Available online at www.sciencedirect.com
ScienceDirect
Solar Energy 81 (2007) 316–328
SOLAR ENERGY
www.elsevier.com/locate/solener

Cooled soil as a cooling source for buildings

Baruch Givoni [*]

UCLA, Los Angeles, CA, USA
BGU, Beer Sheva, Israel

Received 20 March 2006; received in revised form 14 June 2006; accepted 3 July 2006
Available online 1 September 2006

Communicated by: Associate Editor Matheos Santamouris

Abstract

Two approaches have been tested by the author for cooling soil in a given location to temperatures well below the “normal” temperatures in that location. The first approach has been tested in Sde Boqer Campus, in the Israeli Negev desert. The soil was covered with a layer of pebbles, about 10 cm. thick, and watered in the mornings. Substantial cooling of the soil was achieved. This cooling system was tested in test cells in Sde Boqer, Israel, and in a full scale room in Riyadh, Saudi Arabia, and has provided effective cooling. The second approach was tested at A&M University in Tallahassee, Florida. Temperature measurements were taken of moist soil under a wooden shack on stilts raised about 60 cm above the ground. Thus the soil under it was permanently shaded. The cooled soil temperatures were below the outdoors’ minimum temperatures, even during the peak of the summer, providing a potential heat sink for cooling buildings. The thermal performance of an earth covered building in the Negev arid region of Israel is also summarized.

Keywords: Passive cooling; Soil cooling, Soil covered buildings

1. Introduction

In hot regions, where cooling is of interest, the “natural” temperature of the soil in summer is usually too high for serving as a cooling source. However, it is possible by very simple means to lower the soil temperature well below the “natural” temperature characteristics of a given location. In order to cool the soil it is necessary to eliminate or minimize the heating of the soil by the sun, by shading, while enabling cooling by evaporation from the earth surface.

The annual pattern of the soil surface temperature has a wave pattern which is determined by the interplay of the following factors: heating by solar radiation absorbed at the surface, cooling by longwave radiation to the sky, convective exchange between the soil and the ambient air, evaporative heat loss, and heat flow between the surface and the deeper layers of the soil. The surface temperature, in turn, determines the temperature of the deeper layers. Any man-made modification of one of these factors (treatment) can change the surface temperature and consequently the temperature of the layers near the surface.

In regions with very cold winters, where the natural summertime soil temperature at a depth of 2–3 m is about or below 22 °C, the soil can serve as a heat sink for buildings through the use of heat exchangers. In hot regions, on the other hand, the temperature of the near surface soil in summer is too high for such application. The two “strategies” described in this paper demonstrate that it is possible, by simple means, to lower significantly the soil surface temperature and consequently of a layer at depth of 0.5–1 m. Such cooled soil can serve, in different ways, as a cooling source for buildings.

The two “strategies” are:

(a) Covering the soil with a layer of gravel of about 12 cm and keeping the soil moist.

---

[*] Address: 6 Shlonsky Street, Neot Afeca, 69410 Tel Aviv, Israel. Tel.: +972 3 645 1371.
E-mail address: bgivoni@ucla.edu

0038-092X/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.solener.2006.07.004

(b) Keeping moist soil constantly shaded, for instance by a building raised off the ground.

2. Strategy 1: covering the soil with Gravel and keeping it moist

Cooling the soil by covering it with a layer of gravel and keeping it moist was tested at the Sde Boqer campus of the Ben Gurion University of the Negev desert region in Israel. The pebbles have blocked solar radiation during the daytime while evaporation from the soil, kept moist by irrigation, could continue day and night, as long as the vapor pressure at the soil surface is higher than the ambient vapor pressure. This system of soil cooling was tested in two series. First it was applied in a small area of 2×2 m. Soil temperatures were measured in the treated soil and in the nearby untreated soil in depths of 10, 30, and 60 cm below the surface. The measurements lasted for about 6 weeks in the summer. In the second series an area of 5×5 m was covered by the pebbles and soil temperatures were measured, in the treated and in the untreated soil, in depths of 0.05, 1, 2 and 3 m, for a whole year.

By covering the soil with a layer of gravel and keeping the soil moist, naturally or by irrigation, solar radiation in intercepted at the top layer of the gravel while evaporation from the soil surface can continue. In this way the balance of the different factors affecting the soil surface temperatures is changed and the surface is maintained at a temperature lower than the ambient daytime temperature. The gravel layer then provides shading from the sun and thermal resistance to the convective heat flow from the warmer air to the cooler soil. The gravel also provides vapor flow resistance and thus lowers the rate of evaporation from the soil (and lowers the use of water for irrigating the soil). The rate of evaporation is also greatly reduced due to the lower temperature of the soil under the gravel, as compared with evaporation from exposed soil, see Fig. 1.

2.1. Short-term measurements at BGU

Preliminary experiments were conducted in the summer of 1979 by Austi Brown, my UCLA Graduate Student, at the Institute for Desert Research of Ben Gurion University, Sde Boqer Campus. In this study a test plot of 2.5 by 3 m was covered by a gravel layer of 12 cm and kept moist by irrigation, as in this desert area the natural soil is very dry in summer. Soil temperature measurements were measured at the nearby untreated soil and at the treated soil, at 10, 30 and 60 cm below the surface. At the treated plot temperature was measured also at the interface between the soil and the gravel.

Fig. 2 (Givoni, 1998) shows hourly temperature plots of the ambient air temperature (DBT) and the treated and untreated soil temperatures at the different depth levels, when the treated plot was irrigated very early in the morning, in order to utilize the radiant cooling of the top layer of the gravel during the night hours.

With DBT maximum of 34 °C, the untreated soil maximum at a depth of 10 cm was 38 °C and at 60 cm it was 28 °C.

Under the gravel the maximum at the surface was about 23 °C, and at all the layers below the surface the maximum was about 22 °C. Such treatment can be implemented by automatic sprinkling of the gravel at about sunrise (5 am in summer), when the radiant heat loss to the sky could have its full effect, but in practice, during most of this experimental period, the soil was slightly watered at the start of workday, about 8–9 am.

Fig. 3 shows daily maximum, average and minimum DBT, and average temperatures at depths of 10 and 60 cm of the treated soil, during a two weeks' period. The soil temperature was about 24 °C, about 1 K below the average DBT. During the same period the average temperature of the untreated soil at a depth of 60 cm was about 28 °C, about 3 K above the average DBT.

From the data presented in Fig. 2 it can be assumed that with automatic optimized irrigation before sunrise the soil

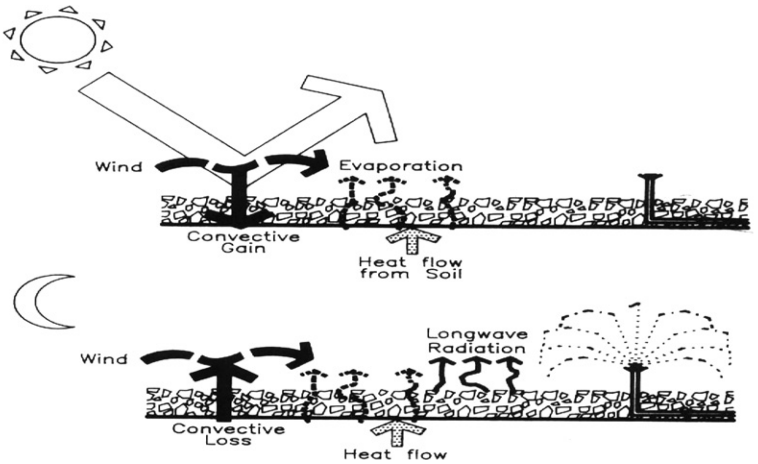

Fig. 1. A layer of gravel blocks solar radiation away from the soil surface and reduces convective exchange.