Effect of Type of Ground Cover on the Ground Cooling Potential for Buildings in Extreme Desert Climate

Farraj F. Al-Ajmai [1], Fahad A. Al-Otaibi [2] and Humoud Melfi Aldaihani [3]

[1] College of Technological Studies (CTS), Public Authority for Applied Educational Training (PAAET), Kuwait. E-Mail: Farraj2010@gmail.com
[2] Associate Professor, Civil Engineering Department, College of Technological Studies (CTS), Public Authority for Applied Educational Training (PAAET); Kuwait. E-Mail: otaibikw@yahoo.com
[3] Part-time Assistant Professor, Civil Engineering Department, College of Technological Studies (CTS), Public Authority for Applied Educational Training (PAAET); and Consultant Engineer, Environmental Affairs Department, Ministry of Public Works, Kuwait.
E-Mail: dr.humoud.aldaihani@gmail.com

ABSTRACT

Developing hybrid cooling techniques to reduce domestic cooling demand is a key objective, but also poses a particular challenge in dry desert climates, such as that of Kuwait. Ground cooling, which is a passive cooling technique, could help meet this objective. In this study, the impact of different soil treatments on underground environment at 2.5m depth was investigated. The three soil treatments in this study were: dry ground (or bare soil) treatment, wet ground treatment and wet shaded treatment with grass ground surfaces in the underground environment. The tests were carried out at the three different locations over an entire year from the beginning of Jan. 2016 to the end of Dec. 2016. The findings revealed that the sub-soil temperature under wet shaded with grass surface is fluctuating less than that under dry ground surface. Sub-soil temperature curve under dry ground surface is showing temporal variations more emphatically than that for wet and wet with grass surfaces. These reductions were expected to be attributed to the variation of the above ground temperature due to vegetation which was carried out for the period from 12 to 26 August for comparison purposes. This comparison showed that vegetation above ground surfaces was found advantageous to reduce summer air temperatures by up to 7 Kelvin (K). To conclude, surfaces under wet and wet with grass ground cover can improve sub-soil cooling potential, creating advantageous soil surface boundary conditions. Furthermore, increase of sub-soil condition performance may be advantageous for sub-soil applications, such as underground buildings or earth cooling pipes, which will be investigated in the next phase in forthcoming research.

KEYWORDS: Ground temperature, Passive cooling, Ground cooling, Sub-soil temperature.

INTRODUCTION

Kuwait is located on the north-western shore of the Arabian Gulf and is bordered by Iraq in the north and west, Saudi Arabia in the south and the Arabian Gulf in the east (Figure 1). It lies between 28° 30′ N and 30° 05′ N latitudes and 46° 33′ E and 48° 30′ E longitudes. Its area is approximately 17,818 km^2, including the mainland and several islands; i.e., Bubiyan, Warba, Failaka and Qubbar (Murakami, 1995; Aldaihani, 2017).

Received on 13/2/2018.
Accepted for Publication on 14/4/2018.

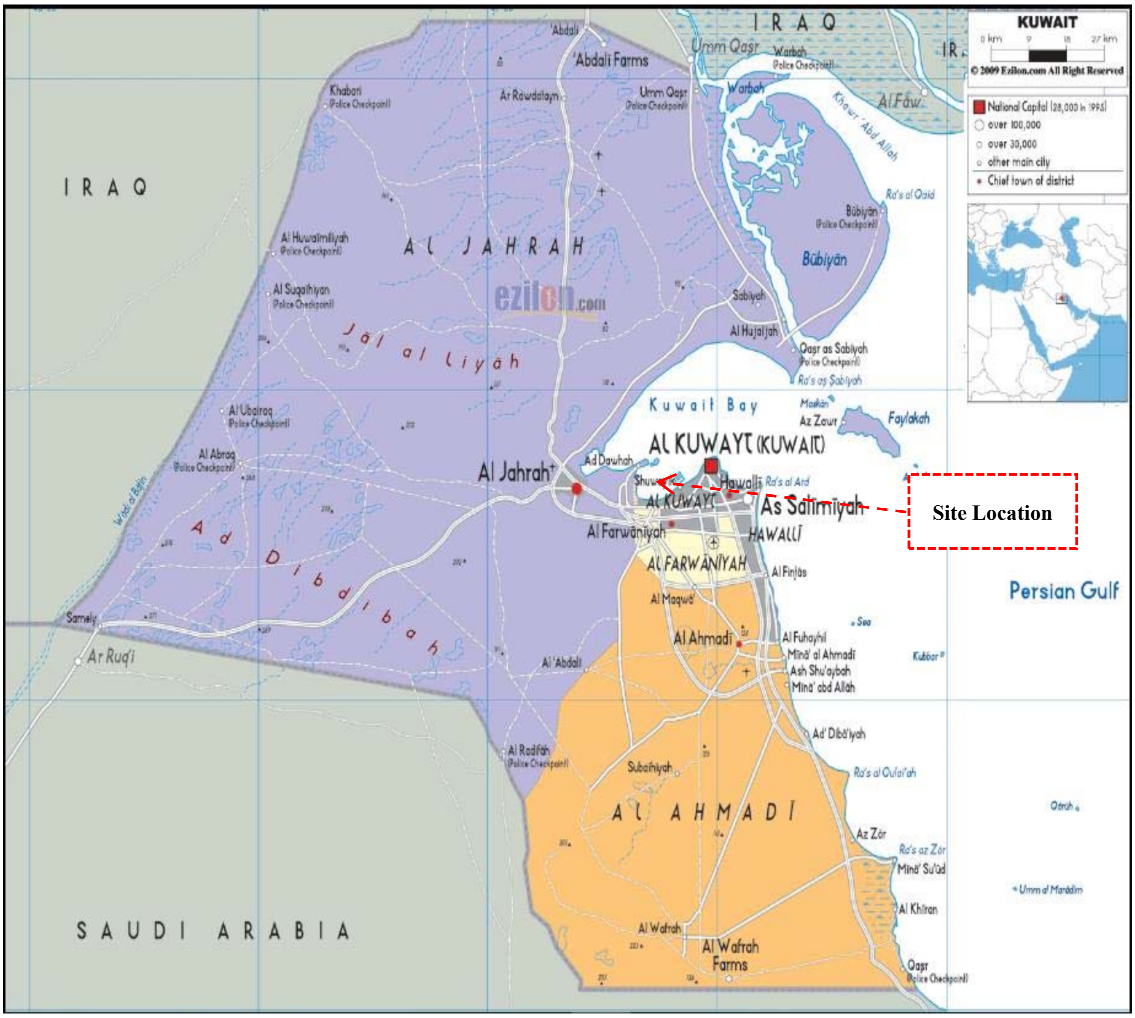

Figure (1): Location map of the study area in western Kuwait (source: Ezilon, 2015)

Because of its location in the northern part of the hot arid desert zone of the Arabian Peninsula, Kuwait is climatically arid and dry. The temperature varies between 3 °C and 15 °C in winter and between 25 °C and 45 °C in summer (Figure 2). Extreme temperatures of 53 °C in summer and -3 °C in winter have been recorded (Al-Kulaib, 1984; Nayfeh, 1990; Aldaihani, 2017). The weather in Kuwait is typical of a dry desert climate, with the highest air temperatures being recorded in July and August with an afternoon average maximum of 45 °C. Summer starts at the beginning of April and continues until the end of October, with a mean air temperature of 37 °C. In addition, the air is generally dry with an average relative humidity ranging from 14% to 42 % in summer and from 42% to 80 % in winter (Al-Ajmi et al., 2017). In winter, the weather is comfortably cool, generally mild, with a monthly mean temperature of 10°C and with occasional minimum recorded temperatures below 5 °C. Precipitation is low and dust storms are common.

The mean annual rainfall is about 105 mm, with most of the rain falling between November and May (Al-Ruwaih, 1995). Winds, which are predominantly from the north-west, are sometimes loaded with dust and followed by thunderstorms and rains in March and April (Figure 3) (Al-Kulaib, 1984).

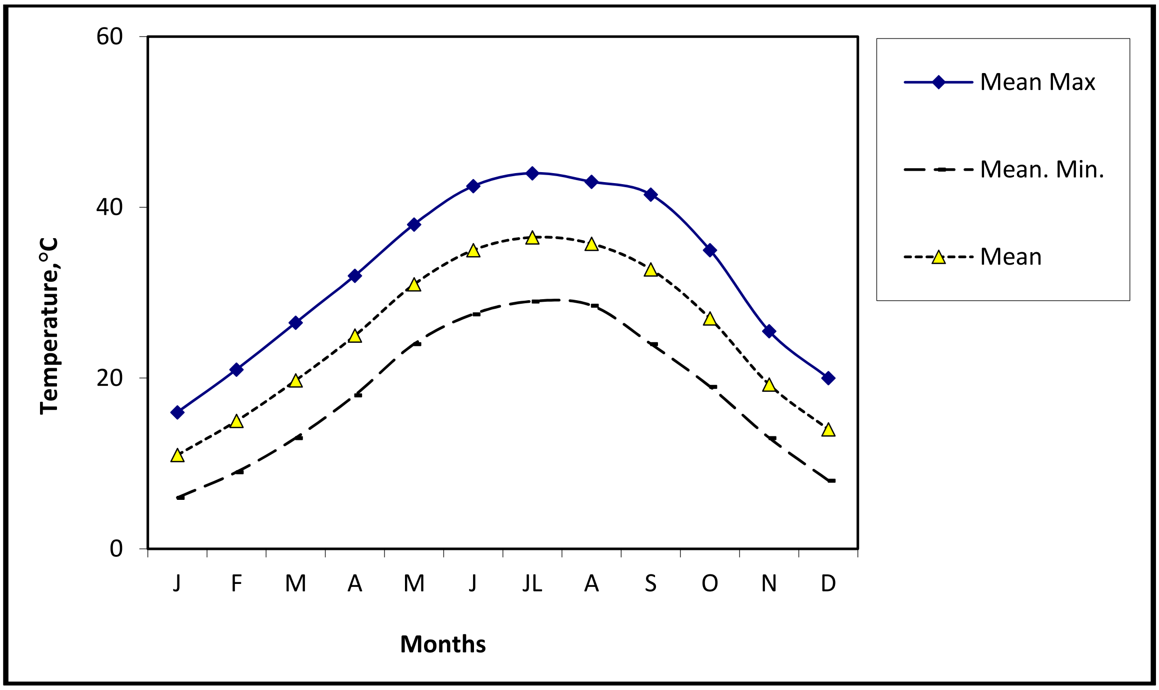

Figure (2): Temperature variations in Kuwait (source: Safar, 1983)

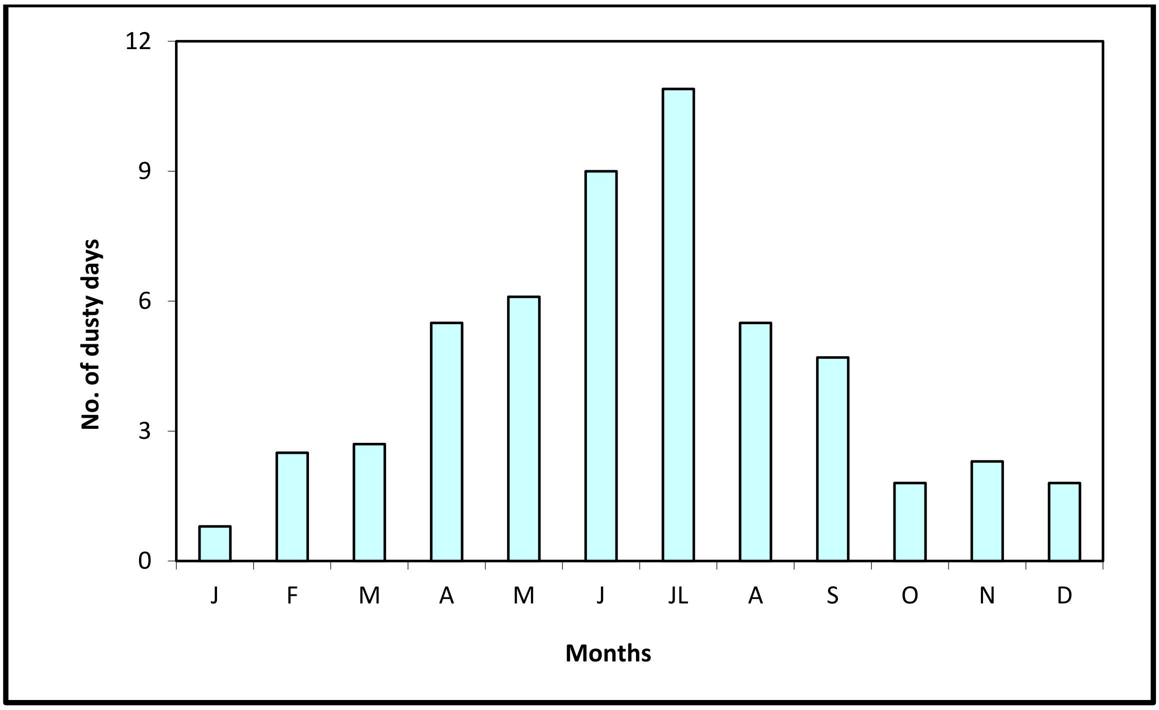

Figure (3): Sandstorm frequency in Kuwait (source: Safar, 1983)

Impact of vegetation on above ground surface can be demonstrated by an experiment conducted by Givoni (1993) in California State, showing that the average surface temperature of the soil covered (and shaded) by grass was lower by about 5 °C as compared with the surface temperature of bare soil. Vegetation surfaces also contribute significantly to a reduction in summer air temperatures and affect the thermal environment of their surrounding areas, thereby decreasing the demand for electrical energy of air-conditioning load during the hot summer season (Givoni, 1993).

An advantageous effect of surrounding buildings on local air temperature is deviating micro-climate around them. Also, the moisture of water on the vegetation surface helps reduce air temperature during summer season due to evaporative cooling.

Furthermore, in the summer season, according to Jacovides et al. (1996), who investigated ground surface temperature of bare soil compared with that of short grass-covered soil, it was found that the mean monthly surface air temperature of short grass-covered soil shows a reduction of 6 ºC compared with the mean monthly surface air temperature of bare soil.

In addition, Kusuda et al. (1983) in Washington, D.C., demonstrated that the average surface temperature of white-painted asphalt was lower in mid-summer by about 7 °C as compared with the average surface temperature of black asphalt.

The study presented herein aims to investigate the impact of different soil treatments on below ground temperatures in Kuwaiti sites. The three soil treatments selected were as follows:

(I) Dry ground surface (i.e., bare soil);

(II) Wet surface;

(III) Wet shaded (with grass) ground surface.

This study is expected to show the importance of using different soil treatments in arid environments.

SITE LOCATION

The study was performed in a location at the College of Technological Studies (CTS) in Shuwaikh area, which is located immediately west of Kuwait city. It lies on the southern shores of Kuwait Bay off the Arabian Gulf. This location, which is shown in Figure 1, is the closest possible one to the industrial areas and is considered one of the busiest areas in Kuwait and expected to represent the highest temperature zones in Kuwait. The long-term testing procedure and supervision required also a close location to the staff.

A depth of 2.5 m below ground was selected for underground temperature measurements, based on the following reasons:

1. As a representative depth for most of basements of buildings in Kuwait.
2. Groundwater table level in Kuwait may be found at depths ranging from 3 to 11m (Al-Ajmi, 2002; Al-Otaibi, 2006).

Therefore, the depth of 2.5 m in this area was above the level of groundwater table, as shown in Figure 4, which represents the adjacent testing pit.

SITE INVESTIGATION AND TESTING METHODS

Information on sub-surface conditions at the selected site was obtained from several reports of working companies in the tested area, shown in Figure 5. Soil exploration consists of determining the profile of natural soil deposits at the site, taking soil samples and determining the engineering properties of soil.

Figure (4): Encountered water table level below 4.5 m depth at the site location

Figure (5): Working companies in the tested area

A. Above-ground Temperature Measurement

For the purpose of comparison, the effects of different surface treatments on air temperature differences for above ground surafces of vegetated and non-vegetated areas at the testing site were measured. This was conducted using "HOBO" data loggers for two weeks. Data was collected during the period from 12 to 26 August, which represents the harshest air temperture values of the year. The device was located at a shaded part in the middle of vegetated and non-vegetated areas at the site. The equipment was monitored continuously and simultaneously during the field work.

B. Below-ground Temperature Measurement

The measurement of sub-soil temperatures at the following soil treatments: dry ground surface (bare), wet ground surface and wet grass-covered ground surface, at CTS area was carried out using modern equipment from Omega with ready-made, insulated, high-accuracy thermocouples. Omega OM-DAQPRO-5300 data loggers with LCD screen displays were also used in this study.

The field work was conducted at the three locations over an entire year from the beginning of January 2016 to the end of December 2016. During the fieldwork at the experimental sites, a backhoe was used to excavate pits to a maximum depth of 2.5 m.

Field measurement preparation was undertaken as follows:

1. The excavation below the ground surface to a maximum depth of 2.5 m was made using a backhole at the studied site (Figure 6).
2. A data logger with several flexible sensor wires was used for measuring and monitoring the sub-soil temperatures, as seen in Figure 7. The sensors were distributed below ground level to the depth of 2.5 m.
3. Several flexible sensor wires were used for measuring and monitoring the sub-soil temperatures.
4. A PVC pipe was placed vertically with its upper end approximately 0.5 m above the ground surface. Sensors were mounted on the long PVC pipe and placed in a hole in the pipe, from which they protruded approximately 15 mm outside (Figure 8). Sensors consisted of PT100 RTDs and type J, K or T temperature thermocouples. All of the sensors were connected to a data logger that could read and record measured data for an entire year (≈8760 hours). Data logger is connected to a laptop computer (PC) capable of downloading the Omega simulation software (Figure 9).
5. The site was protected from public by yellow and black tape.

Figure (6): Excavation below ground surface was made to a maximum depth of 2.5 m using a backhole at the studied sites

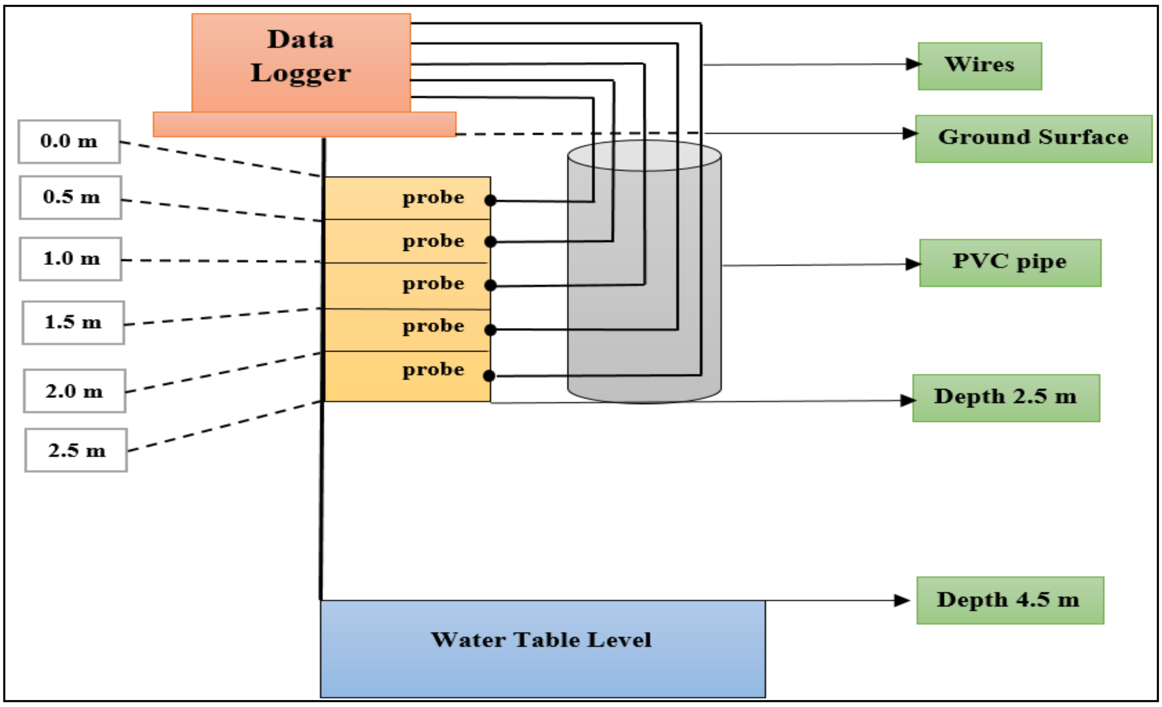

Figure (7): Sketch showing the installation of the probes at the experimental sites

Figure (8): Several flexible sensor wires distributed below ground level to the depth of 2.5 m for measuring and monitoring the sub-soil temperatures

Figure (9): All of the sensors were connected to a data logger that could read and record the measured data for an entire year (≈8760 hours)

RESULTS AND DISCUSSION

The tested location consists of very dense, poorly graded sand with silt and weakly cemented soil layer. The water table level was encountered at 4.5 m, which eased our work in this area.

A. Above-ground Temperature Measurement

The results of the above ground temprature measurment for the period of 12-24 weeks for vegetated and non-vegetated areas located at Shuwaikh (CTS site) are shown in Figure 10. The figure shows repeated cycles for mid-day and mid-night for a maximum temperature of 48 ºC and a minimum temperature of 28ºC, respectively. Results show a maximum air temperature difference of 7 K (Figure 10). This difference may heavily impact micro-climate in general and reduce as a result the energy consumption in the building sector. This, however, may impact indeed ground surafce, as well as underground strata.

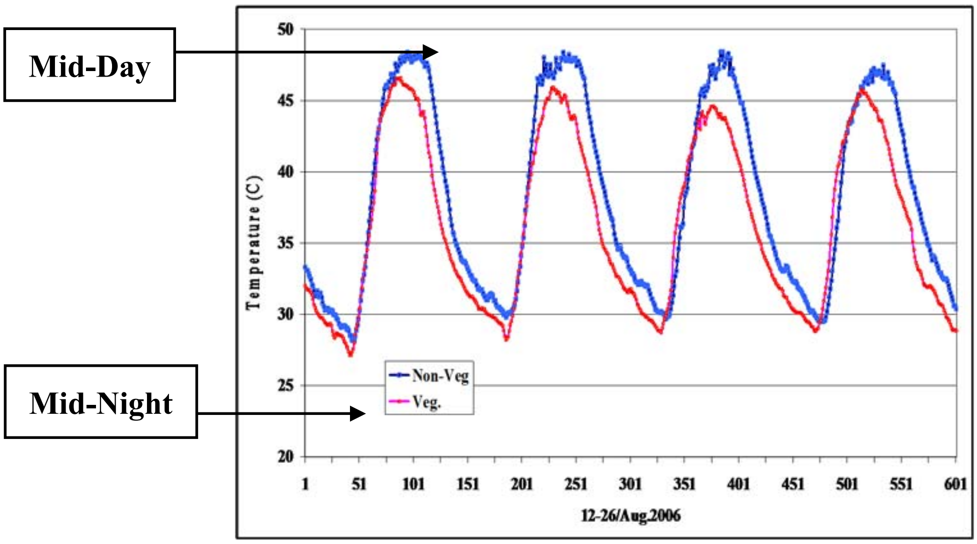

Figure (10): Above-ground temprature measurment difference for the period of 12-24 weeks for vegetated and non-vegetated areas located at Shuwaikh (CTS site)

Based on weather data provided by Kuwait International Airport (2010) and the Kuwait Institute for Scientific Research (2010) as shown in Figure 11, the difference between the monthly average minimum of the above ground temperature measurement (i.e., ambient air temperature) on vegetated area and that on non-vegetated area is about 4ºC in July and August. However, it is clear that grass cover or vegetation has affected the monthly average minimum of the above ground temperature measurement (i.e., ambient air temperature), with a difference of about 4 °C being evident.

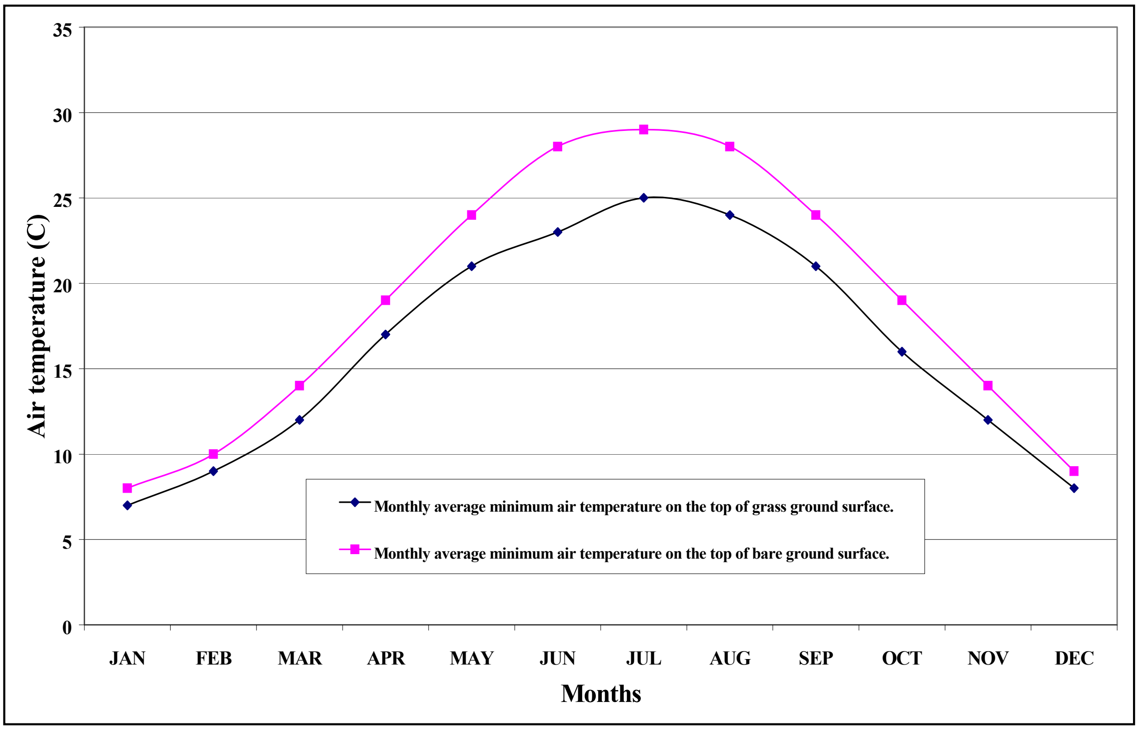

Figure (11): Monthly minimum average ambient air temperature on a bare ground surface and that on a surface covered with short grass (source: Environment Public Authroity (EPA))

B. Below-ground Temperature Measurement

Results for the above ground and below ground treatments: dry ground surface (i.e., bare), wet ground surface and wet shaded with grass ground surface are shown in Figures 12, 13 and 14, respectively. The above ground temperatures in the previous figures represent the readings of dry top soil surface at Shuwaikh area. Also, the subsoil temperatures in the same previous figures represent the field readings at a depth of 2.5 m for the three different treatments.

The results were analyzed and tabulated, as shown in Table 1. The averaged sub-soil temperature below bare, wet and wet with grass cover surfaces is equal to 27.1 ºC, while that for atmospheric outdoor condition is 26.1 ºC.

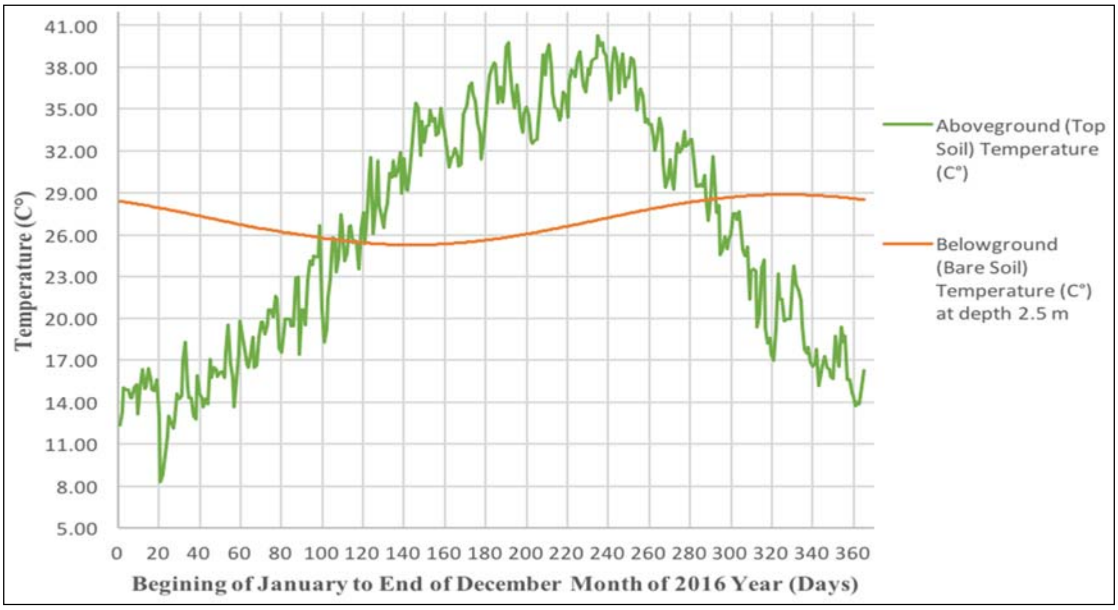

Figure (12): Relationship between above-ground (top soil) and below-ground (bare soil) temperature (°C) measurement at a depth of 2.5 m

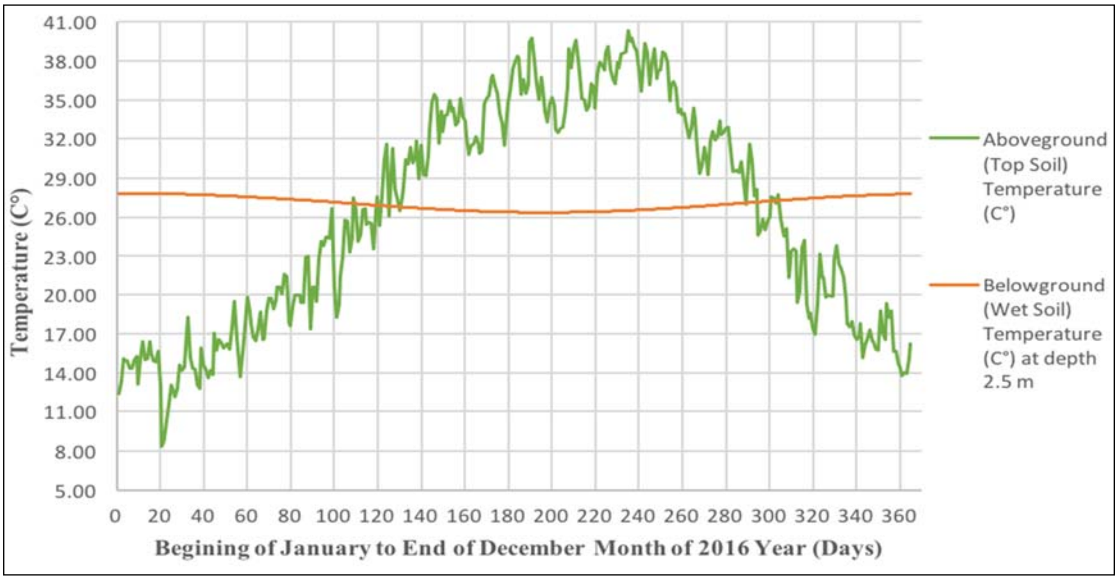

Figure (13): Relationship between above-ground (top soil) and below-ground (wet soil) temperature (°C) measurement at a depth of 2.5 m

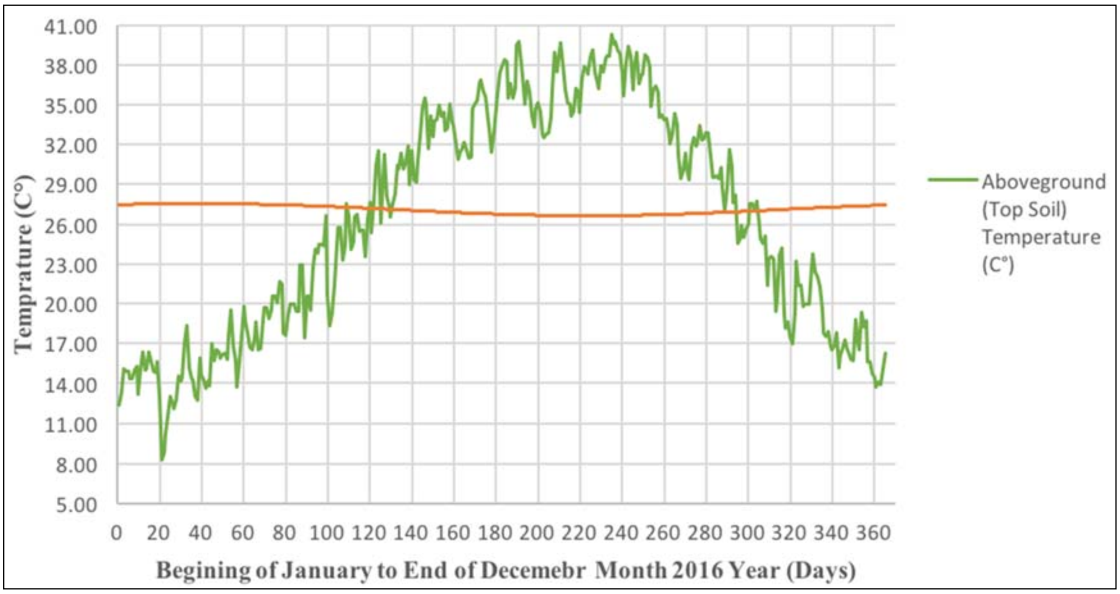

Figure (14): Relationship between above-ground (top soil) and below-ground (wet shaded with grass) temperature (˚C) measurement at a depth 2.5 m

Table 1. Relationship between above-ground (top soil) and below-ground temperature (˚C) measurement at a depth of 2.5 m for bare, wet and wet shaded with grass treatments

Factor Value	Above-ground Temperature Measurement (˚C)	Below-ground Temperature Measurement (˚C) at a Depth of 2.5 m		
		Bare Soil	Wet Soil	Wet Shaded with Grass Soil
Averaged	26.1	27.1	27.1	27.1
Maximum	50.0	28.9	27.8	27.6
Minimum	4.5	25.3	26.4	26.6

Figure 15 shows the reading combination of below-ground temperature measurement in order to determine the effects of the different three treatments (i.e., bare, wet and wet shaded with grass) on the sub-soil temperature.

As shown in Figure 15, the maximum above-ground temperature values for bare, wet and wet shaded with grass cover surfaces are 28.9 ˚C, 27.8 ˚C and 27.6 ˚C, respectively, while that for above-ground temperature condition is 50 °C. The minimum below-ground temperature values for bare, wet and wet shaded with grass surfaces are 25.3 ˚C, 26.4 ˚C and 26.6 ˚C, respectively, while that for atmospheric above-ground temperature is 4.5 ˚C. Sub-soil temperature of bare soil at 2.5 m depth is fluctuating between 25.3˚C and 28.9 ˚C, while those for wet and wet covered with grass surfaces are between 26.4 ˚C and 27.8 ˚C and between 26.6 ˚C and 27.6 ˚C, respectively.

The aforementioned results show that sub-soil temperature under wet shaded with grass cover surface is fluctuating less than that under bare soil, as shown in Figure 15. Also, the sub-soil temperature curve under a bare soil ground surface is showing temporal variation more emphatically than that for wet and wet shaded with grass cover surfaces.

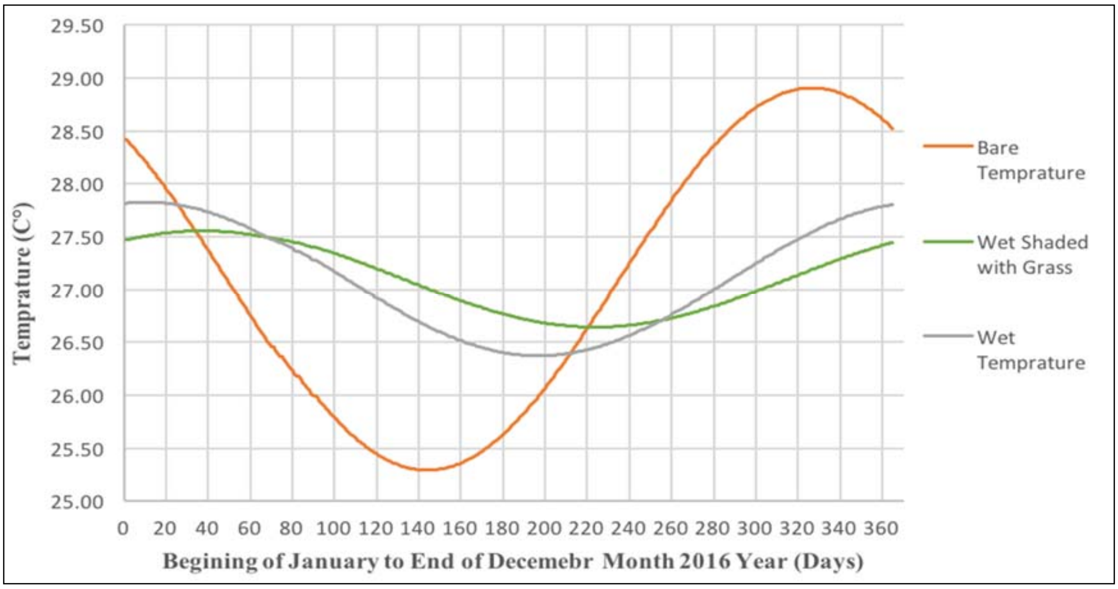

Figure (15): Relationship between bare, wet and wet shaded with grass soil treatment temperatures (°C) at a depth of 2.5 m

CONCLUSION

The purpose of this work was to investigate the effect of different soil treatments on underground environment at 2.5 m depth. The tests were carried out at the three different studied locations over an entire year from the beginning of Jan. 2016 to the end of Dec. 2016. The findings revealed that the sub-soil temperature under wet shaded with grass cover surface is fluctuating less than that under dry ground surface. In other words, ground surface under wet and wet shaded with grass cover can improve sub-soil cooling potential. This observation could be helpful for the improvement of sub-soil temperature by creating advantageous soil surface boundary conditions. Increase of sub-soil condition performance can be advantageous for sub-soil applications, such as earth cooling pipes, which will be investigated in the next phase in forthcoming research.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support provided by Kuwait Foundation for Advancement of Sciences (KFAS).

REFERENCES

Abrams, D.W. (1985). "Low-energy cooling guide to the practical applications of passive cooling and cooling energy conservation measures". 1st Edn., Van Nostrand Reinhold Company, New York.

Al-Ajmi, F.F., Al-Otaibi, F.A., Al-Shemmari, A., and Aldaihani, H.M.Z. (2017). "The potential for ground-source cooling of buildings in the state of Kuwait: investigation of sub-soil environment and properties". Journal of Engineering Technology (JET), 4 (3), 59-65.

Al-Ajmi, F., Hanby, V.I., and Loveday, D.L. (2002). "Thermal performance of sub-soil environment in a dry desert climate". Proceedings of the 2002 International Conference on Transactions-American Society of Heating, Refrigerating and Air Conditioning (ASHRAE), January, 108, 1-11.

Aldaihani, H. M. Z. (2017). "A geotechnical, geochemical and human health risk assessment of a dry oil lake site in Kuwait". Doctoral Thesis, University of Portsmouth, Portsmouth, UK. Retrieved from: https://researchportal.port.ac.uk/portal/files/7004522/Final_Submission_of_my_PhD_Thesis.pdf

Al-Kulaib, A. A. (1984). "The climate of Kuwait". Directorate General of Civil Aviation (DGA), Meteorological Department, 178.

Al-Otaibi, F.A. (2006). "An assessment of the possibility of stabilization of Sabkha soils using oil lake residue-reuse of waste materials". Doctoral Thesis, Cardiff University, Wales, UK. Retrieved from: https://orca.cf.ac.uk/56046/1/U584799.pdf

Al-Ruwaih, F.M. (1995). "Hydrogeochemical variation of carbonate aquifer Al-Sulaibiya (south) Kuwait". Journal of Water, Air and Soil Pollution, 90, 489-505.

Environment Public Authroity (EPA). (2012). "Kuwait's initial national communications under the United Nations framework convention on climate change (report, Kuwait)." Retrieved from: http://cdn.waleedzubari.com/reports/kwtnc1.pdf

Ezilon. (2015). "Kuwait map-political map of Kuwait". Retrieved from: http://www.ezilon.com/maps/asia/kuwait-maps.html

Givoni, B. (1994). "Passive and low-energy cooling of buildings". 1st Edn., Van Nostrand Reinhold Company, New York.

Jacovides, C.P.G., Mihalakakou, M., Santamouris, and Lewis, J.O. (1996). "On-ground temperature profile for passive cooling applications in buildings". Solar Energy, 57 (3), 167-175.

Kusuda, T.O., and Bean, W. (1983). "Annual variation of temperature field and heat transfer under heated ground surface, slab on grade floor heat loss calculation". Building Science Services 156, Gaithersburg, MD: National Bureau of Standards.

Labs, K., and Harrington, K. (1982). "A comparison of ground and above-ground climates for identifying appropriate cooling strategies". Passive Solar Journal, 1 (1), 4-11.

Murakami, M. (1995). "Managing water for peace in the Middle East: alternative strategies". Retrieved from: https://books.google.co.uk/books?id=xVGo3B-82GMC&pg=P A138&lpg=P A138&dq=%22Kuwait+is+located+at+ the + north-western + corner+of+the+Arabian+Gulf%22&source=bl&ots=gt_H4A3FYe&sig=9e N- YbIXxH1oPX6XnlPNPqqkoR0&hl= en&sa=X&ved = 0ahUKEwjG5LDIoZPMAhUHVhQKHcNuDVcQ6AEILTAC#v=onepage&q=%22Kuwait%20is%20located%20at%20the%20north-western% 20corner%20of%20the%20Arabian%20Gulf%22&f=false

Nayfeh, A. J. A. M. (1990). "Geotechnical characteristics of dune sand of Kuwait". Unpublished Master Dissertation. University of Kuwait, Kuwait.

Safar, M.I. (1980). "Frequency of dust in day-time summer in Kuwait." Meteorological Department, Directorate General of Civil Aviation, Climatological Section, State of Kuwait, 107.