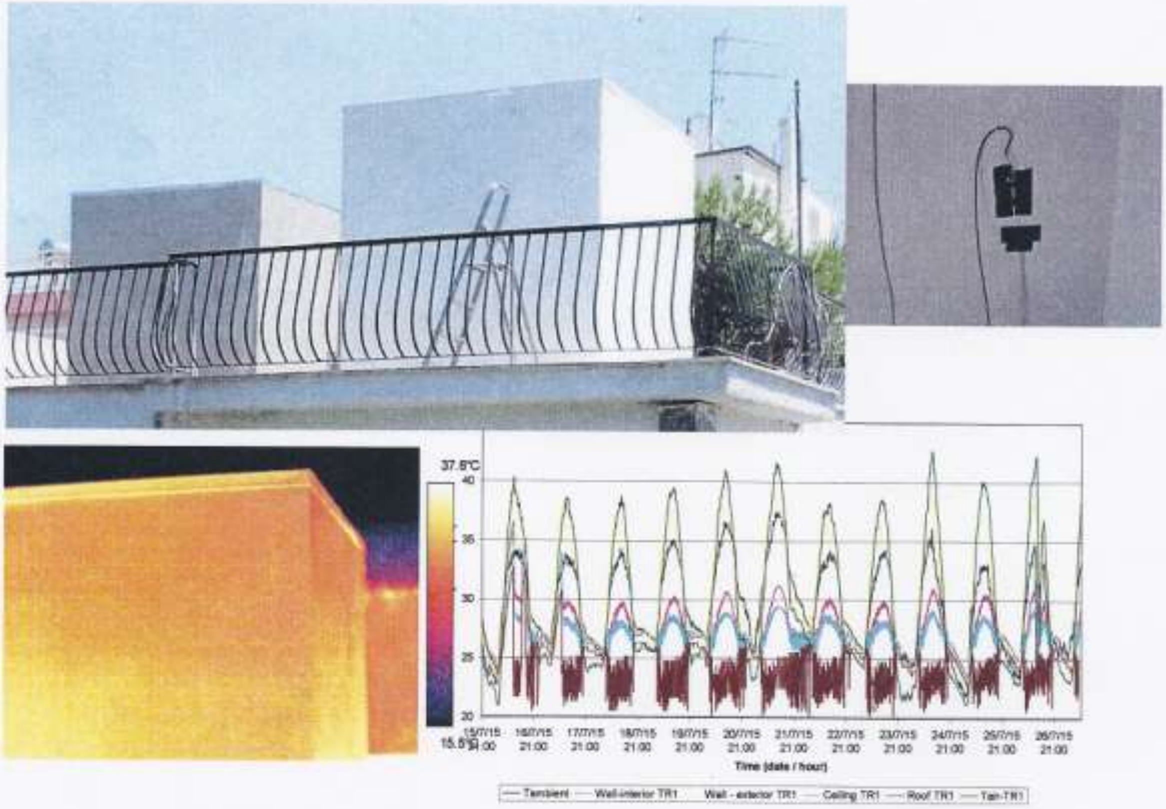
12) PEC-Autorité Palestinienne

ΚΑΠΕ
CRES

CENTRE FOR RENEWABLE ENERGY SOURCES AND SAVING

Energy measurements in 2 test rooms



September 2015

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Title:	**Energy measurements in 2 test rooms for THERMACOTE HELLAS**
Report Nr:	EML 50/2015
Author:	Andreas Androutsopoulos, Mechanical Engineer, MSc Head of Energy Measurements Laboratory

ΕΡΓΑΣΤΗΡΙΟ
ΕΝΕΡΓΕΙΑΚΩΝ
ΜΕΤΡΗΣΕΩΝ
ΚΑΠΕ

Table of Contents

SUMMARY

The ability of a high performance Ceramic coating to contribute to the reduction of the energy needs of a building was investigated in this study. Energy measurements took place in two identical Test Rooms placed outdoors, one equipped with coating and the other without coating and their thermal behavior was recorded. The measurements took place in Mandra area, near Athens, Greece during summer conditions. Measuring equipment was placed on the Test Rooms and recorded air, surface temperature, heat losses, energy consumption and ambient conditions and compared the data collected. Results showed that the Test Room equipped with the coating outperforms the other Test Room presenting lower temperature distribution in every measured surface, vertical or horizontal, exterior or interior. The thermal resistance of the walls was calculated according to ISO 9869" and it was found that the wall equipped with the coating provides with a thermal performance 31% higher than the wall without the application of the coating. In terms of energy use, the electricity consumption of the Test Room with the coating is reduced by 38% when compared to the corresponding one of the Test Room without the coating application.

1. INTRODUCTION

Reflective coatings are considered to help the energy needs of a building by decreasing the incoming solar irradiation to the building shell. Some coatings have also the ability to block heat/cooling losses generated from the interior environment. The contribution of such a coating to the energy behavior of a building was investigated in the present study. In order to realize this, a test room equipped with ThermaCote Ceramic coating was constructed and its energy performance was monitored during summer conditions in Mandra area, near Athens, Greece. The purpose of the study was to record the behavior of the room equipped with a coating layer, and compare the thermal and energy measurements with a test room with the same building components without the application of the coating. The study comprises the test room characteristics, the measurement procedure, the instrumentation utilized, and the comparison of the results found. It is shown that the application of the ThermaCote coating to the building envelope has a substantial beneficial effect to the energy needs of the room.

2. DESCRIPTION OF THE TEST ROOM

For the purpose of the study, two identical test rooms were constructed so as to measure the temperature distribution and heat losses and compare them. The two test rooms were constructed on the roof a single-storey house in Mandra area, in Attika prefecture (refer to Figure 1). The total dimensions of the rooms are: 2.0 m length x 2.0 m width x 2.15 m height. The test rooms were positioned in such an area so as the walls have no shading offered during daytime (see Figure 2). The outer surface of the first Test Room (hereafter called Test Room 1) was coated with ThermaCote coating (0.7 mm thickness). Additionally, its internal surface was also coated with ThermaCote coating at 0.3 mm thickness resulting in a total wall thickness of 95.5 mm. The second Test Room (hereafter called Test Room 2) is identical to Test Room 1 except for the ThermaCote layers.

Figure 1: Mandra area – building used to place the test rooms. [source: Google Earth]

The layers of the test room walls, from outside to inside, are

- ❖ Test Room 1 (equipped with ThermaCote coating)

- ThermaCote Ceramic coating, appr. 0.7 mm
- Plaster, 1 mm thickness
- Cement board, 10 mm thickness
- Air gap – metallic spacers, 75 mm thickness
- Plasterboard, 9.5 mm thickness
- ThermaCote Ceramic coating, appr. 0.3 mm

❖ Test Room 2

- Plaster, 1 mm thickness
- Cement board, 10 mm thickness
- Air gap – metallic spacers, 75 mm thickness
- Plasterboard, 9.5 mm thickness

Figure 2. The two test rooms positioned on the roof – View from the West.

Figure 3 presents the different layers of the Test Rooms walls.

The layers of the roof are

❖ Test Room 1 (equipped with ThermaCote coating)

- ThermaCote Ceramic coating, appr. 0.7 mm
- Bitumen membrane, 2.5 mm thickness
- Cement board, 10 mm thickness
- Air gap – metallic spacers, 55 mm thickness
- Plasterboard, 9.5 mm thickness
- ThermaCote Ceramic coating, appr. 0.3 mm

- Test Room 2
  - Bitumen membrane, 2.5 mm thickness
  - Cement board, 10 mm thickness
  - Air gap – metallic spacers, 55 mm thickness
  - Plasterboard, 9.5 mm thickness

The total roof thickness for Test Room 1 is 78 mm and for Test Room 2 is 77 mm.

Additionally, the Test Rooms are equipped with an air conditioning unit to control the indoor environment. The AC is a slit type unit, of 9.000 Btu/h cooling capacity (refer to Figure 4)

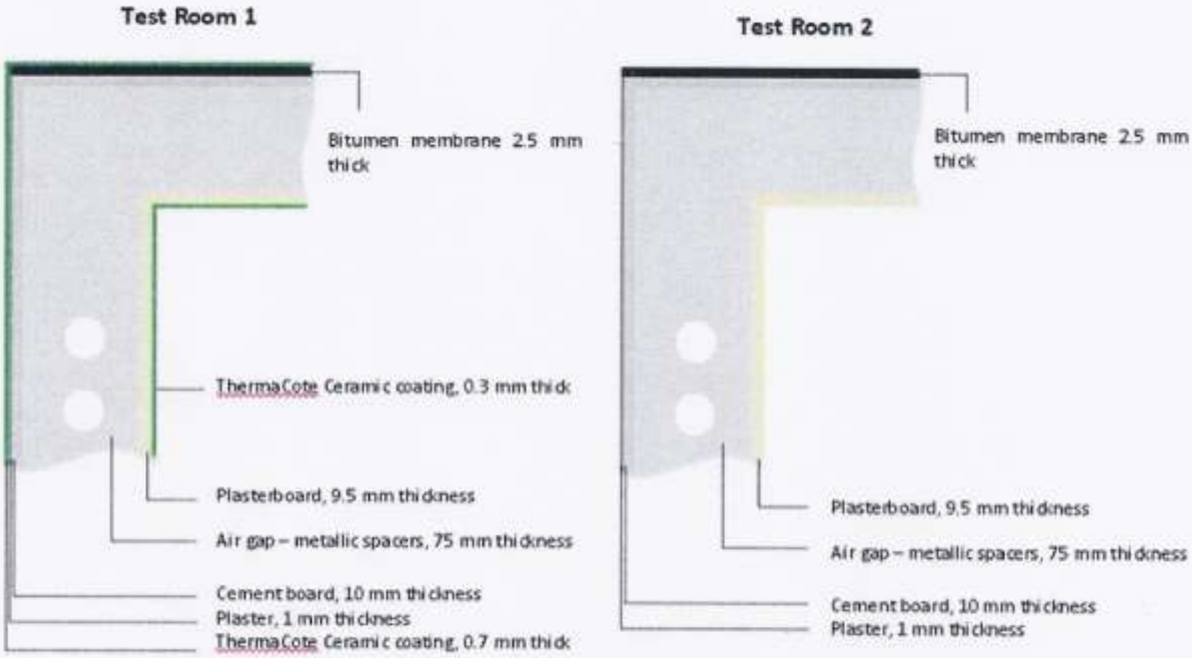


Figure 3. The layers of the Test Room walls structure.

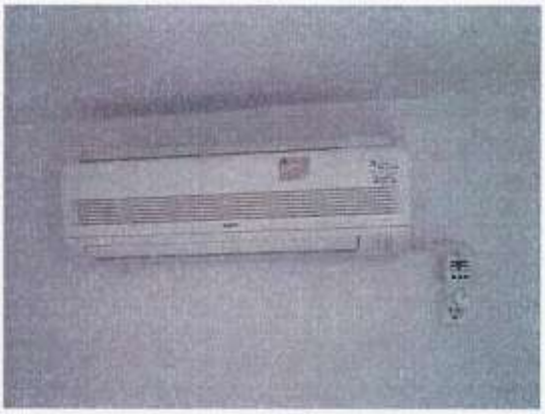


Figure 4. Test Room AC unit.

3. MEASURING EQUIPMENT

Measuring instruments were used in order to record the temperature conditions and the energy needs of the test rooms. The metering equipment was positioned in various areas so as to study the temperature and energy consumption regimes of the two Test Rooms. So, temperature sensors were positioned in the test rooms to collect data about wall surface temperatures, roof temperatures, room air temperatures, heat transfer through the wall, both internally and externally. The ambient conditions were also recorded together with the total energy consumption of each room. Same sensors were placed in exactly the same position in the two test rooms in order to be able to compare their readings. The measurement equipment used Is as follows:

For Test Room 1

- 1 temperature sensor for the measurement of the external wall surface temperature (°C) [Figure 5]
- 1 temperature sensor for the measurement of the internal wall surface temperature (°C) [Figure 6]
- 1 temperature sensor for the measurement of the exterior roof surface temperature (°C) [Figure 7]
- 1 temperature sensor for the measurement of the ceiling surface temperature (°C) [Figure 8]
- 1 temperature sensor for the measurement of the air temperature of the room (°C) [Figure 9]
- 1 heat flux sensor for the measurement of the heat losses through the wall (W/m^2) [Figure 6]

Additionally, since the measurements took place under a constant indoor air temperature regime, an energy meter was also positioned to measure the electrical energy consumption of the air conditioner unit. The same measuring equipment was used in Test Room 2. All temperature measurements - except the room air temperature - and heat flux were collected in a data logger positioned in each room (see Figure 10). The room air temperature was equipped with a built-in data logger.

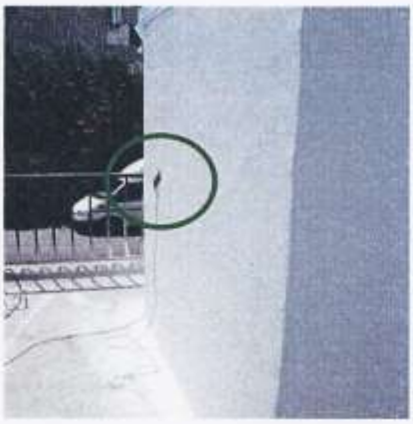


Figure 5. Outdoor wall sensor (Test Room 1).

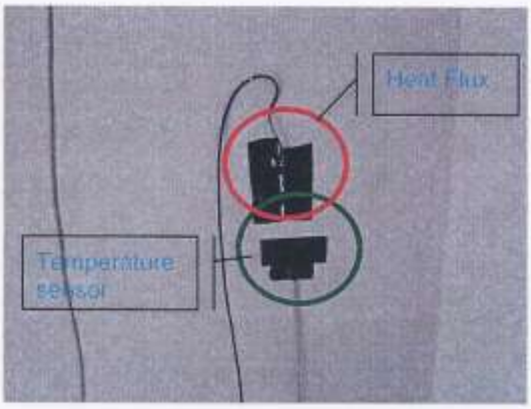


Figure 6. Internal wall sensor (Test Room 1).

Figure 7. Roof temperature sensor.

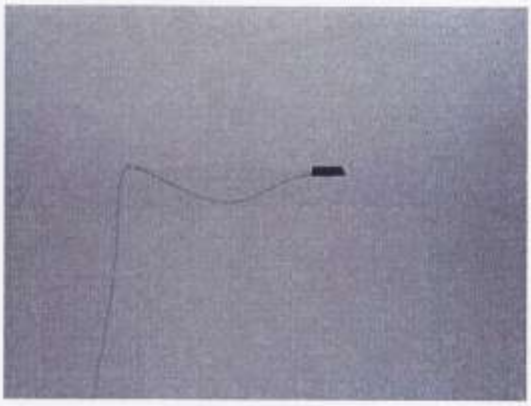


Figure 8. Ceiling temperature sensor.

Figure 9. Room air temperature sensor.

Figure 10. Data logger.

Apart from the above mentioned sensors, the ambient temperature and the solar radiation on a horizontal plane were also collected. These sensors were placed at the top of Test Room 2 roof (refer to figures 11 and 12). Attention was paid so that the sensors remain no shaded during daytime.

Figure 11. Ambient temperature sensor.

Figure 12. Solar radiation sensor on top of Test room 2 roof.

The instrumentation used has the following characteristics:

Temperature: Pt100, range: -50 to +100 °C, accuracy: ±0.3 °C

Heat flux: Hukseflux HFP01, temperature range: -30 to +70 °C, sensitivity: 50 μV/Wm^2

Ambient temperature: Pt100 shielded, range: -50 to +100 °C, accuracy: ±0.3 °C

Solar radiation: Kipp & Zonen puranometer CM 6, sensitivity: 10 μV/W/m^2, Response time: 18 s

Indoor air temperature: HOBO temperature & rel. humidity sensor, accuracy: ±0.5 °C, 5% RH

Data logger: Symmetron Stylitis 100, 18 analog/digital channels, accuracy 1%

Energy meters: HQ EL-EPM 02 HQ, 240 V AC 50 Hz, load: 16A, 3.7 kW, accuracy ± 0.5%

4. MEASUREMENT PROCEDURE

In order to study the full extent of the coating capabilities to block thermal radiation it was decided to perform the measurements during summer weather conditions. July was chosen to carry out the test, a month with moderate mean ambient temperature of 27 °C and mean relative humidity of 58% [Attiki area meteorological data]. The measurement procedure involved continuous measurements of the Test Rooms sensors so that their performance can be recorded and compared with each other. Measurements were taken from the 15th of July to the 27th of July 2015 having previously installed the instruments and check their behavior. However, due to electrical power failures the data utilized are from the 18th of July to the 27th of July 2015 (10 days).

The data logging of the sensors readings was performed on a 10 minutely basis in a flash memory card. The indoor environment was set to 26 °C in both Test Rooms, and was controlled by the air conditioning unit.

During the measurements period the total energy consumption was also recorded through an energy meter connected to the air conditioning socket.

5. RESULTS

The recorded measurements first went under a visual analysis so that possible outliers were eliminated. Then, a comparison of the performance of the two Test Rooms took place in order to investigate their thermal needs and possible energy savings. Apart from the measurements, a thermography study took place to visualize the temperature regime of indoor and outdoor surface areas of the two Test Rooms, the results of which are given in section 5.1. An estimation of the thermal resistance of the walls of the two test rooms, and a comparison of the rooms energy needs took place. Additionally, the electrical energy consumption for the cooling needs of every Test Room was recorded and compared to each other. This chapter presents the findings from both thermal and energy monitoring procedure.

5.1. Thermography of building envelope

The thermography of the building shell identifies areas of energy leaks and indicates points which require corrective intervention (applies to examine both transparent and opaque building components). The use of thermographical images can identify, among others:

- Thermal bridges in building shells.
- Points of air leakage from the shell.
- Points of thermal insulation failure in heating and cooling systems and distribution networks,

- Possible defects in between the different wall materials, such as cracks, voids.

The principle of thermography is based on the fact that every body with a temperature greater than 0 K, emits thermal (infrared) radiation, which depends solely on the temperature of the body and the emissivity of its surface. The thermographic camera is equipped with an infrared detector, which converts the thermal radiation in voltage difference and then through suitable software in color image corresponding to its emitted radiation.

For the requirements of the thermography the thermal camera ThermaCAM PM595 from FLIR Systems was utilized. The thermal camera has the following characteristics:

Detector	Focal Plane Array (FPA), uncooled microbolometer, 320x240 pixels
Nominal wavelength range	7.5-13μm
Minimum detected temperature difference	< 0.1°C
Temperature measurement accuracy	± 2%
Temperature range	-40°C to +2000°C

Thermographical images were taken in various areas of the building, in vertical and horizontal surfaces of the building envelope, both in the exterior and the interior sides. The surface materials of the construction and the estimated emissivity are given in Table 1.

Table 1. Estimated surface emissivity values.

Surface material	**Estimated emissivity**
White colour coating	0.95
Grey color surface	0.75
Light color surface	0.91
Metallic surface	0.93

The thermography took place on July 8, 2015, at 13:00 and thermographical images were taken in both the exterior and interior of the Test Rooms. The weather conditions during the thermography were: clear sky with an ambient temperature of 33.2 °C. The thermography duration was approx. 1 hour.

The thermographs taken are found in the following pages (thermographs 1 to 2) and in Annex 1, and depict selected outdoor and indoor building elements. The indicated temperatures shown at the thermographs' tables show the temperature in degrees C related to the particular points on the thermograph.

Thermogragh 1 shows the variation in exterior temperature on Test Room 1 with East orientation. It can be seen that the various surface temperature ranges from 34.7 to 36.9 °C. It is noted the temperature homogeneity of the surface although it is comprised of different building materials, i.e. plaster, metallic areas, which is attributed to the complete spread of the coating.

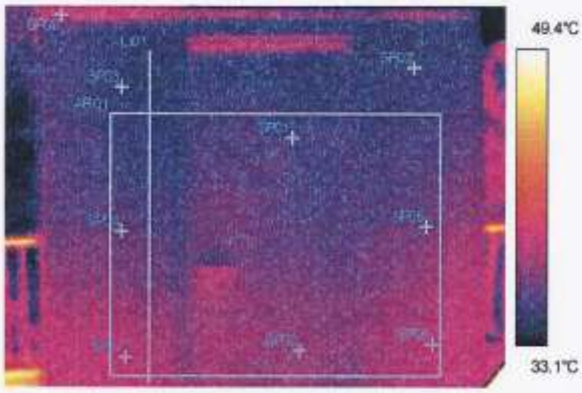


Figure 13. Test Room 1 - East wall.

Measurement Point	Temperature (°C)
SP01	35.6°C
SP02	35.3°C
SP03	35.2°C
SP04	35.8°C
SP05	35.7°C
SP06	36.6°C
SP07	36.6°C
SP08	36.3°C
SP09	36.5°C
AR01: max	36.9°C
AR01: min	34.7°C

Thermograph 1. Test Room1 - East wall.

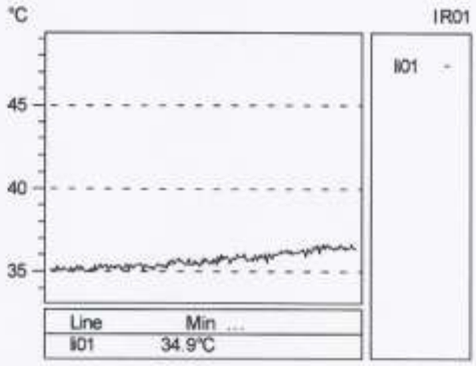
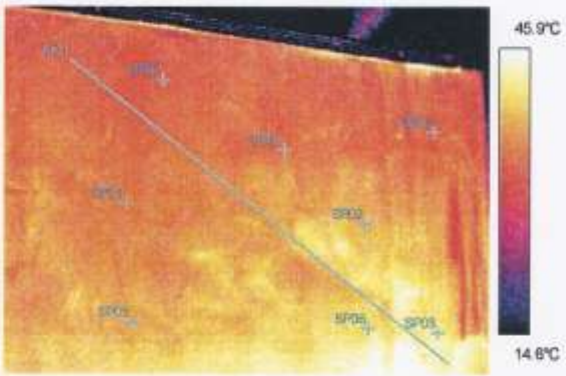


Diagram 1. Surface temperature over line LI01.

Thermogragh 2 shows the variation in exterior temperature on Test Room 2 with South orientation. In this wall the various surface temperatures range from 43.5 to 45.7 °C. A temperature difference between the two walls of appr. 9 °C is notable. It should be noted that all wall surfaces of the Test Rooms showed similar temperature readings.

From the thermographs the following can be concluded:

- The exterior surfaces of the Test Rooms showed a thermal homogeneity (thermographs 1,2,3,4,5).
- The exterior surface temperatures of Test Room 1 are significantly lower than whose of Test Room 2 ranging from 6.6 to 11 °C (thermographs 1,2,3,4).
- The interior surface temperatures of Test Room 1 are significantly lower than whose of Test Room 2 ranging from 6 to 10.5 °C (thermographs 6,7,8).



Measurement Point	Temperature (°C)
SP01	44.2°C
SP02	44.6°C
SP03	44.5°C
SP04	43.5°C
SP05	43.5°C
SP06	46.2°C
SP07	44.2°C
SP08	45.5°C

Thermograph 2. Test Room 2 - South wall.

Figure 14. Test Room 2 - South wall.

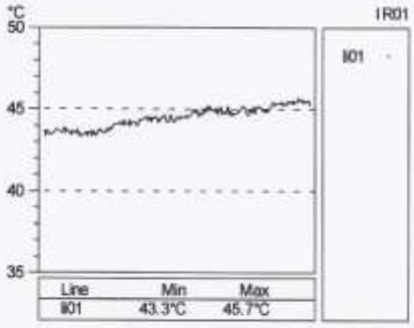


Diagram 2. Surface temperature over line LI01.

- The temperature of the ceiling of Test Room 2 is significantly higher than the corresponding temperature of Test Room 1 (thermographs 7,8). The temperature difference ranges between 13.5 and 16 °C.
- Thermal homogeneity was observed between the various wall surfaces of the shell at the interior of the Test Rooms (thermographs 6,7,8,9).
- Heat gains appear to be on the walls and roof of the Test Rooms implying the absence of thermal insulation (thermograph 6,7,8,9).
- The joints of the construction elements in the interior of the Rooms, although visible, did not show any significant thermal bridges (thermographs 7,8).

5.2. Temperature Measurements

The data from the measuring equipment were gathered and are presented in this section. At first, the meteorological data are shown, depicting the weather conditions under which the measurements took place, and then the data from the thermal behavior of the two Test Rooms are presented. A comparison between the measurements of the Test Rooms follows for both the total test duration and a typical day distribution.

5.2.1. Complete data sets

The meteorological data during the testing period in terms of solar irradiation and ambient temperature can be seen in Figure 15. The graphs show the measurements from 00:00' of July 18th until 09:00' of July 27th 2015. It can be seen that the test took place under sunny sky conditions and a rather typical ambient temperature for the Attiki area ranging from 22 to 37.5 °C.

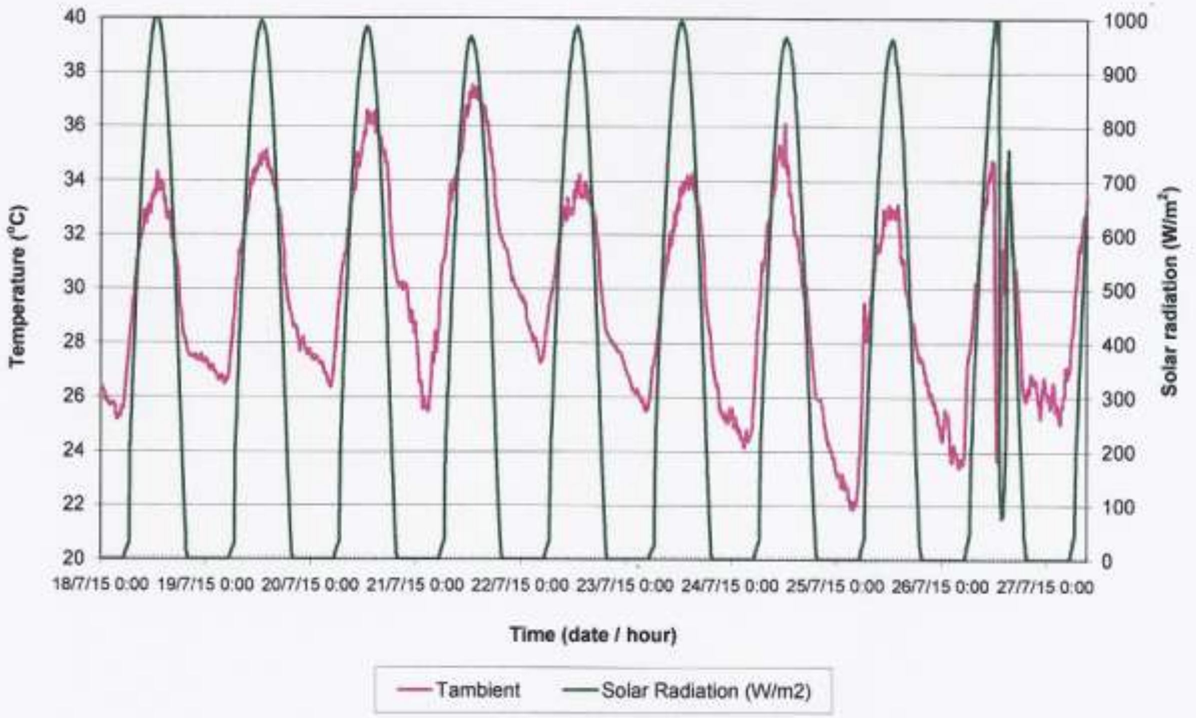


Figure 15. Ambient temperature and solar radiation during the testing period.

Test Room 1 measurements can be found in Figure 16. It can be seen that the roof temperature (Roof TR1) reaches the higher levels (up to 42.5 °C) followed by the exterior wall temperature (Wall-exterior TR1) which reached up to 39.2 °C.

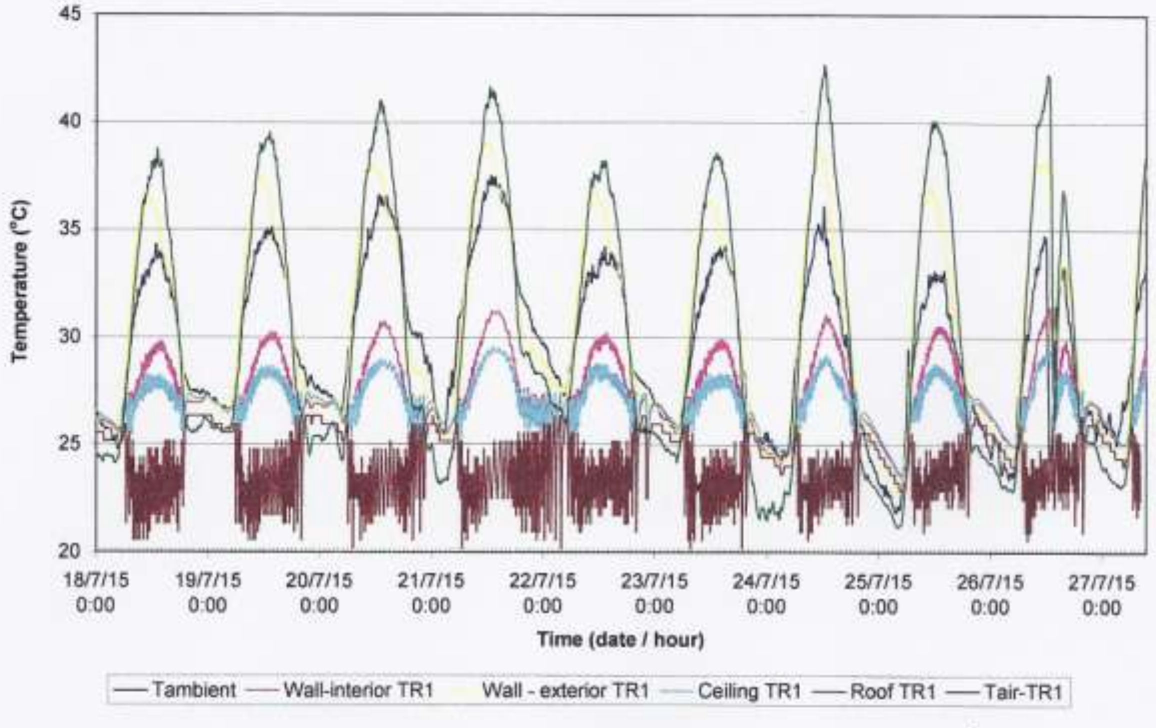


Figure 16. Surface temperature distribution – Test Room 1.

Test Room 2 measurements can be found in Figure 17. It can be seen that the roof temperature (Roof TR2) reaches the higher levels (up to 58.9 °C) followed by the exterior wall temperature (Wall-exterior TR2) which reached up to 45.4 °C.

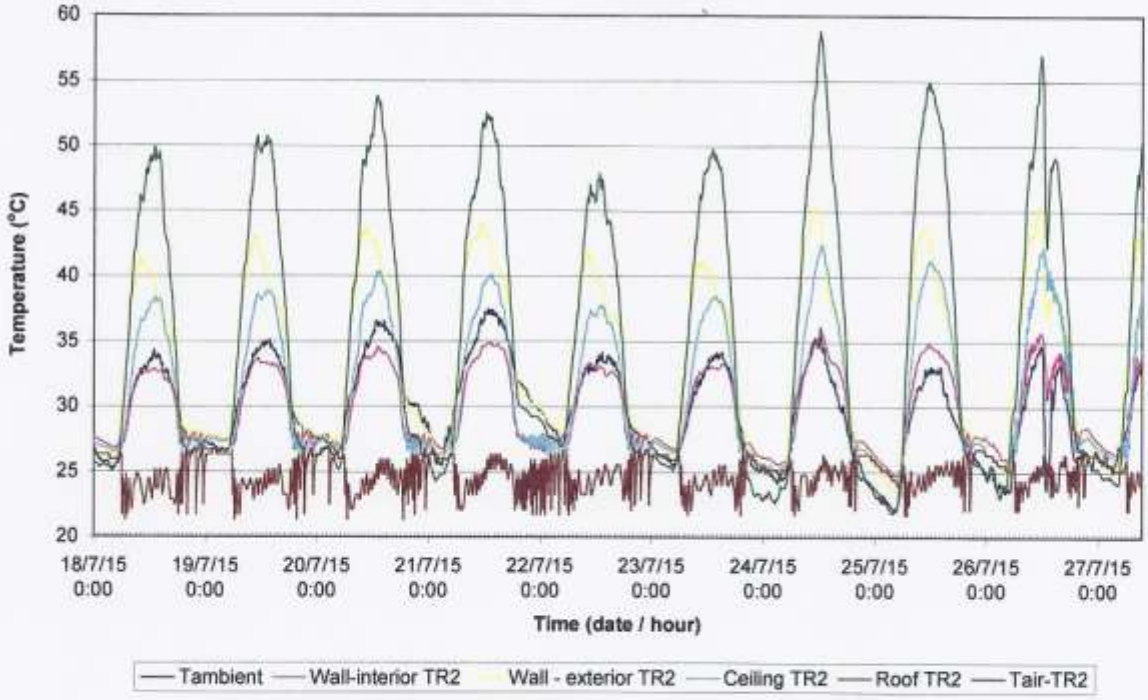


Figure 17. Surface temperature distribution – Test Room 2.

The recorded heat losses from the internal wall surface are shown in Figure 18. It can be seen that the heat losses of Test room 1 wall are much lower than those of Test Room 2. The maximum difference between the two walls heat fluxes was 1.83 W/m^2, achieved at 14:00 on the 26th of July. The average difference between the two test rooms South wall heat losses was 0.46 W/m^2.

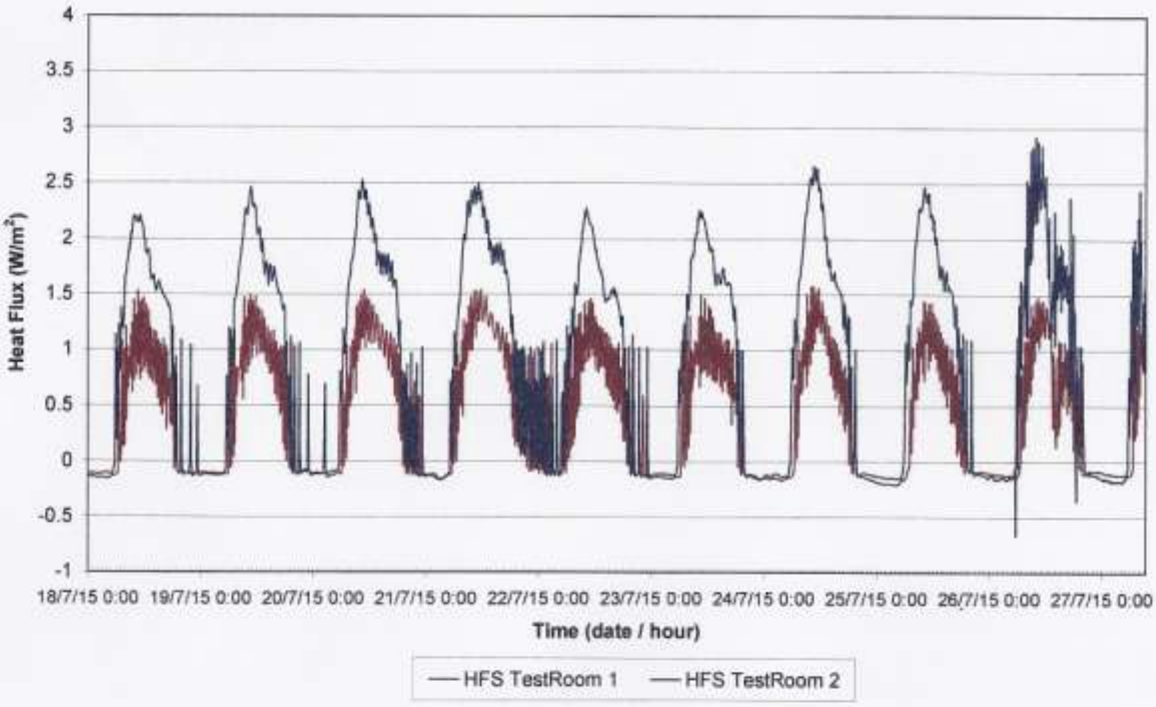


Figure 18. Heat Flux measurements.

5.2.2. Test Rooms comparison

Figure 19 presents the temperature distribution of the Test Rooms roofs and their difference is visible in Figure 20. During appr. 13:00' the roof of Test Room 2 reaches very high values (more than 50 °C) while the corresponding measurements of Test Room 1 rarely exceed 40 °C. During nighttime, these temperatures are equalized, the roof temperature of Test Room 1 being slightly cooler. The maximum temperature difference ranges between 10 and 17 °C (Figure 20).

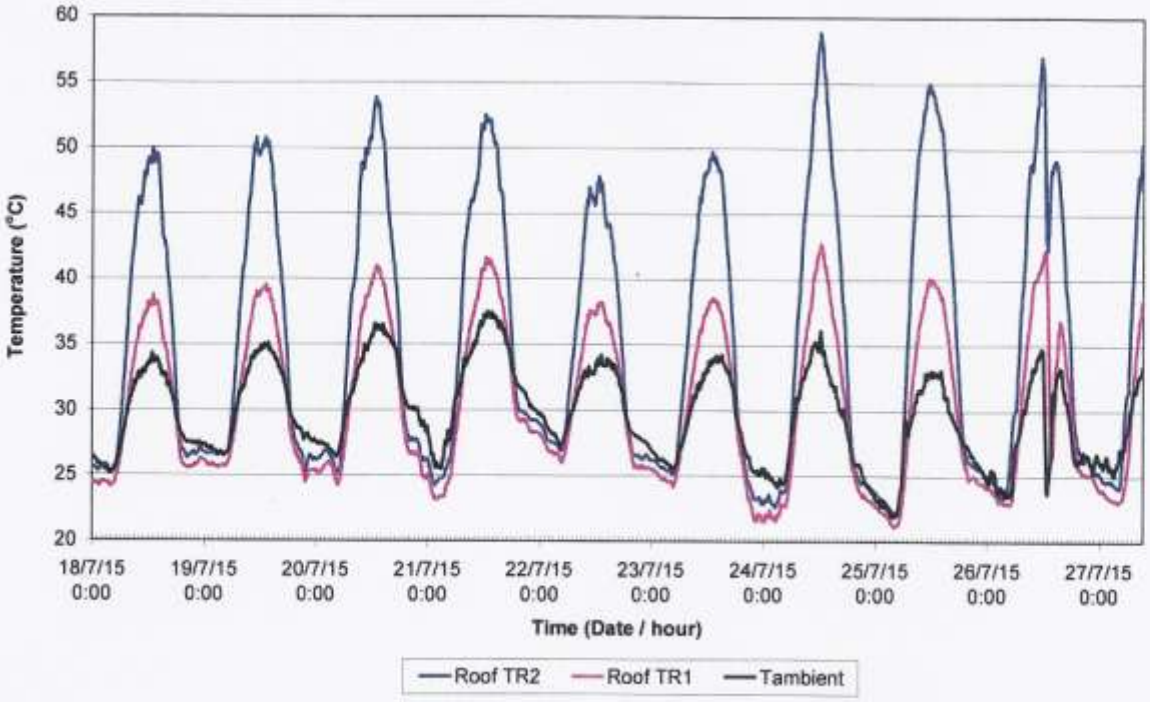


Figure 19. Test Rooms Roof temperature distribution.

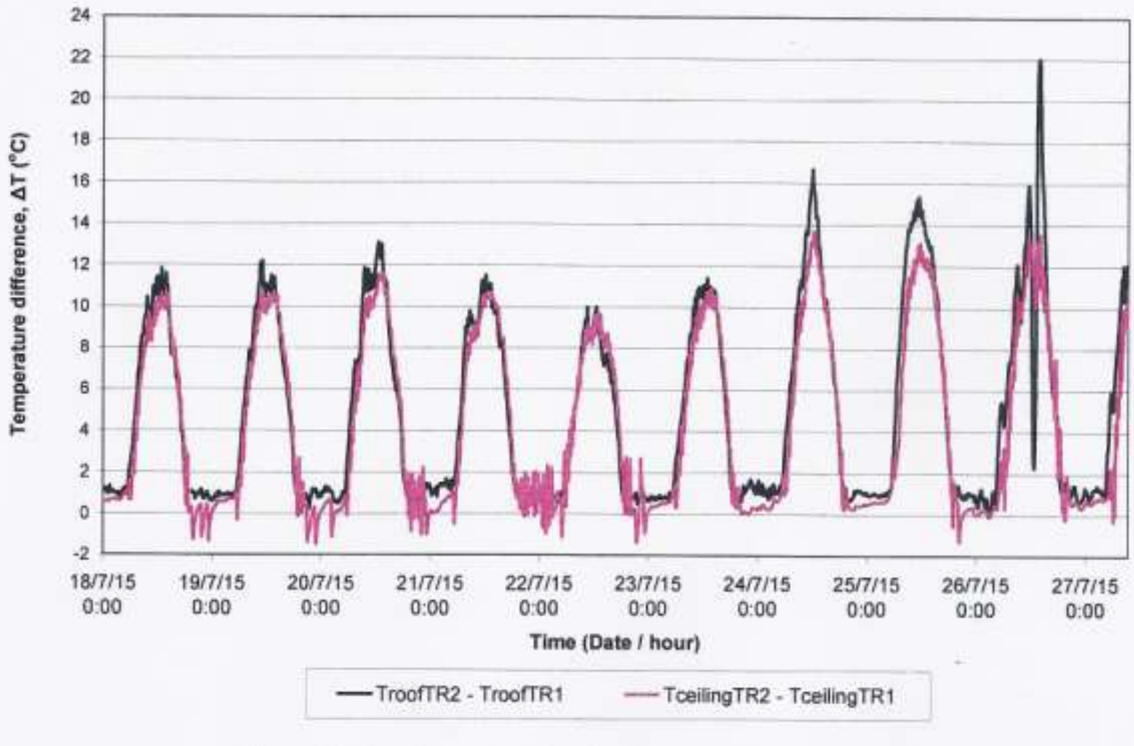


Figure 20. Test Rooms Roof and ceiling temperature difference.

The temperature distribution of the Test Rooms ceiling are shown in Figure 21. During appr. 13:00' the ceiling of Test Room 2 reaches high values (up to 42.4 °C) while the corresponding measurements of Test Room 1 rarely exceed 29 °C. The difference in ceiling temperature is found in Figure 20. The maximum temperature difference ranges between 10.1 and 14 °C. During nighttime, these temperatures are equalized, the ceiling temperature of Test Room 1 being slightly cooler.

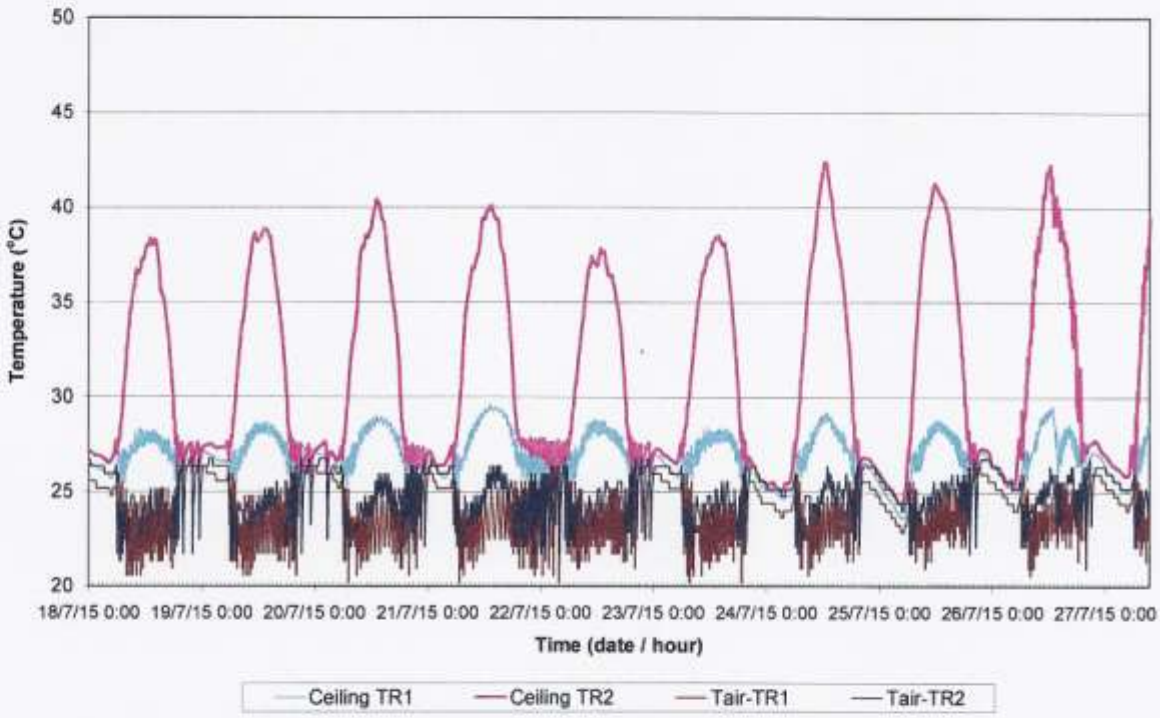


Figure 21. Test Rooms ceiling temperature distribution.

Figure 22 presents the exterior wall temperature distribution of the Test Rooms while their difference is visible in Figure 23. During appr. noon Test Room's 2 wall temperature reaches temperature values up to 45.3 °C while the corresponding measurements of Test Room 1 rarely exceed 38.5 °C. During nighttime, these temperatures are equalized. The maximum temperature difference ranges between 5 and 8 °C (Figure 23). Again, Test Room 1 presents lower distribution of wall temperature than the corresponding wall temperature of Test Room 2, which results in lower surface absorbance and lower energy needs for cooling.

Figure 24 presents the interior wall temperature distribution of the Test Rooms. The interior wall temperature difference can be seen in Figure 23. During appr. 13:00' Test Room's 2 wall internal surface temperature reaches up to 35.2 °C while the corresponding measurements of Test Room 1 reaches up to 30.9 °C. During nighttime, these temperatures are equalized. The maximum temperature difference ranges between 4.3 and 7 °C (Figure 23).

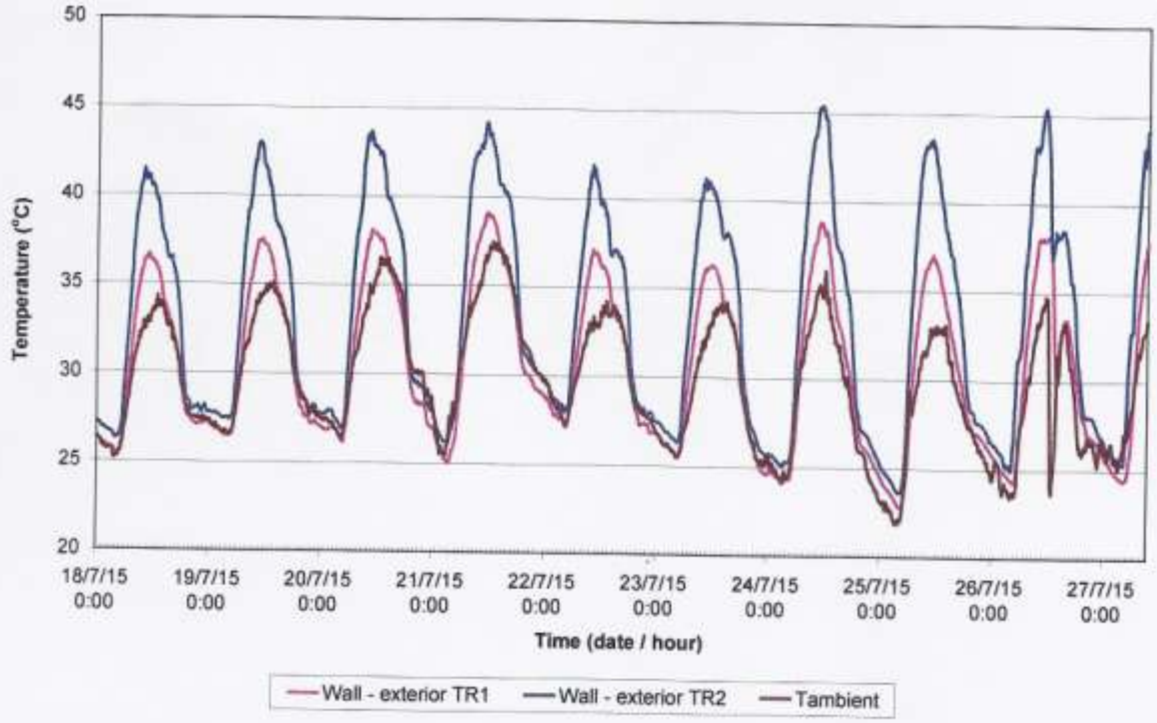


Figure 22. Test Rooms exterior Wall temperature distribution.

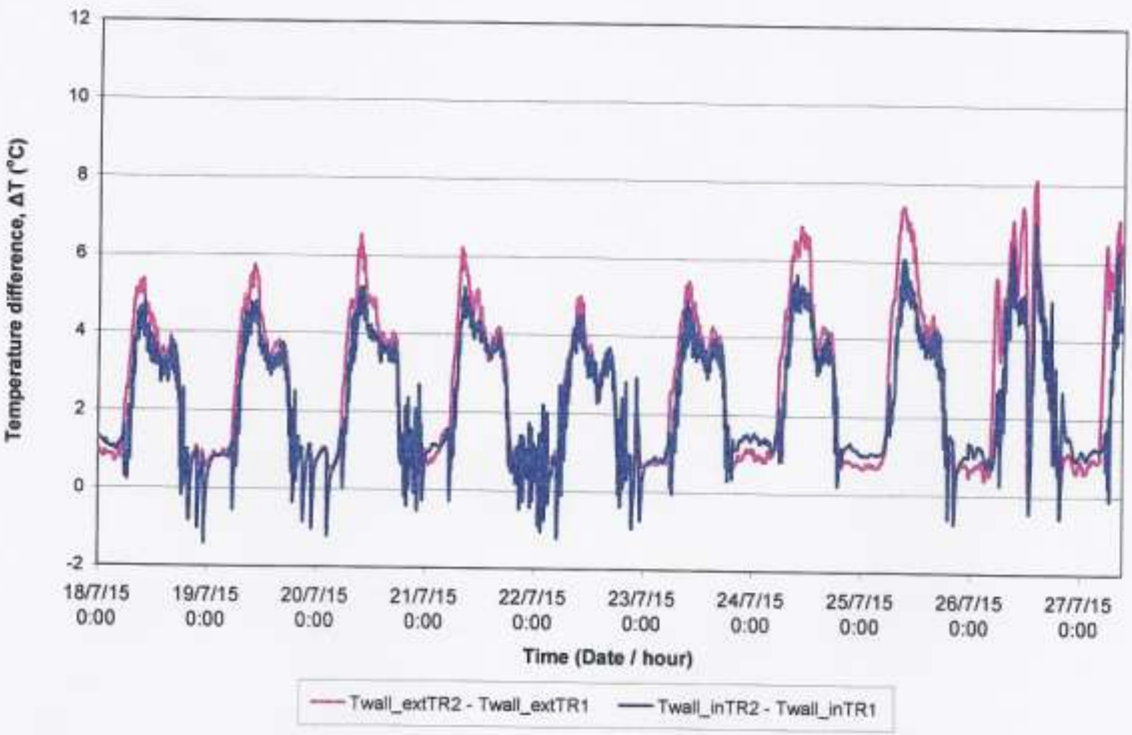


Figure 23. Test Rooms exterior and interior surface Wall temperature difference.

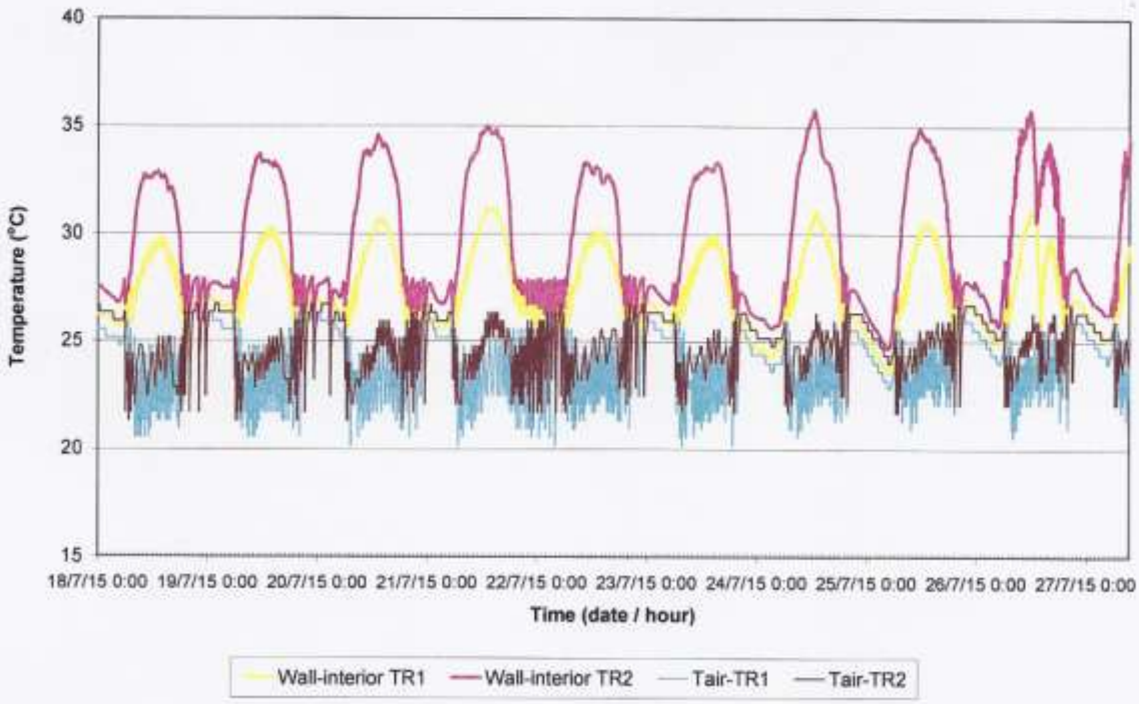


Figure 24. Test Rooms interior wall surface temperature distribution.

The indoor air temperature distribution of the 2 Test Rooms is presented in Figure 25 together with the ambient temperature. It can be seen that the temperature varies in narrow limits, i.e. from 20.7 to 25.5 °C in Test Room 1, and from 21.7 to 26.7 °C in Test Room 2 depicting the effort to keep the internal air temperature to the set point temperature of the AC unit (26 °C). It can be also seen that the air temperature of Test Room 1 rarely exceeds 25 °C, while that of Test Room 2 more often showing the difficulty of Test Room 2 to keep temperature set.

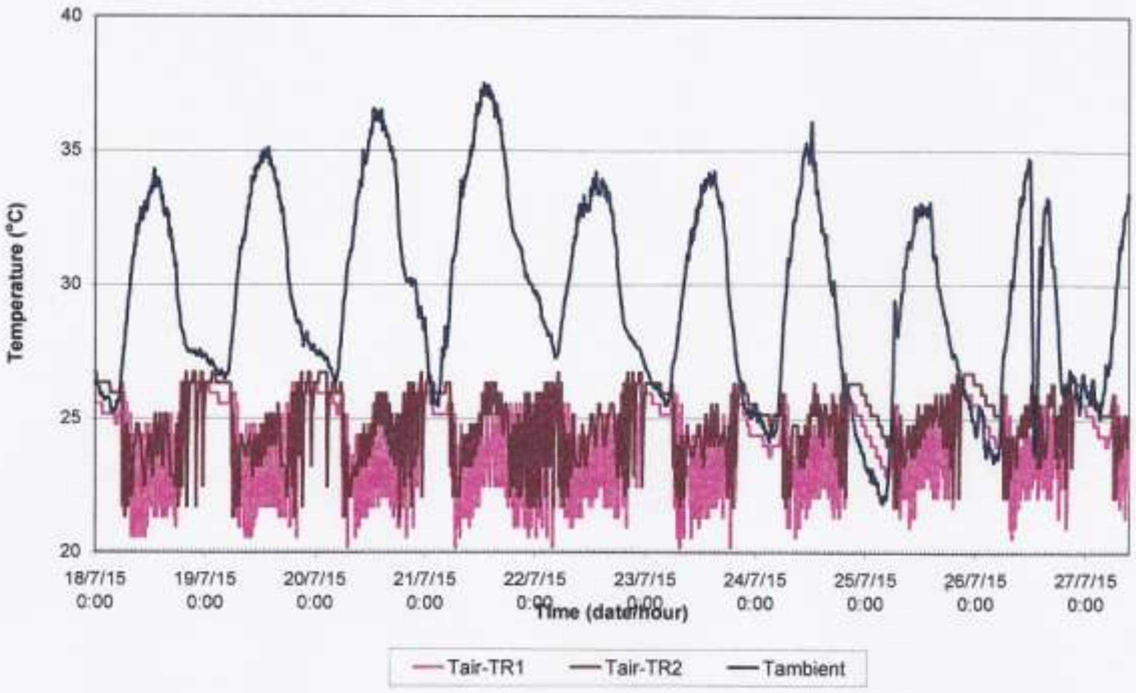


Figure 25. Test Rooms indoor air temperature distribution.

In Figure 26 the temperature difference between ambient environment and air room temperatures can be found together with the difference of the two rooms indoor air temperature difference. It is observed that this temperature difference reaches a maximum ranging from 10 to 14 °C. The average temperature difference between the Test Rooms ($T_{airTR2} - T_{airTR1}$) was found to be 0.92 °C.

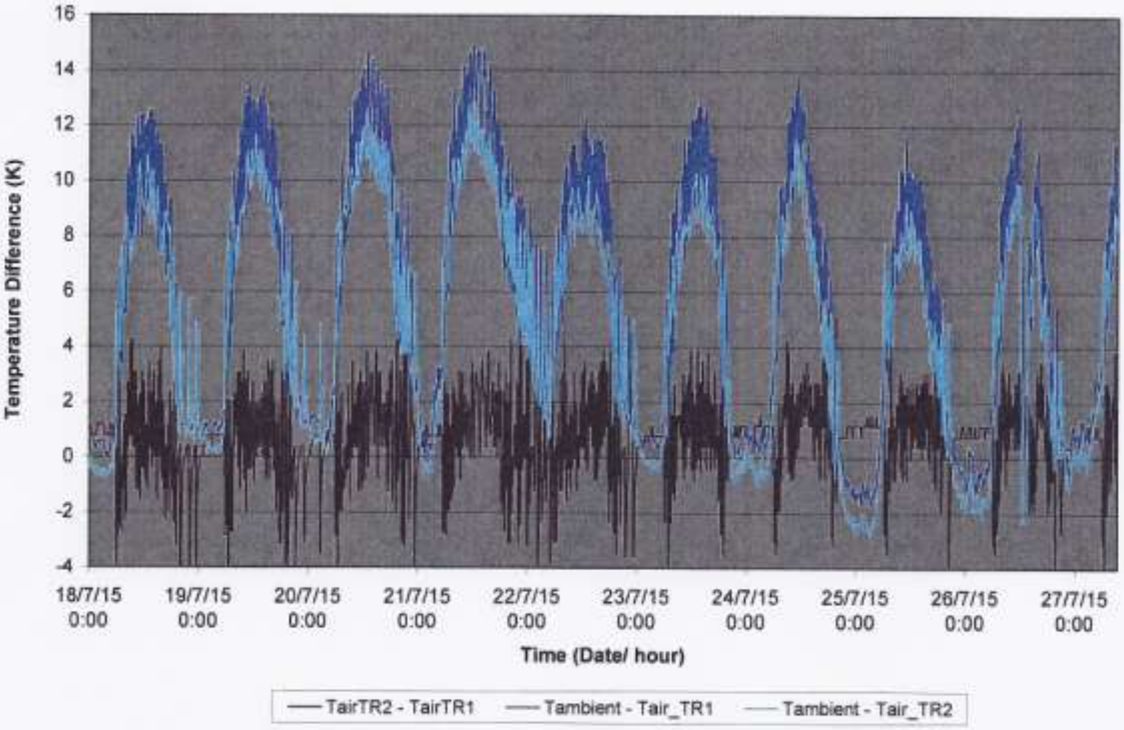


Figure 26. Interior air temperature differences.

Figure 27 presents the fluctuation of the relative humidity inside the Test Rooms together with indoor air temperature. It can be seen that humidity ranges from 25% to 74% and it lays in acceptable indoor levels.

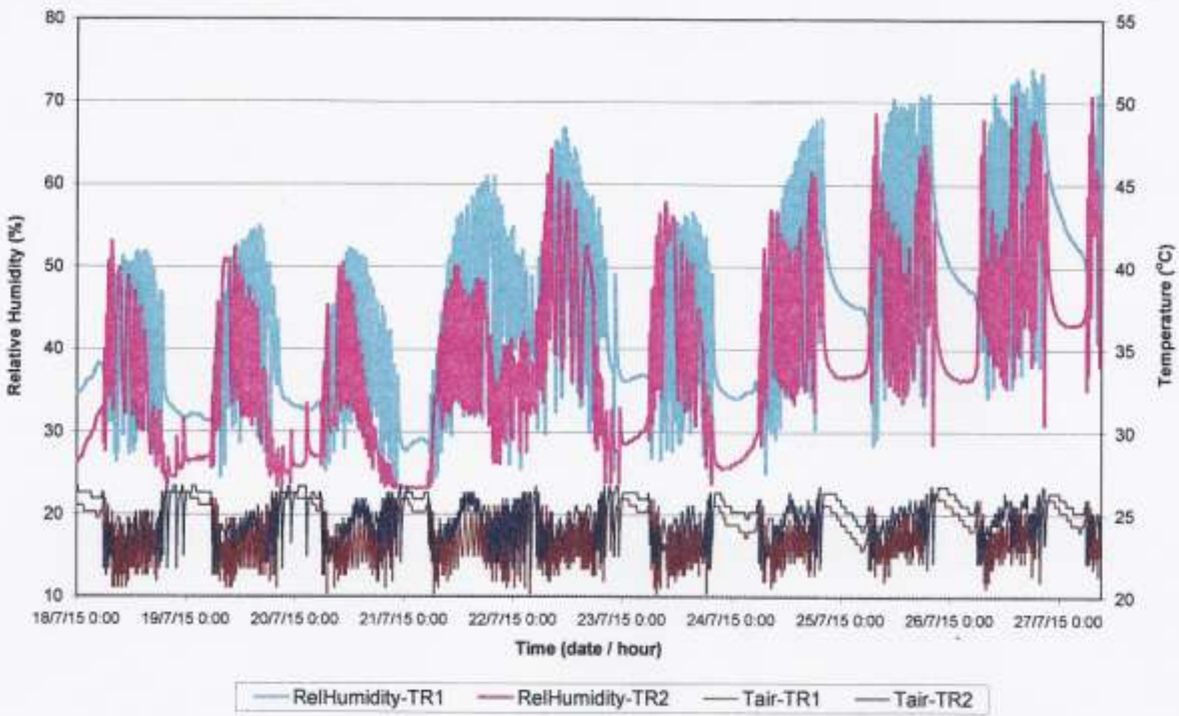


Figure 27. Indoor relative humidity distribution.

5.2.3. Typical day distribution

The thermal behavior of the Test Rooms was looked into in more detail through the comparison of the measurements of a typical day regime. July 22 was selected for this comparison since it showed a rather typical ambient temperature (up to 34.2 °C) and solar radiation distribution (Gsol=980 W/m^2) with clear sky conditions (refer to Figure 15).

Figure 28 illustrates the roof and ceiling temperature distribution of Test Room 1 together with the indoor air and ambient temperature. Figure 29 shows the same measurements for Test Room 2. It is noted that although the indoor air conditions are similar (approx. 26 °C) a roof temperature difference of 10.4 °C is reached at noon, together with a ceiling temperature difference of 9.5 °C (Figure 30). The average roof temperature difference was found to be 4 °C.

In Figure 31 the wall internal and external temperature distribution for Test Room 1 is presented. The same data for Test Room 2 are shown in Figure 32. It can be seen that during sunshine hours the exterior wall temperature of Test Room 2 is always higher than that of Test Room 1 and reaches up to 5 °C difference (Figure 33). The interior wall temperature of Test Room 2 is, again, always higher than that of Test Room 1 and reaches up to 4.5 °C difference (Figure 33). The daily average exterior wall temperature difference was found to be 2.4 °C.

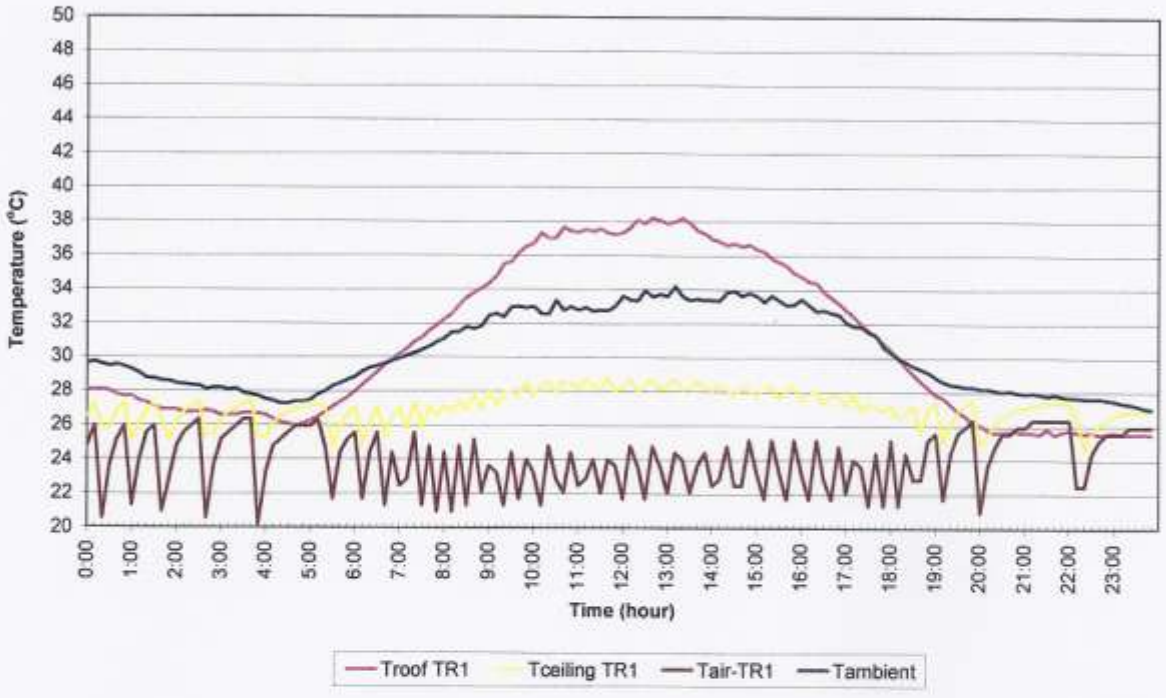


Figure 28. Roof, ceiling temperature distribution - Test Room1 (July 22nd).

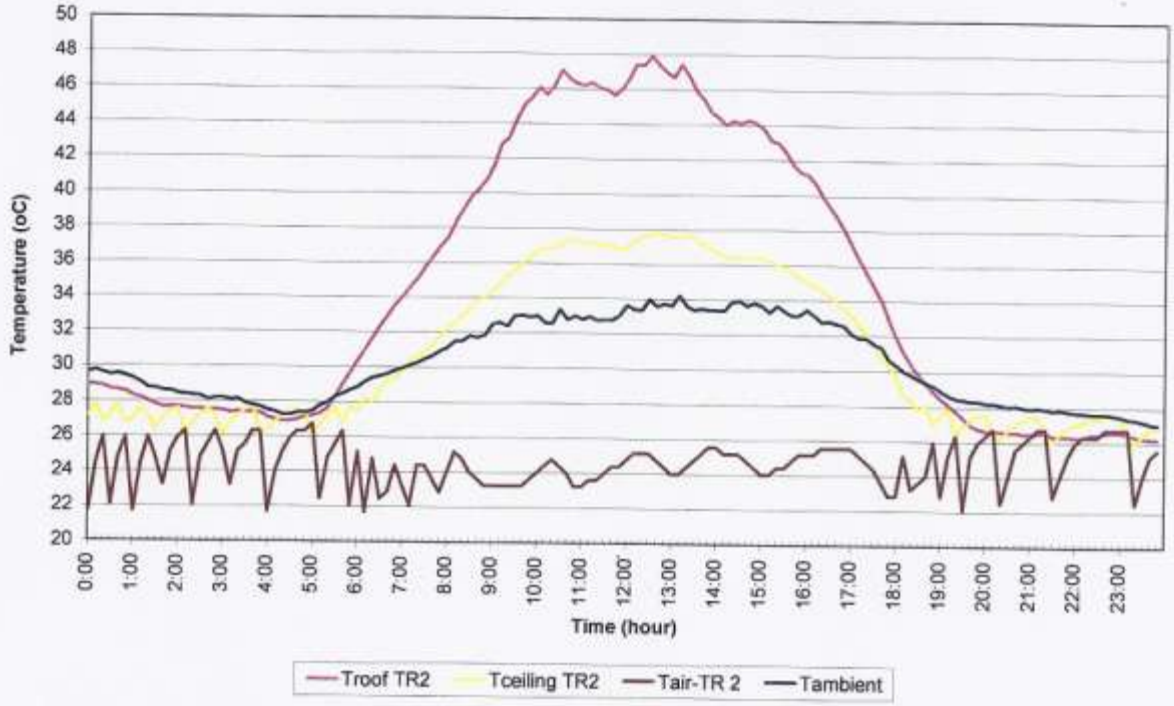


Figure 29. Roof, ceiling temperature distribution - Test Room 2 (July 22nd).

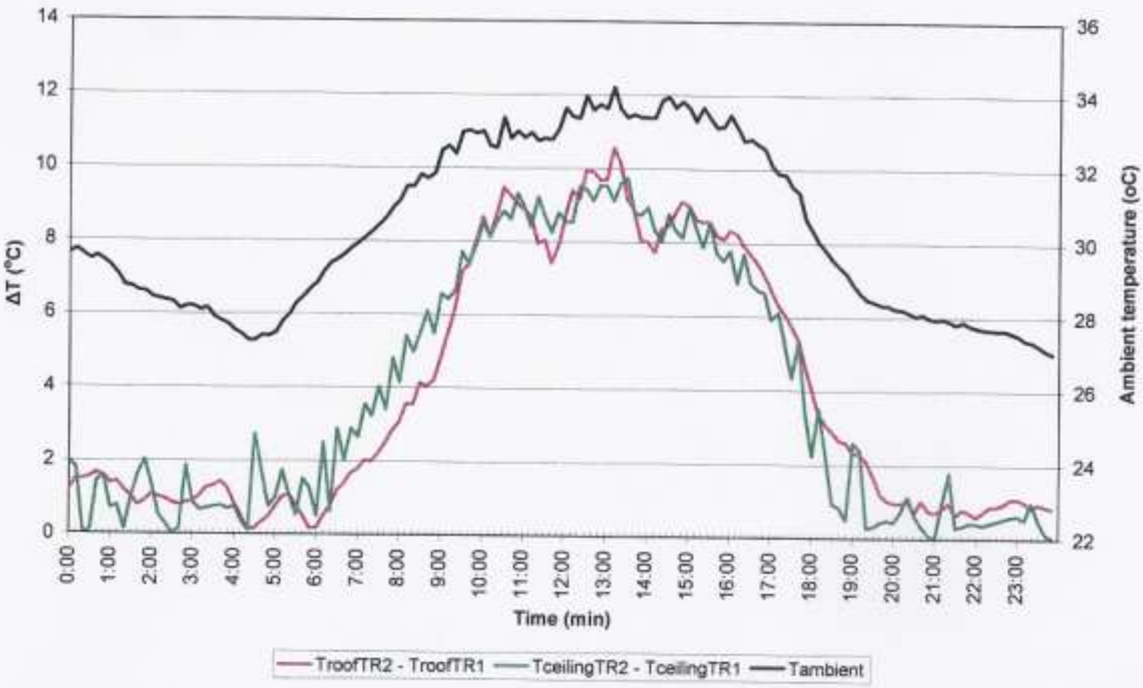


Figure 30. Roof, ceiling temperature difference (July 22nd).

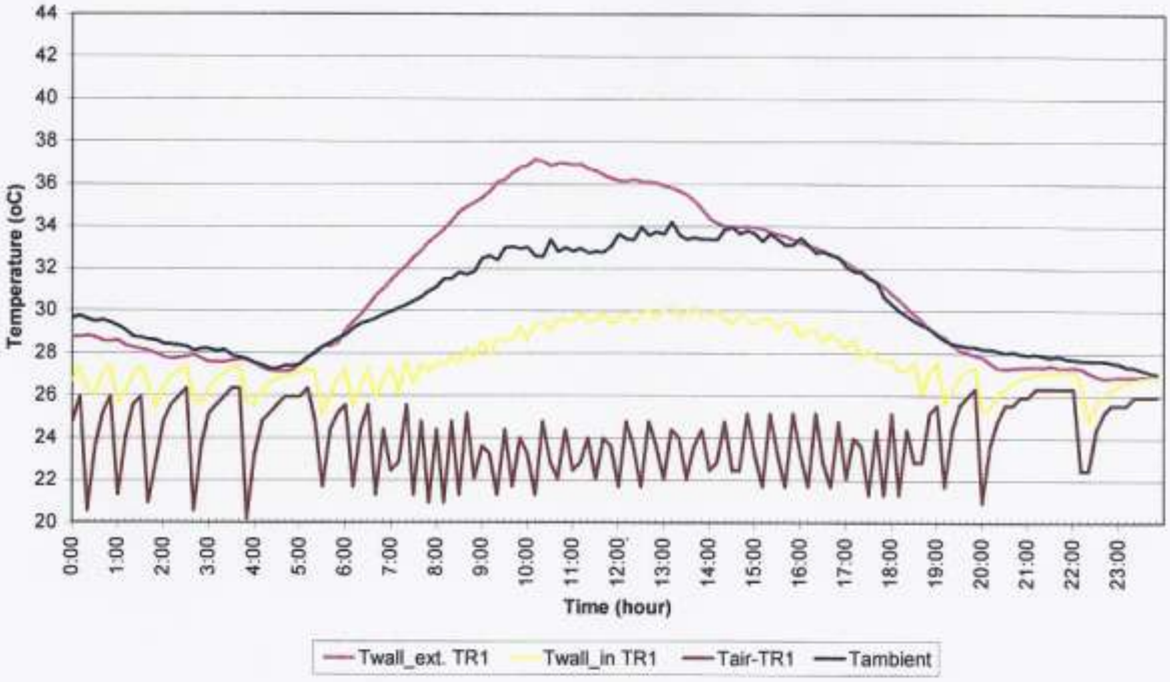


Figure 31. Wall surface temperature distribution - Test Room 1 (July 22nd).

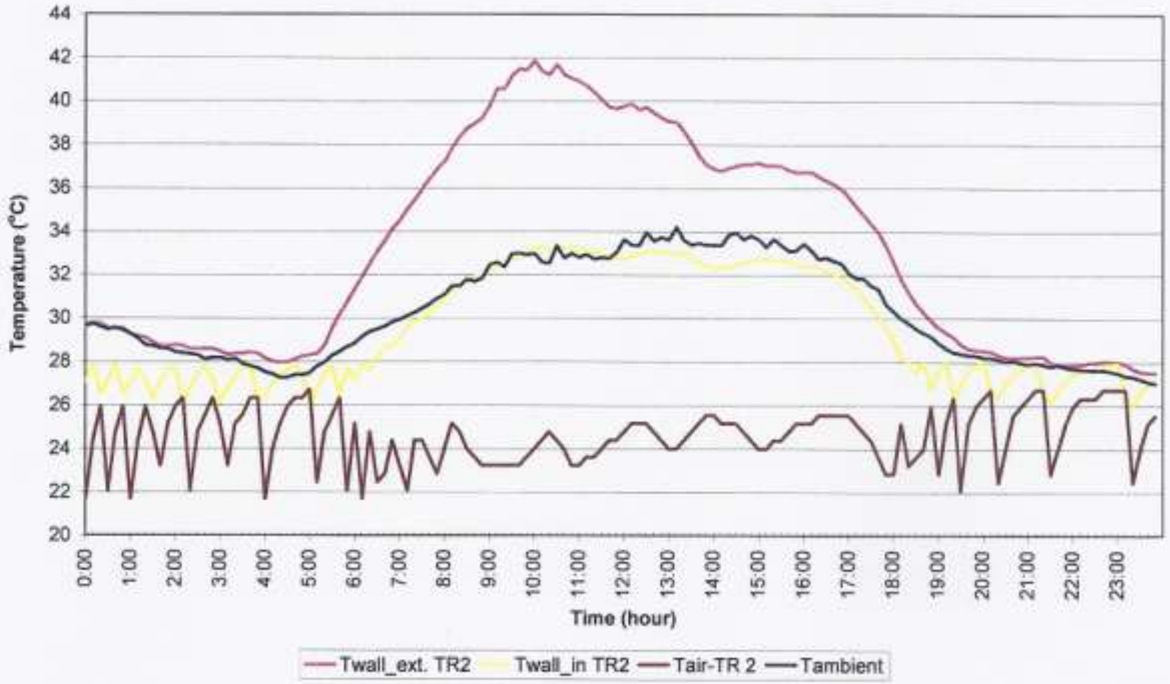


Figure 32. Wall surface temperature distribution - Test Room 2 (July 22nd).

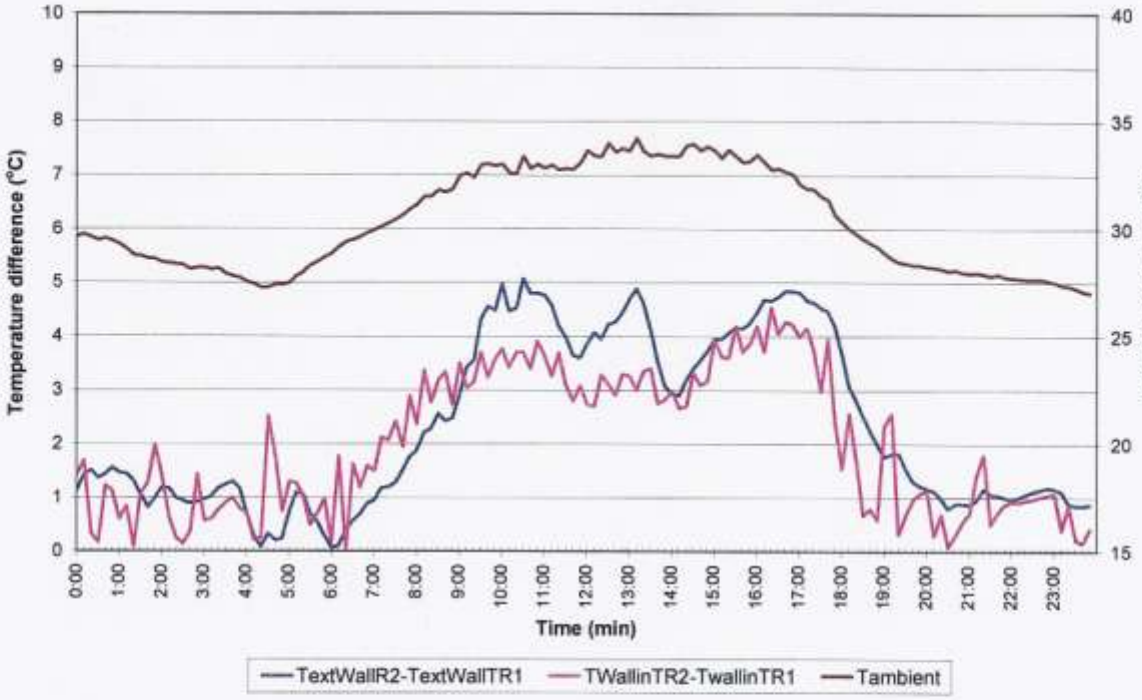


Figure 33. Exterior and Interior wall temperature difference (July 22nd).

Figure 34 shows the indoor air temperature distribution of the two Test Rooms. Both air temperatures are very close to the set point and remain almost constant on a 24-hour basis. A slight difference between the temperatures is observed, with the air temperature of Test Room 2 being higher than that of Test Room 1, implying the ability of Test Room 1 to keep the temperature in low levels which corresponds to less energy needs. The average temperature of Test Room 1 is 24 °C while that of Test Room 2 was found to be 24.6 °C.

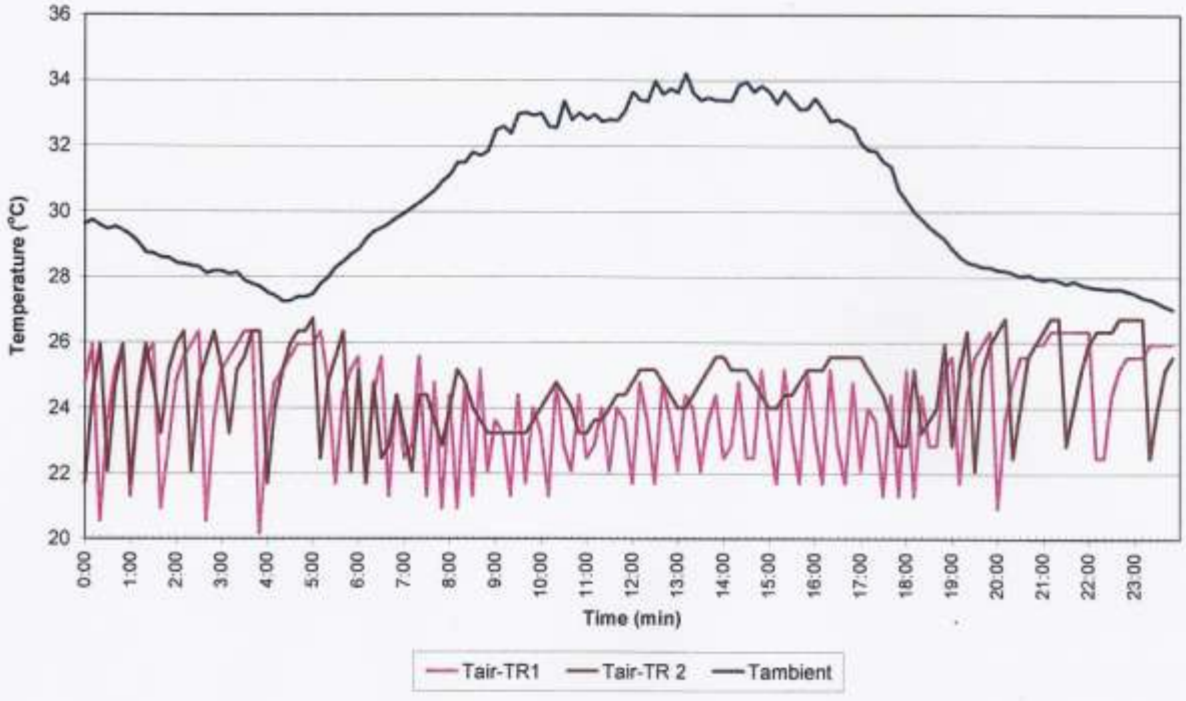


Figure 34. Indoor air temperature (July 22nd).

Figure 35 depicts the heat losses from the walls of the Test Rooms. It can be seen that during sun hours, the heat losses of Test Room 2 are higher than those of Test Room 1, however, during nighttime they balance. The average heat losses difference is 0.41 W/m^2 which corresponds to 56% less energy losses.

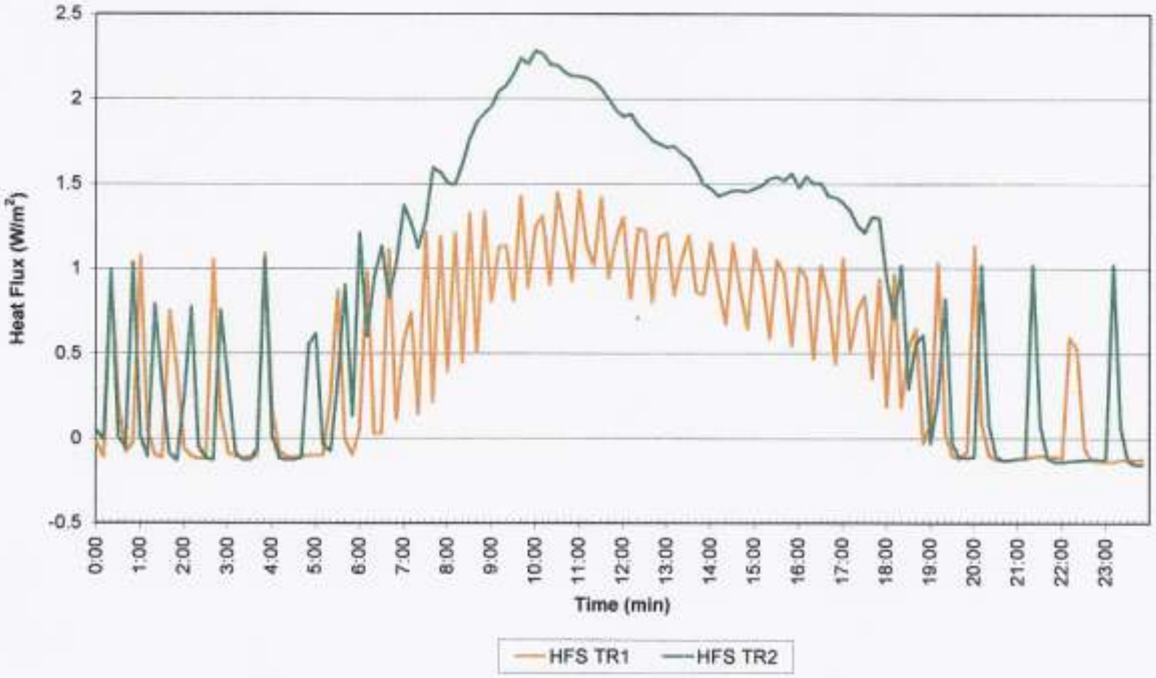


Figure 35. Wall heat losses (July 22nd).

From the figures above it can be seen that during a typical summer day (Attiki area weather conditions) the Test Room coated with ThermaCote layer on both exterior and interior surfaces showed good thermal behavior and provided less surface temperature profiles resulting in reduced energy needs when compared with a same Test Room without the coating layers.

5.3. Wall Thermal Resistance

From the measurements collected a calculation of the thermal Resistance, R of the walls of the Test Rooms took place. The sensors used are: the 2 wall surface temperatures of Test Room 1 (external and internal), and the heat flux sensor HFS TR1. The heat flux sensor was placed in full contact with the internal wall area and measured the conductive and convective heat transfer (refer to Figures 36 and 6). The same sensors readings were used for Test Room 2.

Figure 36. Heat Flux sensor.

The procedure followed the requirements of standard ISO 9869 "Thermal insulation - Building elements - In-situ measurement of thermal resistance and thermal transmittance" which state to:

- Position the sensors on a representative area of the wall.
- Ensure the complete contact of the thermal flow meter.
- Avoid proximity to such particular points as thermal bridges, front's geometrics variations.
- Avoid direct heat radiation to the sensors.
- Maximize the temperature difference between internal and external environment.
- Test duration: from 60 to 80 hours.

For the test sequence three consecutive days were selected, July 18 to July 20 (72 hours data), and the temperature and heat flux measurements for Test Room 1 can be seen in Figure 37. The calculation of the thermal resistance of the Test Room 1 wall was performed by the use of the following expression:

$$R_{wall} = \frac{\sum_{j=1}^{n}(T_{sij} - T_{sej})}{\sum_{j=1}^{n} HFS_j}$$

where

R_{wall} = Thermal resistance of the wall (m^2K/W),
T_{si} = Internal surface temperature (°C),
T_{se} = External surface temperature (°C),
HFS = Heat losses (W/m^2).

The calculation used the moving average method and consists of calculating a quantity by using the average values calculated in all the previous instants, for a predefined time step. The outcome of the calculation procedure, yielded to a Test Room 1 average wall thermal resistance of $R_{wallTR1}$ = 1.23 m^2K/W.

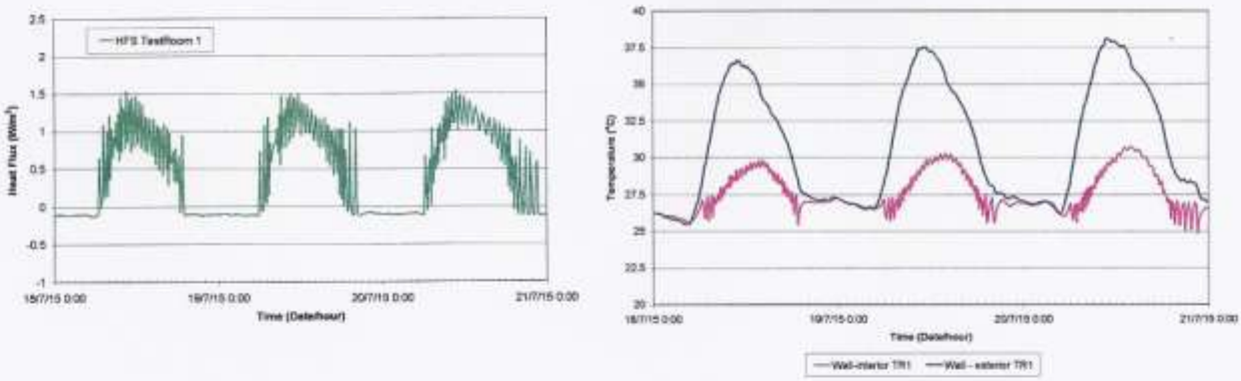


Figure 37. Heat losses and wall temperatures – Test Room 1 (18-20 July).

The temperature and heat flux measurements for Test Room 2 can be seen in Figure 38. The calculation of the Room's wall thermal resistance showed a $R_{wallTR2}$ = 0.85 m^2K/W. A comparison of the two wall thermal resistances shows that the wall equipped with the coating ameliorates the thermal behavior of the building component by 31%.

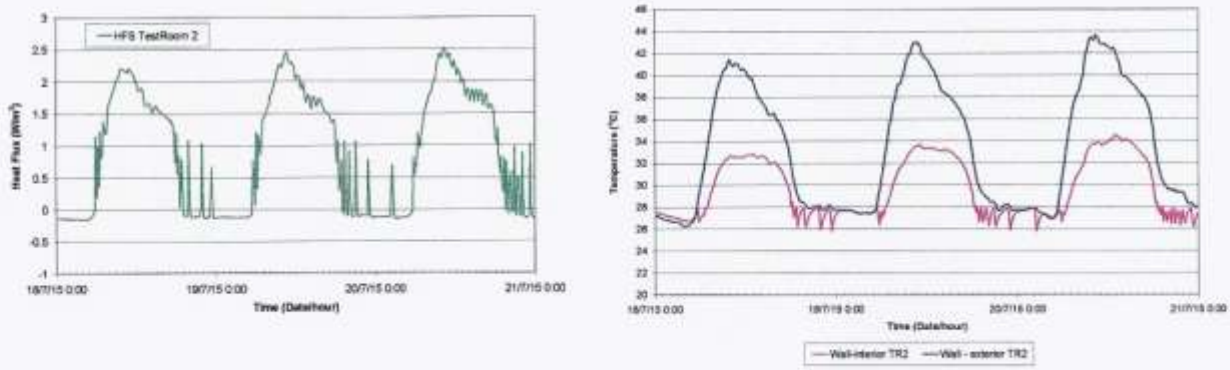


Figure 38. Heat losses and wall temperatures – Test Room 2 (18-20 July).

5.4. Cooling energy consumption

The energy needs to keep the air temperature of the Test Rooms in a controlled environment were also recorded by the use energy meters. So, during the test procedure, an energy meter has been connected to the air conditioner in order to record the electrical energy consumed by the unit to keep the indoor temperature to 26 °C. The energy meter measured the electricity needs continually and recorded the readings at the end of the measuring sequence. The two energy meters installed in the Test Rooms can be seen in Figures 39 and 40. The data from the energy meters can be found in Table 2.

Figure 39. Energy meter in Test Room 1.

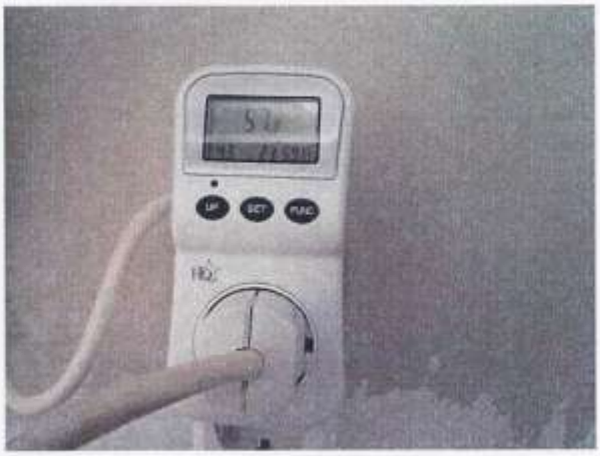


Figure 40. Energy meter in Test Room 2.

Table 2. Energy meters results.

a/a	Description	Energy, kWh
1	Energy meter – Test Room 1	35.9
2	Energy meter – Test Room 2	57.8

It can be seen that the application of the coating on the exterior and interior surfaces of the room resulted in savings in electricity consumption of appr. 38%. The internal coating layer is mainly responsible for this result, since it blocked the cooling energy to be transmitted through the building components.

6. CONCLUSIONS

The energy performance of ThermaCote high performance Ceramic coating was studied. Two identical Test Rooms were constructed, one of which (Test Room 1) was equipped with an exterior and interior coating layer. The thickness of the exterior ThermaCote Ceramic Coating was 0.7mm and of the interior ThermaCote Ceramic Coating 0.3mm (as the applicator supported). The measurements were conducted under real weather conditions, during July 2015 in Mandra area, near Athens, Greece. Measurements of surface temperature, air temperature, heat losses, ambient conditions, and energy consumption were taken at a controlled indoor room environment. Results showed that the Test Room coated with ThermaCote layers keeps the temperature distribution at low levels when compared to the Test Room without the application of ThermaCote (Test Room 2). More specifically

- The roof temperature difference between the Test Room without the coating - Test Room 2, and the one with the application of the coating reaches up to 17 °C providing an average temperature difference of 5 °C.
- The temperature difference of the ceiling between the Test Room without and with the coating layers reaches up to 14 °C providing an average temperature difference of 4.3 °C.
- The external wall surface temperature of the Test Room equipped with coating provided lower values up to 8 °C when compared to the corresponding ones from the Test Room

without the coating. The average temperature difference of external wall surfaces was found to be 2.7 °C.

- The wall interior surface temperature difference between Test Room 2 and Test Room 1 (with coating) reaches up to 7 °C and the average temperature difference of the internal wall surfaces was found to be 2.4 °C.
- The measured heat losses from the wall surface during the test sequence showed that the Test Room with the coating layers has reduced heat losses through the building envelope compared to the heat losses of the Test Room without the coating. The average heat losses of Test Room 1 were 0.40 W/m^2 while the ones of Test Room 2 were found to be 0.82 W/m^2.

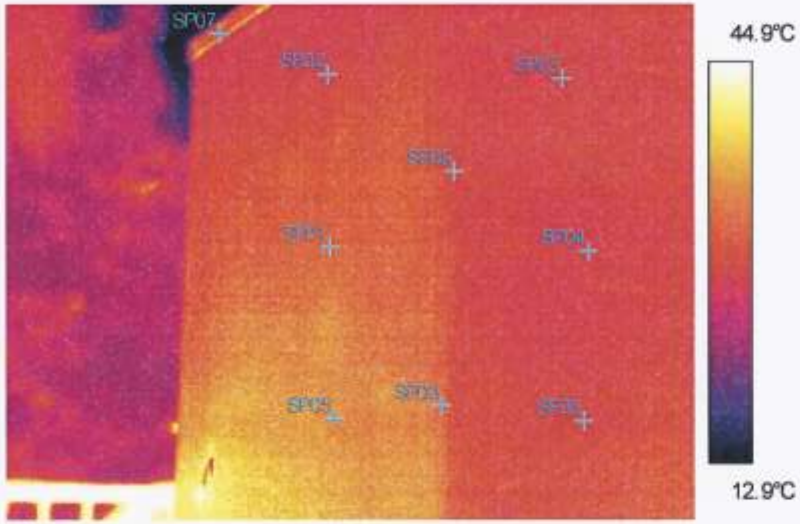
A thermography study performed on exterior and interior surfaces of the two Test Rooms supports the above findings.

By the use of the measured data, a calculation of the thermal resistance, R_{wall} of the wall components of the two Test Rooms was carried out. Results showed that the wall with the coating layers yields to an increase of thermal resistance by 31% when compared to the identical wall without the application of the coating.

Finally, the energy consumption for cooling purposes to regulate the indoor environment of the Test Rooms was found to be much less in the Test Room equipped with the coating layers compared to the Test Room without the coating. The electricity consumption is reduced by 38% which is a result of the reflective coating layers that block heat radiation to and from the interior of the room.

ANNEX 1

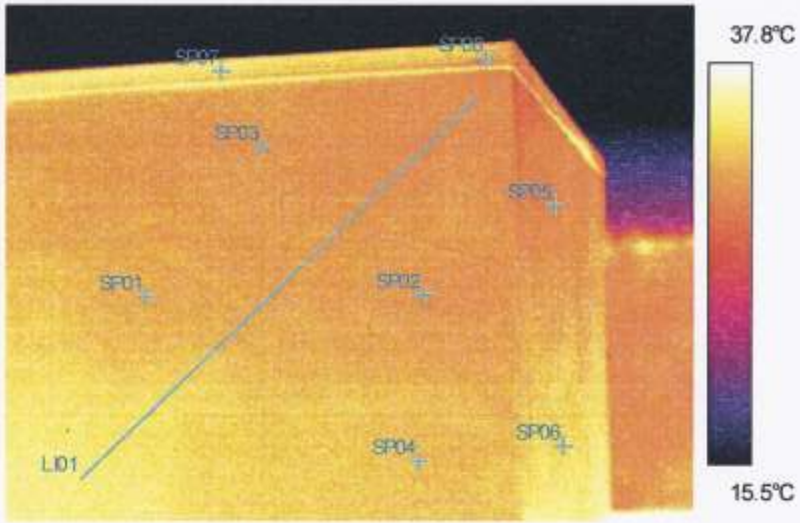
Thermographs



Measurement Point	Temperature (^oC)
SP01	35.9°C
SP02	35.4°C
SP03	35.2°C
SP04	35.0°C
SP05	36.6°C
SP06	35.6°C
SP07	35.4°C
SP08	35.5°C
SP09	36.4°C

Thermograph 3: South-East façade – Test Room 1

Figure A3: South-East façade – Test Room 1



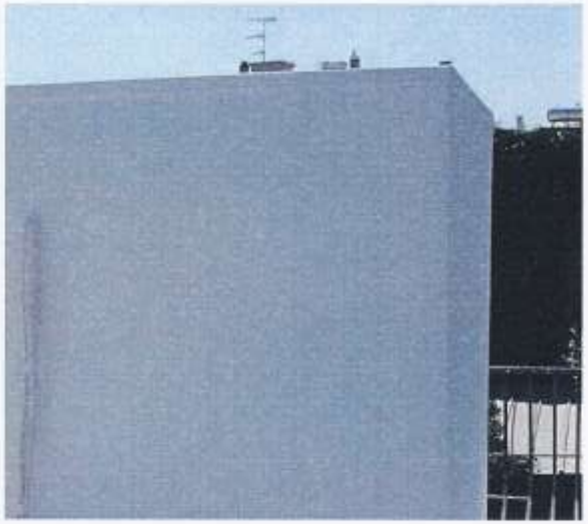


Figure A4: North façade, upper part - Test Room 1

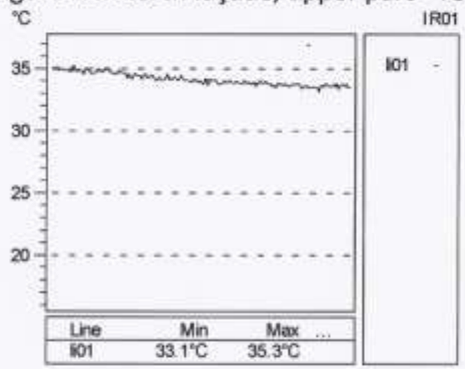
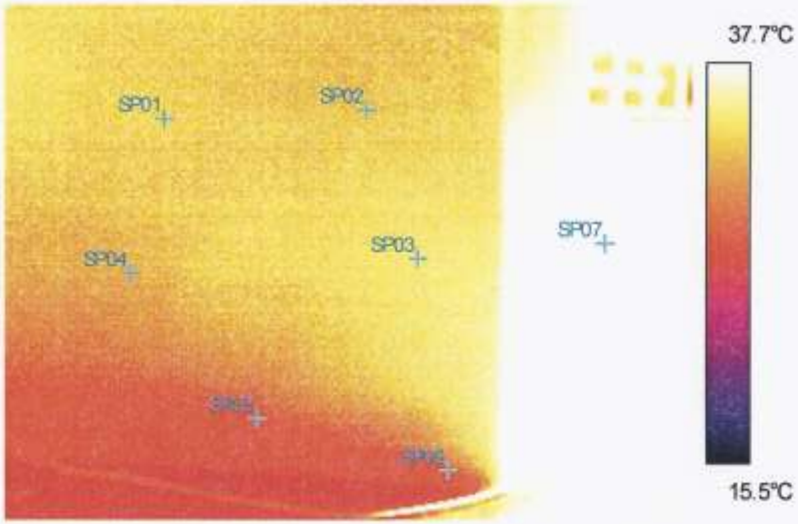


Diagram 3: Surface temperature over line LI01

Measurement Point	Temperature (°C)
SP01	34.1°C
SP02	33.6°C
SP03	34.1°C
SP04	34.2°C
SP05	33.2°C
SP06	34.7°C
SP07	35.1°C
SP08	33.8°C

Thermograph 4: North façade, upper part - Test Room 1



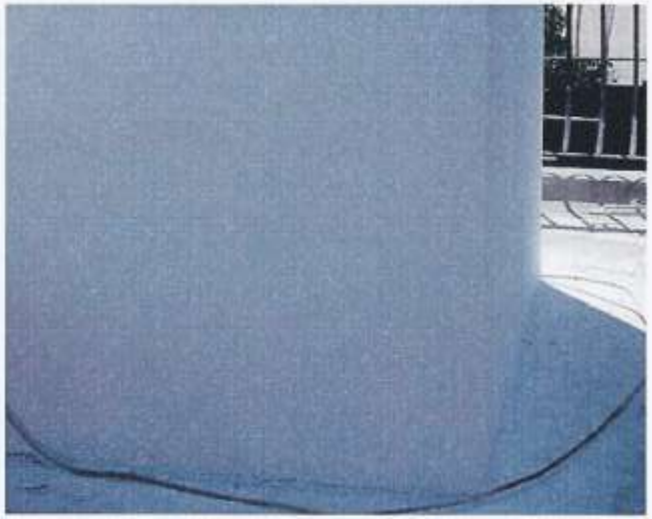
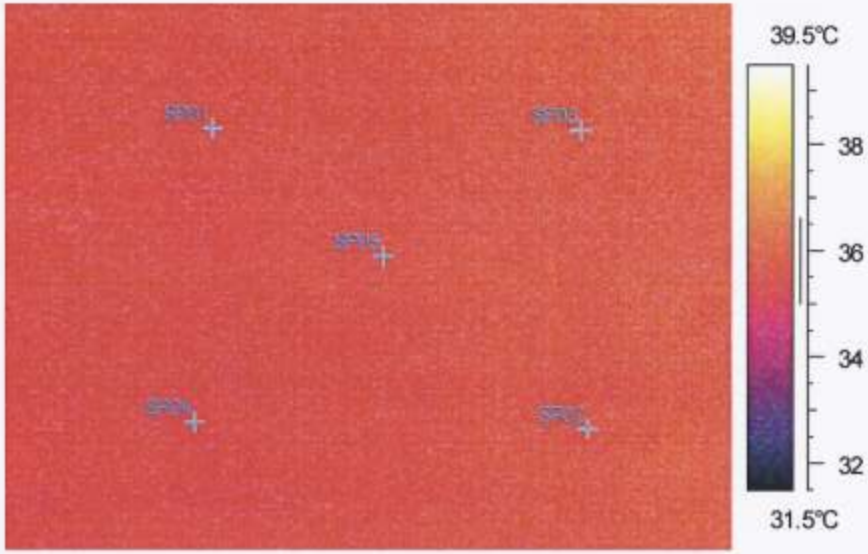


Figure A5: North façade, lower part - Test Room 1

Measurement Point	Temperature (°C)
SP01	34.9°C
SP02	34.7°C
SP03	35.3°C
SP04	34.5°C
SP05	33.5°C
SP06	33.8°C
SP07	39.4°C

Thermograph 5: North façade, lower part - Test Room 1



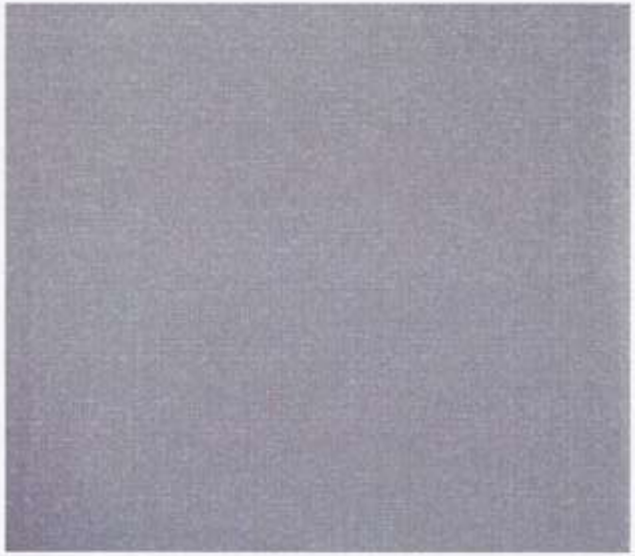
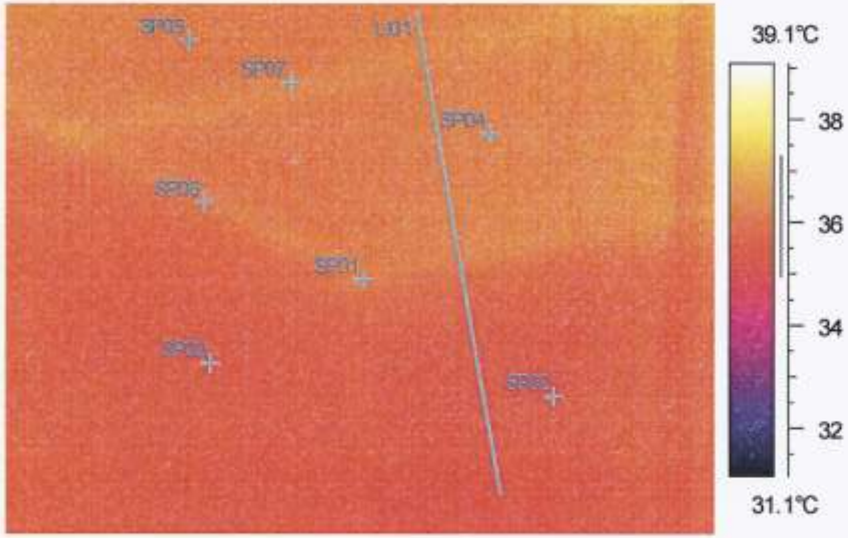


Figure A6: Wall surface, internal – Test Room 1

Measurement Point	Temperature (°C)
SP01	35.7°C
SP02	36.0°C
SP03	35.6°C
SP04	35.5°C
SP05	35.4°C

Thermograph 6: Wall surface, internal – Test Room 1



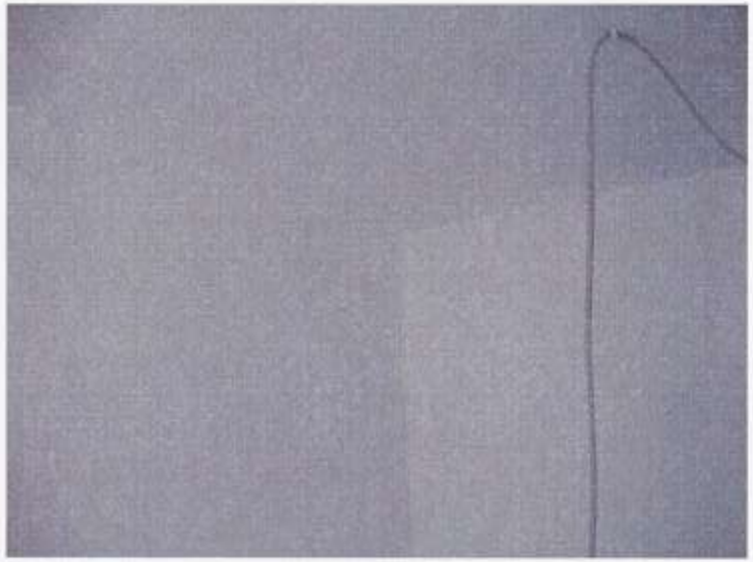


Figure A7: Wall-ceiling joint, Test Room 1

Measurement Point	Temperature (°C)
SP01	36.3°C
SP02	35.1°C
SP03	35.7°C
SP04	36.6°C
SP05	36.1°C
SP06	36.5°C
SP07	36.3°C

Thermograph 7: Wall-ceiling joint, Test Room 1

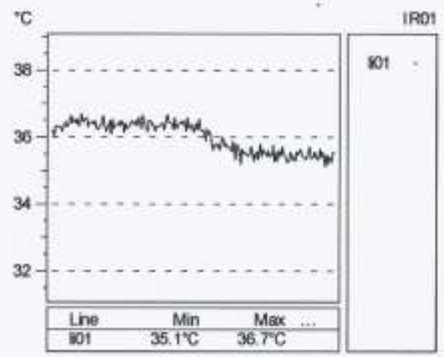


Diagram 4: Surface temperature over line LI01

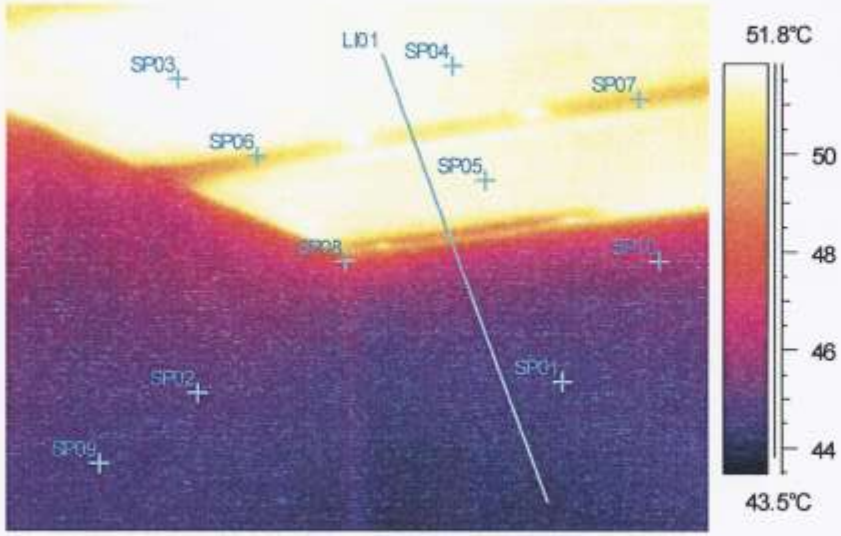


Figure A8: Wall-ceiling joint, Test Room 2

Measurement Point	Temperature (°C)
SP01	44.8°C
SP02	44.9°C
SP03	52.1°C
SP04	51.6°C
SP05	51.5°C
SP06	50.1°C
SP07	50.2°C
SP08	48.5°C
SP09	44.6°C
SP10	46.2°C

Thermograph 8: Wall-ceiling joint, Test Room 2

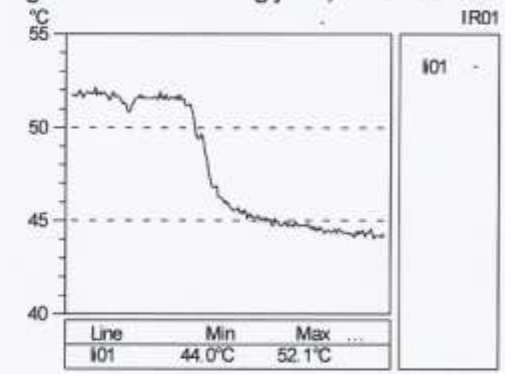
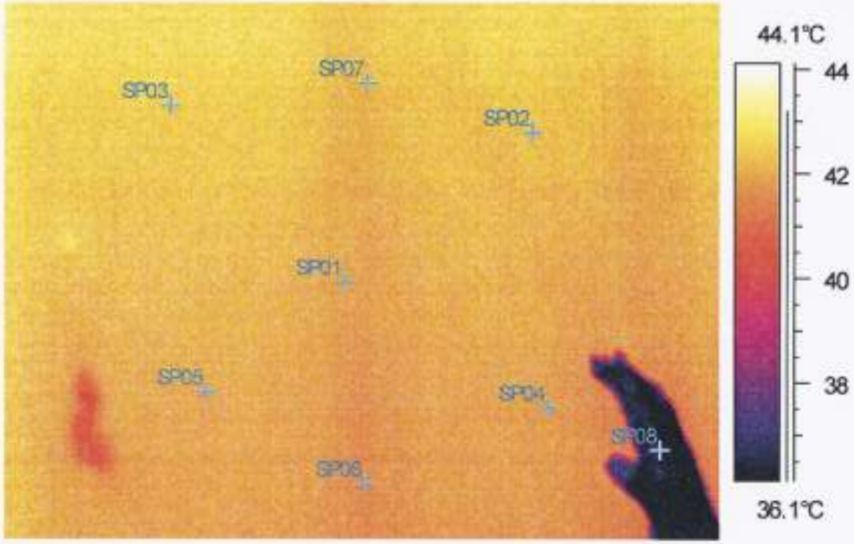


Diagram 5: Surface temperature over line LI01



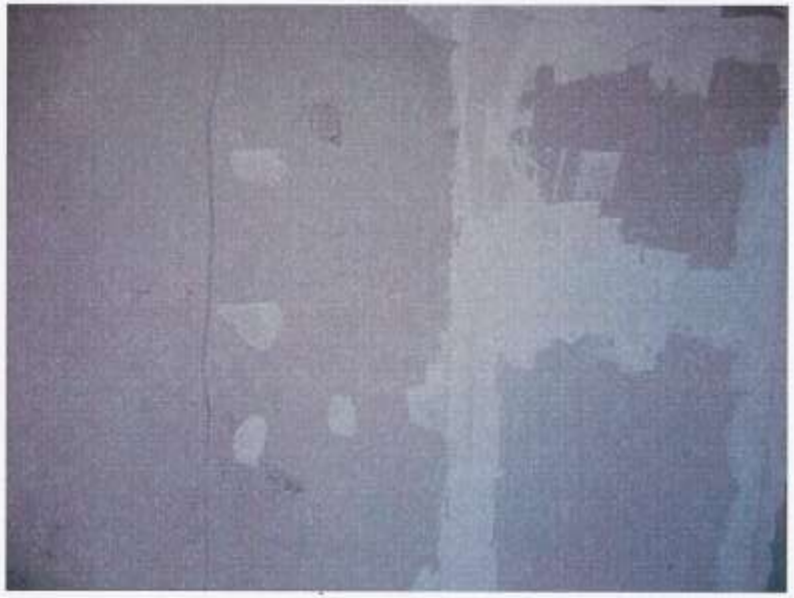


Figure A9: Wall surface, internal – Test Room 2

Measurement Point	Temperature (°C)
SP01	42.1°C
SP02	42.4°C
SP03	42.6°C
SP04	42.0°C
SP05	42.1°C
SP06	41.7°C
SP07	42.4°C
SP08	36.5°C

Thermograph 9: Wall surface, internal – Test Room 2

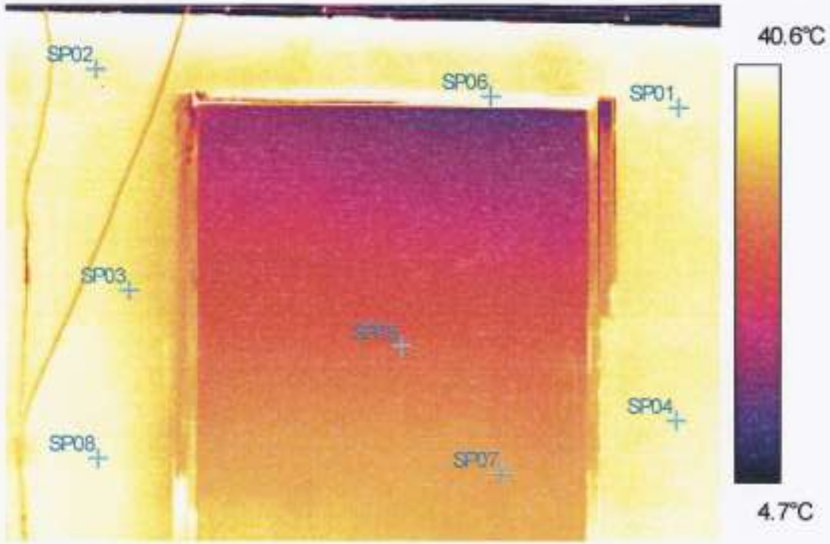


Figure A10: South façade, Test Room 2

Measurement Point	Temperature (°C)
SP01	38.8°C
SP02	38.1°C
SP03	37.4°C
SP04	38.0°C
SP05	32.5°C
SP06	41.5°C
SP07	34.8°C
SP08	38.6°C

Thermograph 10: South façade, Test Room 2

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Instant Wall Thermal Resistance

Energy measurements took place in two identical Test Rooms one of which was coated with ThermaCote Ceramic coating in order to compare their thermal performace.

During the testing period, from 15^{th} to 27^{th} of July 2015, readings were recorded at a 10 minutes interval.

Apart from the analysis conducted in the 2 Test Rooms, an evaluation of the instant value of the wall thermal resistance for experimental use was asked by ThermaCote Hellas.

It was observed, that the Thermal Resistance, because of unstable heat losses of the two Test Rooms, was fluctuating.

As a result, the instant maximum value of total wall Thermal Resistance of Test Room 1 was found to be 3.52 m^2K/W , and it was calculated with a wall surface temperatures Tw_{in} = 30.3 °C, Tw_{ext} = 38.8 °C, and relative humidity 40.8% at 11:30', 24^{th} of July, while the ambient temperature was 33 °C, the solar radiation was 960 W/m^2 and the indoor room temperature was 23.6 °C.

The Test Room 2, at the same time, with surface temperatures T_{in} = 35.1 °C, T_{ext}= 45.3 °C, inside room temperature 24.1 °C, and relative humidity 49.1%, achieved an instant total wall thermal resistance of 1.65 m^2K/W.

However, during night time, when the temperatures inside and outside the two test rooms were equalized, the heat flux was minimized. This had as a result the minimum value of thermal resistance.

The minimum instant value of total wall Thermal Resistance of Test Room 1 was found to be 0.33 m^2K/W, and it was calculated with wall surface temperatures T_{in} 26.63 °C,T_{ext}_26.56 °C, and relative humidity 31.6% at 3:50', 19th of July, while the ambient temperature was 25.1 °C and the inside room temperature was 25.6 °C.

The Test Room 2, at the same time, with surface temperatures T_{in} 27.5 °C, T_{ext}_27.51 °C, inside room temperature 26.3 °C, and relative humidity 27%, achieved a total wall thermal resistance of 0.17 m^2K/W.

Further tests are needed to investigate the performance of the coating under different weather conditions and various building components so as to evaluate more accurate results.