Consiglio Nazionale delle Ricerche
Istituto di Scienze dell'Atmosfera e del Clima

Tender CT 2592/04

Environmental Monitoring
at Hagar Qim and Mnajdra Temples

Results and Recommendations
on the microenvironmental impact of the shelters for the Temples

June 2006

Order to Start Work: 6 June, 2005

End of Contract: 5 August, 2006

Contracting Authority: Department of Contracts, Malta
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Contents

Summary

The present report includes some considerations and recommendations concerning the impact of the projected shelters on the temples.
The document explains the role and the impact of the main physical, chemical and biological factors on the unsheltered temple stones, and offers various scenarios related to the possible effects caused by the utilisation of the shelters.
This document was requested from Heritage Malta during the Valletta meeting on 10th May 2006 and was produced in advance as regards the Contract Timetable.
Some parts of this document will be utilised

Introduction

The monitoring and evaluation of environmental conditions at Hagar Qim and Mnajdra Temples in Malta are fundamental prerequisites in order to determine the strategy for the protection and preservation of these monuments. The specific objectives and expected results of the environmental monitoring have focused on the characterization of both sites from the meteorological and climatological point of view and on the identification of the main weathering processes affecting the monuments, with the purpose of proposing strategies to be implemented for the protection of the temples against the action of many natural processes.

Measurements carried out at the Temples

CNR ISAC has performed the following measurements over one year (1 July 2005 - 30 June 2006) at Hagar Qim and Mnajdra Temples:

- meteorological data at Hagar Qim and Mnajdra (15 minutes sampling frequency):
  - temperature
  - relative humidity
  - solar radiation
  - rainfall
  - wind speed and direction
  - pressure
- contact stone temperature (Resistance Temperature Detectors or RTDs)
- non-contact stone temperature (Infrared Thermal Imaging Camera)
- stone surface wetness (direct and indirect measurements)
- wind fields inside the temples
- water run-off
- structure vibration
- biological patinas and crusts on stone surfaces
  - contact measurements with the culture media
  - lichen coverage (observation of aesthetic damage)
- biological aerosol
  - viable
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- non-organic aerosol
  - optical microscopy (OM)
  - scanning electron microscope with dispersive energy analyser (SEM-EDX)
  - ion chromatography (IC)
- stone damage analyses
  - optical microscopy (OM)
  - scanning electron microscope with dispersive energy analyser (SEM-EDX)
  - X-ray diffraction analyses (XRD)
  - differential and gravimetric thermal analysis (DTA–TGA)
  - porosimetry
  - ion chromatography (IC)

Results

Presented below are the main results of all the measurements made at Hagar Qim and Mnajdra Temples from 1 July 2005 to 30 June 2006.
Full details of the measurements are provided in the Quarterly Reports, Interim Report and Final Report.

Climate profile of the site

The climatic profile is based on data supplied by the Balzan Malta Weather Station. The data presented below are respectively: Temperature (°C), Rainfall (mm) and Wind (m/s).

Mean Average Temperature (°C) over the last 20 years in Malta

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High	14.7	14.9	17.1	17.5	21.6	26.5	29.3	29.5	26.5	23.9	19.5	16.2
Low	11.5	10.8	13.1	14.7	17.8	22.8	25.4	26.5	24.0	19.9	16.1	12.4
Mean	13.0	12.9	14.6	16.5	20.3	24.5	27.1	27.7	25.1	22.1	18.0	14.6

Highest Maximum Temperature (°C) over the last 20 years in Malta

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High	22.2	23.4	33.5	29.4	34.5	39.8	43.1	43.0	39.2	33.5	28.9	24.9
Low	16.8	15.8	18.5	22.7	24.0	30.0	33.8	33.2	30.4	26.5	24.2	19.5
Mean	19.5	20.0	23.4	26.0	30.4	34.5	36.8	37.0	33.6	30.0	26.3	21.6

Lowest minimum Temperature (°C) over the last 20 years in Malta

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High	8.2	8.3	9.8	10.6	15.0	18.1	21.9	22.0	19.2	15.7	11.9	8.3
Low	3.9	2.6	4.8	6.5	10.5	14.8	17.4	18.0	15.4	11.3	5.7	3.8
Mean	5.6	5.6	7.1	8.8	12.4	16.6	20.0	20.7	17.5	14.1	9.5	6.6

Mean Monthly Rainfall (mm) over the last 20 years in Malta

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High	232	181	125	163	34	29	2	39	390	233	383	211
Low	25	2	5	2	0	0	0	0	0	9	7	24
Mean	100	64	35	29	11	3	0	7	70	68	119	109

Number of Rain Days [>=0.1mm] over the last 20 years in Malta

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High	24	20	14	12	7	3	1	5	12	18	22	21
Low	9	3	2	1	0	0	0	0	0	4	4	7
Mean	14	11	8	7	3	1	0	1	5	8	13	15

Highest 24-hour totals [mm] over the last 20 years in Malta

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High	125.3	43.7	63.4	131.5	16.3	16.5	2.0	32.0	226.3	97.4	193.1	69.4
Low	4.9	0.8	3.3	1.1	0.0	0.0	0.0	0.0	0.0	7.0	5.5	13.9
Mean	34.3	20.3	16.1	17.0	6.0	1.8	0.2	5.9	37.0	29.6	48.0	35.3

Maximum wind gusts (m/s) over the last 10 years in Malta

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
19	19	19	20	17	16	14	13	15	17	20	19

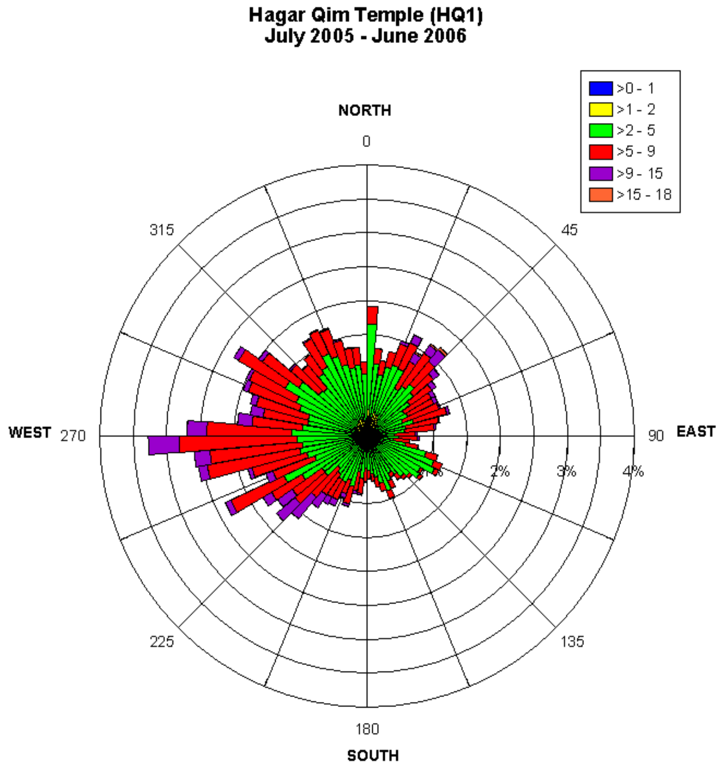
Solar radiation

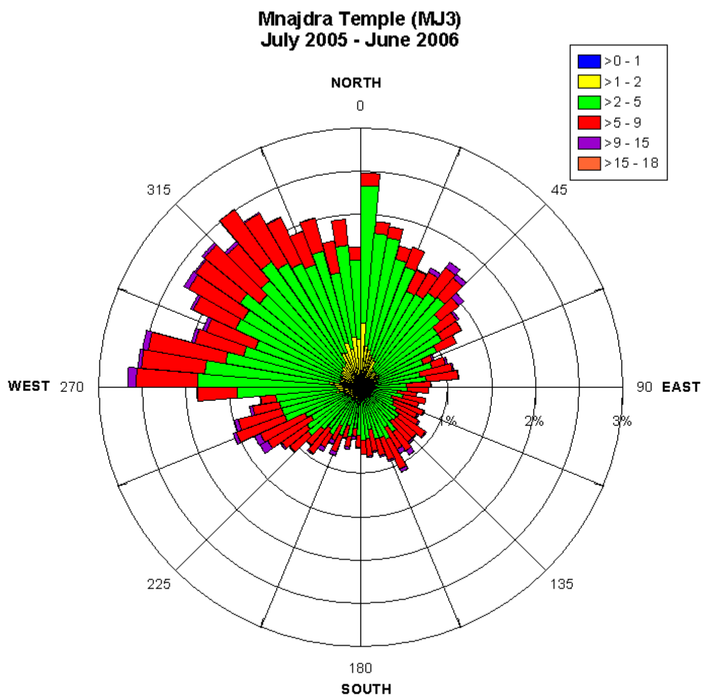
The most energetic part of the solar radiation is the ultra-violet region, which accounts for about 9% of the total solar radiation on a sunny day. The visible light region has a 45% share, while the infrared region takes up the remaining 46%. The total radiation reaching an object on the ground can be divided into direct radiation, which is the energy arriving directly from the sun's disc, and indirect or diffuse radiation, which is the amount of radiation reaching the object from the surrounding (albedo) or reflected by clouds. The diffuse component is about 20% of the total solar radiation on a sunny day and could reach up to 100% on a cloudy day. In Malta, the values of global radiation throughout the year are generally high, with some days exceeding 1000 watt per square meter during the summer season and 800 watt per square meter during the winter season. The mean annual solar radiation falling on a square meter of horizontal surface is 5 kW per day (6 kW in summer; 4 kW in winter).
The main effects produced on the temple stones by the solar energy are:

- surface heating (thermoclastic weathering at microscale)
- cycles of condensation-evaporation of water (migration of water and soluble salts)
- salt crystallisation (fracturing and alveolization)
- growth of biological patinas and crusts (colonies of lichens, algae, bryophytes)

Wind

As can be seen in the graphs, the prevailing wind direction at Hagar Qim is West-South West, while at Mnajdra it is slightly rotated West-North West. Low wind speeds of between 0 and 4 m/s are meanly more frequent at Mnajdra compared to Hagar Qim, where the wind speed is higher on average. Days with calm wind are very few during the winter season. From December to March the wind speed is higher than during the rest of the year. The highest wind speed value (17.5 m/s) was registered at Hagar Qim in February 2006.





The wind speed classes of frequency are expressed as m/s.

Rainfall and run-off heavy events

The table below reports the rain events recorded by the CNR meteorological station at Mnajdra from July 2005 to June 2006.

Rainfall		mm per month	n. of days of rain
2005	July	0	0
	August	7.8	5
	September	22.8	5
	October	130.8	8
	November	60.6	19
	December	110.4	18
2006	January	241.4	23
	February	44.4	11
	March	41.2	10
	April	2	3
	May	2.4	2
	June	3.8	4

October, December and January are the rainiest months, with daily heavy rainfall events, respectively, of 65 mm, 59 mm, and 58 mm.
The run off is correlated to the intensity of rain and the soil conditions. During the winter very intense rainfalls produce moderate surface runoff processes due to the presence of herbaceous vegetation. This slackens the impact of the raindrops on the ground, and favours infiltration, also thanks to the influence of the roots that increase soil porosity as they develop. Moreover during the summer the water run off is very abundant due to the absence of vegetation on the ground.
During the winter the processes of soil erosion produced by the rain prevail, while during the summer prevail the erosion produced by the wind.

Stone surface heating

The IR thermographic measurements were carried out on the stones, using a special thermal camera to monitor the daily heating gradient of the stone surface.
During winter there is the greatest temperature difference between day and night, due to a clearer sky. The values are reported in the table below.
The heating process can produce natural "thermoclastic" damage, due to the daily temperature rise and fall. Through IR thermographic measurements, it can be evaluated whether the surface conditions are favourable to water vapour condensation or evaporation.

	Winter	Spring	Summer	Autumn
ΔTstone/24h (°C)	42.0	37.0	23.0	29.0

Stone wetness

The measurements of liquid water on the stone surfaces indicate that the east (Hagar Qim) and west (Mnajdra) facing surfaces are those that most frequently experience the phenomenon of water condensation. The tables below report the percentage of water condensation times (%WCT) for the various directions of exposure of the stones in different seasonal periods, in two different temples. In bold are highlighted the exposure most wetted.

% WCT-Hagar Qim / Exposure to	North	South	West	**East**
Autumn - Winter	40	35	30	**80**
Spring- Summer	20	17	11	**60**

% WCT - Mnajdra / Exposure to	North	South	**West**	East
Autumn - Winter	10	40	**60**	20
Spring- Summer	40	47	**61**	19

Stone damage

Sea salt deposition on surface material favours salt crystallisation, which is the main weathering process leading to stone degradation at Hagar Qim and Mnajdra temples. Sodium chloride is the most abundant salt present in the stone samples analysed. Na+ and Cl- have more abundant concentrations on the samples collected at higher levels than at lower ones, indicating that chlorides are transported vertically by rising damp. Furthermore sea salt deposition induces the crystallisation of calcium chloride due to the chemical attack by Cl- anion of the stone surface. The pressure created by soluble salt crystallisation induces mechanical stress within the porous stone system causing fracturing and alveolization, eventually leading to a complete powdering of the material. The starting points of the alveolizazion process are strictly linked to the sedimentary structure and texture present (bioturbation).

A further damage process takes the form of calcite recrystallisation on the surface layer of the stone. The different texture and porosity of the substrate and the external layer are the characteristics of the material that make the interface a point of weakness. In fact, in the presence of salts, solar radiation and wind action on the surface and high relative humidity in the air stimulate cycles of salt dissolution and recrystallisation. The consequent mechanical stress causes the partial detachment of the surface crust.

Wind action strongly concurs to cause stone degradation, producing material erosion and abrasion phenomenon induced by soil dust transported by wind. The erosion of material is particular favoured in areas in which there is a discontinuity in the consistency of the surface material and within the alveoli.

Intense and frequent cycles of heating and cooling of the stone surface can produce natural thermoclastism, due to the diurnal thermal gradient.

The proliferation of lichens on stones represents a potential risk, first, of aesthetic impairment and, second, of structural damage of the stone. A generalised and abundant growth was observed not only of lower plants (mosses, liverwort, ferns etc), but also of superior plants (pellitory, trefoil, grasses etc), particularly in the accumulation areas of soil and nutrients.

Total suspended particulate

The total suspended particulate (TSP) measured in atmosphere using active samplers, show that the aerosol concentration varies between 16.7 and 49.2 $\mu g/m^3$, with a mean concentration of 37.1 $\mu g/m^3$ in winter and 28.7 $\mu g/m^3$ in spring. The water-soluble fraction constitutes, as ion concentration, the 26% of the TSP. Major ions detected are chloride and sodium, followed by sulphate, calcium and nitrate. The contribution of sea spray to TSP is estimated to be 28% in winter and 15% in spring, due to high wind speed blowing from the sea, which characterises the winter season.

Biological aerosol

The Total Microbial Load (TML) measured during the different seasons to monitor the presence in the atmosphere of fungal and bacterial spores shows a clearly seasonal character: during summer it is three times higher than the winter value. During autumn and spring, the TML reaches its maximum values. The table shows the concentration of microorganisms in the atmosphere expressed as colony forming unit per cubic metre (CFU/m^3). The highest concentrations of biological particles in the atmosphere surveyed during the year were collected from within the rooms of the two temples, where air turbulence is low. The value of TML is a good predictor of the potential risk of biological colonisation of the surfaces.

	Winter	Spring	Summer	Autumn
Hagar Qim (CFU/m^3)	420	3360	2730	2200
Mnajdra (CFU/m^3)	530	2230	1570	2590

The colonies' survival depends on the microclimatic conditions (T, RH, solar radiation).

Biological patinas and crusts

The investigation carried out during the winter campaign revealed the presence of moss in the numerous cavities of the coralline limestone of Mnajdra otherwise occurs during the other seasons when the availability of the water is poor and the strong solar radiation hinders the biological growth, giving rise to evaporation and dehydrating the substrate.
A generalised and abundant growth was observed when the availability of the water is abundant and not only relatively to the lower plants (mosses, liverwort, ferns etc), but also the superior plants (pellitory, trefoil, grasses etc).
The observed presence of lichens on the stones represents a potential risk first of all of aesthetic impairment and, second of structural damage to the stone.

Structure vibration

No significant vibration on the temples stones was detected during the measurement campaign.

Outside and under the shelters: how the microclimate changes?

Solar radiation
UNSHELTERED
The flux of solar radiation drives some important physical, chemical and biological processes on the stone surface (water condensation and evaporation cycles; growth of biological material, salt crystallisation). The values of global radiation throughout the year are generally high, with some days exceeding 1000 watt per square meter during the summer season and 800 watt per square meter during the winter season. In Malta the mean annual solar radiation falling on a square metre of horizontal surface is 5 kW per day.
SHELTERED
The incoming radiation inside the shelter will be only the indirect or diffuse radiation (UV, visible and IR) reflected by the immediate surroundings, equal to 20% of the global solar radiation. Another 5-10% of radiation (only visible and IR) will be transmitted through the shelter membrane. The radiation under the shelter will also depend on the type of shelter membrane and the shape and size of the perimetral openings. Moreover, the heating of the membrane due to solar radiation (70% reflected; 10% transmitted; 20% transformed to heat) must be taken into account.
RECOMMENDATIONS
Monitoring of the Solar Radiation under the shelters in different seasonal conditions.

Temperature
UNSHELTERED
See open air conditions measured during the CNR monitoring.
SHELTERED
The shelter may cause a variation of temperature in relation to the meteorological conditions.
RECOMMENDATIONS
Continuous monitoring of the temperature under the shelters by cordless sensors

Relative humidity
UNSHELTERED
See open air conditions measured during the CNR monitoring.
SHELTERED
The shelter can cause a variation of relative humidity in relation to the meteorological conditions.
RECOMMENDATIONS
Continuous monitoring of the RH under the shelters by cordless sensors.

Wind
UNSHELTERED
Visual damage assessment has evidenced how wind action concurs to cause stone degradation. In particular, the wind action is responsible for stone erosion, while an abrasion phenomenon is induced by soil dust transported by wind. Occurring synergically with salt crystallisation, it causes the deepening of alveoli in the stones. See open air conditions measured during the CNR monitoring.
SHELTERED
The shelter openings might produce turbulence under the shelter, causing stone erosion and abrasion.
RECCOMENDATIONS
Reduce wind turbulence by means of adjustable windshields to deflect and channel the air masses under the shelter. Monitoring of the wind speed under the shelters in different conditions.

Rainfall and run-off heavy events
UNSHELTERED
See open air conditions measured during the CNR monitoring. The run off is correlated to the intensity of rain and the soil conditions. During the winter very intense rainfalls produce moderate surface runoff processes due to the presence of herbaceous vegetation. This slackens the impact of the raindrops on the ground, and favours infiltration, also thanks to the influence of the roots that increase soil porosity as they develop. Moreover during the summer the water run off is very abundant due to the absence of vegetation on the ground. During the winter the processes of soil erosion produced by the rain prevail, while during the summer the prevailing erosion is produced by the wind.

SHELTERED
The shelters will totally protect the temples from the rainfall, thus halting the growth of vascular plants. The shelter will prevent the washing away of salt from the stones. Finally, a positive consequence of the covering will be to stop water stagnation in the soil inside the temples.
RECOMMENDATIONS
Further pedological and geological investigations around the temples area are suggested. Utilize the meteorological data of heavy rainfall events to test the efficiency of water-spouts. There should also be a rigorous control of water run-off in the area surrounding the shelter. To consolidate the soil around the temples and avoid stagnation, we suggest stimulating the growth of autochthonous vegetation.

Stone surface heating
UNSHELTERED
See open air conditions measured during the CNR monitoring. The process can produce a natural thermoclastism, due to the daily temperature rise and fall.
SHELTERED
Heating and cooling cycles of stone surfaces will be modified: the shelter will provoke a decrease in solar radiation and the frequency and amplitude of the cycles will slow down. The solar radiation reflected by the landscape will involve only the external perimeter of the temples. Therefore, only the peripheral stones will be subjected to thermoclastic phenomena.
RECOMMENDATIONS
Close attention must be paid to the damage on the peripheral stones. Occasional seasonal thermographies of the stones should be scheduled.

Stone wetness
UNSHELTERED
See open air conditions measured during the CNR monitoring. East-facing surfaces are the ones that most frequently present the phenomenon of water condensation.

SHELTERED

The stone wetness will result only from vapour water condensation. The shelter may cause a variation in relative humidity depending on the meteorological conditions and in particular during windy conditions.

RECOMMENDATIONS

It will be necessary to control the relative humidity cycles.
Monitoring of the wetness conditions under the shelters by wetness sensors should be scheduled.

Sea salt deposition

UNSHELTERED

Sea salt deposition on surface material favours salt crystallisation
See open air conditions measured during the CNR monitoring.

SHELTERED

The quantity of sea salt deposited on the stones depends on the atmospheric concentration of marine aerosol and the air turbulence in proximity of the stone surface. Under the shelter the impact of the marine aerosol on the stones will probably be reduced, but the salt deposited will not be removed by the rain action. Sea salt deposition will affect especially those surfaces under the shelter that are exposed to the wind.
The reduced solar radiation will decrease the intensity of the cycles of evaporation and condensation.

RECCOMENDATIONS

Measurements of sea salt deposition on the stone surfaces, particularly on perimetral stones, should be scheduled.

Total suspended particulate

UNSHELTERED

See open air conditions measured during the CNR monitoring.
The water-soluble fraction constitutes the 26% of the TSP. Major ions detected are chloride and sodium, followed by sulphate, calcium and nitrate.
The contribution of sea spray to TSP is estimated to be 28 % in winter and 15 % in spring, due to high wind speed that characterises the winter season.

SHELTERED

The TPS, probably, will be reduced.

RECOMMENDATIONS
Continuous seasonal measurements of aerosol under the shelter are recommended.

Bioaerosol
UNSHELTERED
The bioaerosol measurements give an evaluation of the potential risk of biodeterioration of the stones. See open air conditions measured during the CNR monitoring.
SHELTERED
Low ventilation inside the temples may cause an increase in the concentration of airborne microorganisms. An increase in relative humidity and temperature will favour the growth of microorganisms on the stones.
RECOMMENDATIONS
Continuous monitoring of T, RH and ventilation under the shelters is recommended, and continuous seasonal measurements of biological aerosol should be performed to evaluate the modification of the sheltered environment.

Biological patinas and crusts
UNSHELTERED
The observed presence of lichens on the stones represents a potential risk, first of all, of aesthetic impairment and, second, of structural damage to the stone. See open air conditions measured during the CNR monitoring.
SHELTERED
The planned shelter for the temples is likely to determine variations in microclimatic conditions. The phenomenon observed during the winter campaign could also occur in other months of the year (not only December–February). The shelter will cause a decrease in air temperature and an increase in relative humidity, thus making available a greater quantity of water vapour for the growth of microorganisms. The shelters will totally protect the temples from the rainfall, thus halting the growth of the vascular plants. The type of material utilised for the shelter will transmit only a small fraction of solar radiation, and the UV component will be almost entirely blocked. This will significantly limit the plant growth, especially on the stones.

RECOMMENDATIONS
Continuous monitoring of the RH under the shelters by cordless sensors is recommended. The modified ventilation under the shelter could alter the quantity of deposited biological components, thus reducing stone damage. A census of the lichens on the stones is suggested, since the microclimatic change produced by the shelter could provoke a variation in the species present, causing a modification of the current biological spectrum.

Recommendations

Microclimatological survey

In view of the need to continue the microclimatological survey outside and within the temples, before and after shelter construction, the following recommended actions be suggested.

The microclimatic stations, currently installed at the temples, are ready to accept other sensors, connected with or without cable.

Outside the Mnajdra shelter:

- The present microclimatic station is equipped with: T, RH, global solar radiation, rainfall, pressure, wind speed and direction (5 m height pole); power supply: solar panel; data transmission: to remote PC via GPRS radio signal.
- It is strongly recommended that the current location of the station remain unvaried.
- Also suggested are the acquisition and installation on the station of a radio receiver module for cordless sensor signals.

Inside the Mnajdra shelter:

- Further sensors are required: n.1 sensor of temperature/relative humidity (cordless); n.1 sensor of global solar radiation (needing electric power and cordless transmitter)
- The external microclimatic station manages both sensors.
- It should be noted that other measurements, such as wind speed inside the shelter, could be performed occasionally using mobile equipment.

Outside the Hagar Qim shelter:

- The present microclimatic station is equipped with n.2 poles 5 m height, with sensor of wind speed and direction each: power supply: solar panel; data transmission: to remote PC via GPRS radio signal.
- It is strongly recommended that the current location of the station remain unvaried and that the station be modified as follows: a) remove the wind pole toward Mnajdra temple; b) replace the present 5 m wind pole closed to Hagar Qim temple with a tower 10 m height; c) install the available wind sensors respectively at 5 and 10 meters.
- Also suggested are the acquisition and installation on the station of a radio receiver module for cordless sensor signals.

Inside the Hagar Qim shelter:

- The addition of further sensors is required: n.1 sensor of temperature/relative humidity (cordless); n.1 sensor of global solar radiation (needing electric power and cordless transmitter)
- Both sensors are managed by the outside microclimatic station
- It should be noted that other measurements, such as wind speed inside the shelter, could be performed occasionally using mobile equipment.

Data transmission and data management
As is known, all the measurements performed by the microclimatic stations are transmitted via mobile modem GPRS and automatically received at the remote data centre by a special software.
At the same time it is possible to display all the environmental data at other sites (e.g. Visitor Centre).

The Heritage Malta meteorological station at Hagar Qim
Since the set of measurements carried out at the temples are considered sufficient to ensure a correct microclimatological monitoring and, having achieved a rigorous standard of equipment, it is suggested that the HM station be removed for occasional temporary measurements or for employment at other sites.

CNR Assistance and Advice
At the end of the present Contract, CNR ISAC will be available to give to Heritage Malta the necessary assistance in setting up the final system for microclimatological monitoring.
The assistance will be provided directly and/or through other Companies approved by our Institution.

Water run-off and surrounding soil management

Pedological and geological information.
Further pedological and geological information about the temples area is necessary to plan the management of the landscape and the water run off.

Water run-off around the temples
It will be necessary to plan the collection of the water run off through the circular drains around the temples.

Vegetation
To consolidate the soil around the temples and avoid stagnation, we suggest stimulating the growth of autochthonous vegetation.

Wind impact on and inside the shelters

Windshields
To control the wind impact on the shelters, it will be necessary to install simple adjustable windshields to deflect and channel the air masses moving towards the shelters.

Periodical inspection on monument conditions

Mapping and conservation plan
We suggest the implementation of a mapping and conservation plan to evaluate the stone damage through periodical inspections at the temples:

- Stone damage
- Lichen cover
- Special measurements, such as solar radiation and wind speed under the shelter, bioaerosol sampling, aerosol sampling, sea salt deposition sampling on the stone surfaces and thermographies.
- Efficiency of the monitoring instrumentation

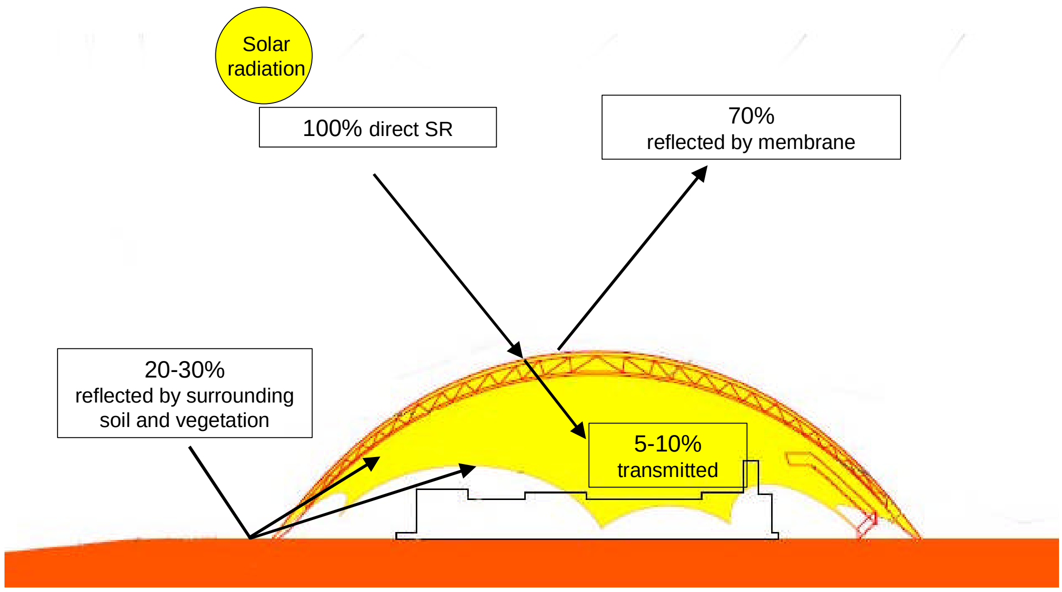
Evaluation of the samples of PVC and PTFE shelter membranes

The analyses on the samples carried out at CNR confirm the data supplied by the manufacturers as reported below.

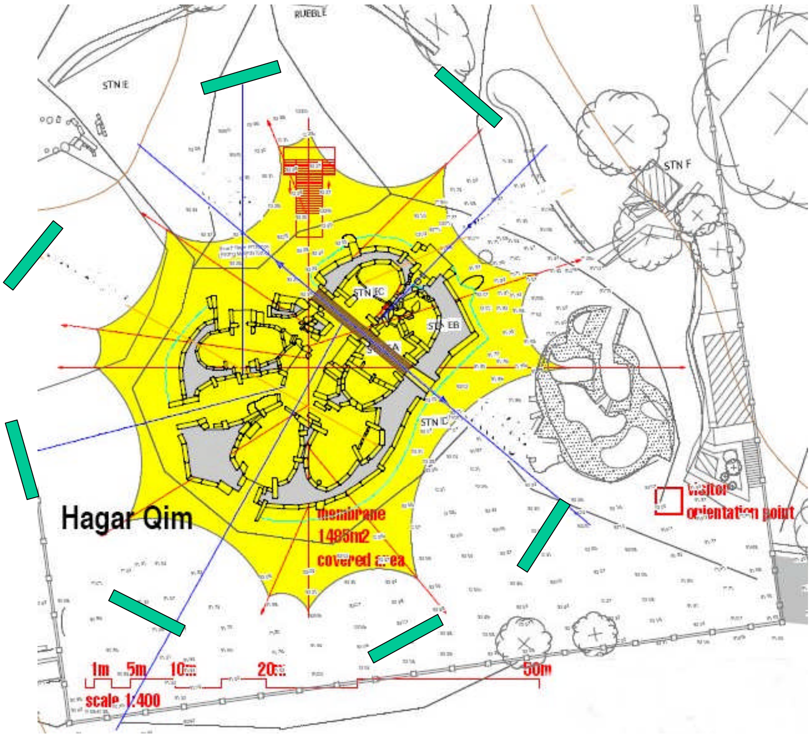
Material	Surface coating	*Light transmission %	*Light reflection %
Verseidag / Canobbio Duraskin B18089	PTFE	12	60
Ferrari Fluotop T2 1302	PVC / PVDF	10	70
Verseidag Duraskin B18059	PTFE	8	60

*At 550 nm

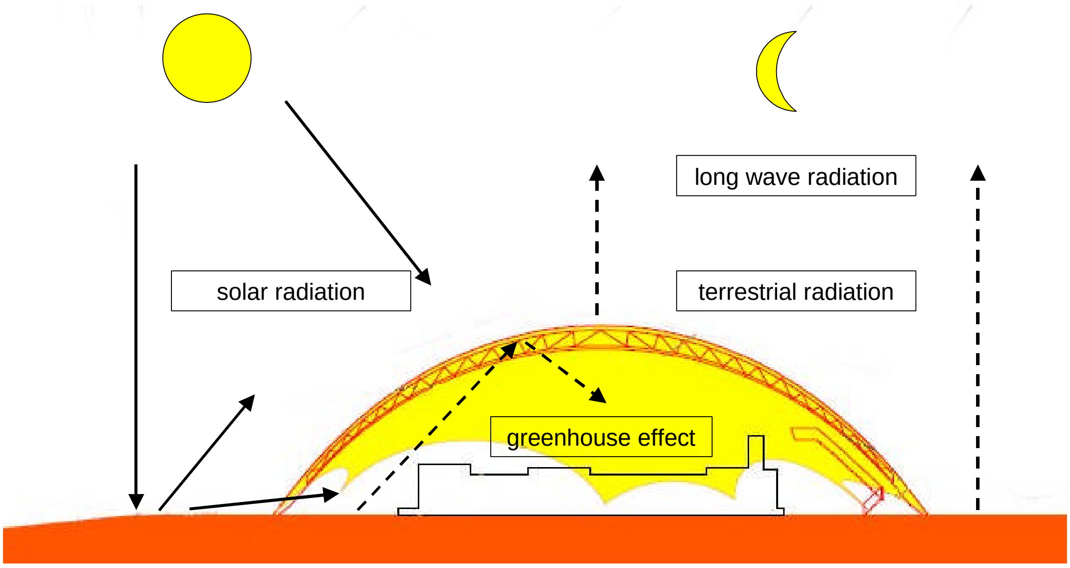
To reduce wind turbulence we suggest designing adjustable windshields to deflect and channel the air masses on and under the shelters.



Solar radiation balance outside and inside the shelter. Please note that only 25-40% of the global solar radiation income under the shelter.



Windshields (green color) located around the shelter. Please note that size, dimension and location are absolutely as an example.



Atmospheric radiation budget. The cooling of the ground and the stones during the night will be strongly reduced by the presence of the shelter.

Contractors involved

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