Cooled soil as a cooling source for buildings

B. Givoni
UCLA, Los Angeles, CA, USA and BGU, Beer Sheva, Israel

ABSTRACT

Two approaches have been tested 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.

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, about 60 cm above the ground. Thus the soil under it was permanently shaded.

In Sde Boqer the pebbles have blocked solar radiation during the daytime while evaporation from the soil, kept moist in the desert by irrigation, could continue day and night. This system of soil cooling was tested in two series. First it was applied in a small area of 2x2 m. Soil temperatures were measured in the treated soil and in the nearby un-treated 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 5x5 m. was covered by the pebbles and soil temperatures were measured, in the treated and in the un-treated soil, in depths of 0.05, 1, 2 and 3 m. for a whole year.

This system for cooling a building was tested by my former student, Dr. Nasser Al Hemiddi, in Riyadh (Al Hemiddi, 1995). A concrete roof of a room was covered by soil and then by a layer of pebbles, and the soil was watered. One day's indoor temperature of the cooled roof, and of a "control" room without cooling, is shown in figure 1.

In Tallahassee the second approach to soil cooling was tested. At the A&M University Campus there was a wooden shack on stilts, about 60 cm above the ground. Thus the soil under it was permanently shaded. As the summer is the rainy season in Florida the soil was naturally moist. Temperatures were measured at depths of 5, 50 and 100 cm throughout the summer in the soil under the shack. The cooled soil temperatures were below the outdoors' minimum temperatures, even during the peak of the summer, providing a heat sink for cooling buildings.

1. INTRODUCTION

The annual pattern of the soil surface temperature has a wave pattern which is determined by the interplay of the following factors: solar radiation absorbed at the surface, longwave radiation floe to the sky, convective exchange with 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 layers at a depth of 2-3 meters. 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 meters is about or below 22 oC, the soil can serve s 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 is too high for such application. The two "treatments" 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 meters. Such cooled soil can serve, in different ways, as a cooling source for buildings.

The two "treatments" are:

a) Covering the soil with a layer of gravel of about 12 cm. and keeping the soil moist.
b) Keeping the moist soil constantly shaded by a building raised off the ground.

2. COVERING THE SOIL BY GRAVEL

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 thermal resistance to convective heat flow from the warmer air to the cooler soil. The gravel layer thus serves both as a shade and as partial insulation for the soil.

Preliminary experiments were conducted in the summer of 1979 by Austi Brown, my UCLA Greduate 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 meters 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.

Figure 1 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 late at night in order to utilize the radiant cooling of the top layer of the gravel.

With DBT maximum of 34 oC, the untreated soil maximum at a depth of 10 cm was 38 oC and at 60 cm it was 28 oC. Under the gravel the maximum at the surface was about 23 oC, and at all the layers below the surface the maximum was about 22 oC. The effect of such treatment

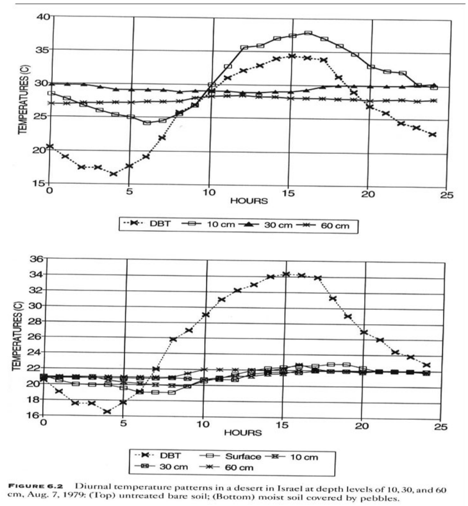

Figure 1: DBT and soil temperatures of the treated (bottom) and untreated (top) soil at 10, 30 and 60 cm depth levels. The treated plot was irrigated very late at night.

can be maximized by automatic sprinkling of the gravel at about sunrise (5 a.m. in summer), when the radiant heat loss to the sky could have its full effect, but in practice the soil was slightly watered at the start of work, about 8 a.m.

Figure 2 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 oC, about 1 oK below

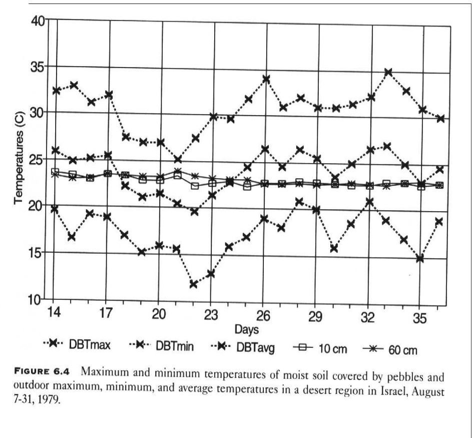

Figure 2: Daily maximum, average and minimum DBT, and the average temperatures at 10 and 60 cm of the treated soil, during a two weeks' period.

the average DBT. During the same period the average temperature of the un-treated soil at a depth of 60 cm was about 28 oC, about 3 oK above the average DBT.

It can be assumed that with automatic optimized irrigation before sunrise the soil temperature would be lower.

A second, long term study testing this soil cooling system was done by Ellis Hayeem, my technician, who later submitted the data as a M.Sc. Thesis at Trinity University in San Antonio, Texas. He measured treated and untreated soil temperatures during a whole year. The plot was circular with a diameter of 6 meters. The plot covered by gravel was irrigated during the summer of 1982. During the winter the plots are watered only by the scarce rains. Hayeem took measurements of the soil temperature at depths of 5cm, 1m, 2m and 3 meters (Hayeem, 1984).

Figure 3 shows the annual temperature patterns of the untreated soil (top) and the treated soil (bottom). The time unit is 2 weeks.

During mid-summer the near surface temperature of the untreated soil was about31.5 oC while under the gravel it was about23 oC. The maximum temperatures at the different depth levels of the treated soil were about the same, with a time lag of about 3 weeks per meter depth

On the other hand, in winter the gravel cover had very little effect on the minimum temperatures. It seems that with the negative

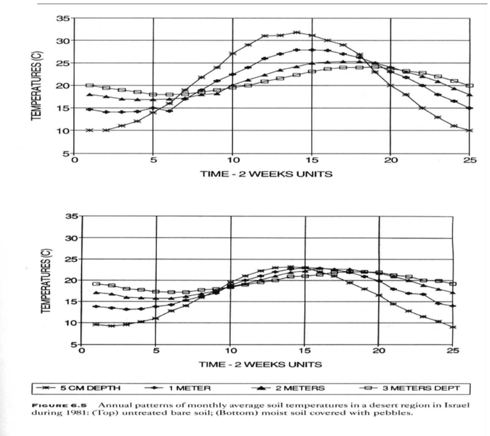

Figure 3: Annual temperature patterns of the untreated soil (top) and the treated soil (bottom). The time unit is 2 weeks.

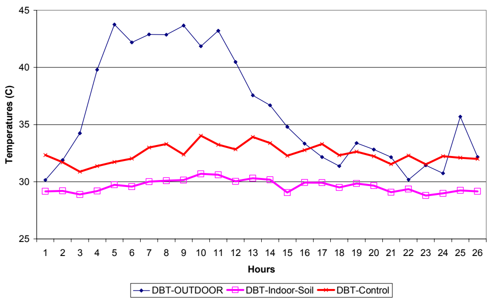

Figure 4: A room with cooled soil and un-cooled room in Riyadh.

radiant balance in winter prevailing in winter (longwave radiant heat loss exceeding the solar gain); the gravel reduced both the solar gain and the longwave loss to a similar effect.

2.1 Application of Gravel cooled Soil in Riyadh

My Ph.D. student, at UCLA, had done his experimental research at his home University in Riyadh, Saudi Arabia. He got a 5 room's full size single story building with an un-insulated concrete roof. One room has served as his office and was air-conditioned. One room has served as a control, without any treatment. The remaining three rooms were cooled by different passive systems that I have developed. One cooling system has used the cooled soil with gravel cover.

Figure 4 shows temperature patterns of the DBT and the cooled and control rooms during one "moderate" day in August.

With outdoor maximum of about 44 oC the indoor maximum was about 31 oC (13 oK below outdoors). The cooling system has lowered the indoor temperature by about 3 oK below the maximum of the control room. On extreme days, with maximum of about 47 oC, the reduction below the control was up to 5-6 oK.

2.2 Watering Strategies

In arid regions the objective would be to maximize energy extraction from the soil by the evaporation process while minimizing water consumption. Any evaporation from the gravel does not contribute directly to the lowering of the soil temperature. Thus, the most effective watering strategy would be to apply the water directly to the near-surface layer of the soil, bypassing the gravel layer. It could be accomplished by a dense network of "drip irrigation" water pipes between the soil and the gravel.

3. MOIST SOIL UNDR A RAISED BUILDING

In Tallahassee the second approach to soil cooling was tested. At the A&M University Campus there was a wooden shack on stilts, about 60 cm above the ground. Thus the soil under it was permanently shaded. As the summer is the rainy season in Florida the soil was naturally moist. Temperatures were measured at depths of 5, 50 and 100 cm throughout the summer in the soil under the shack.

Figure 5 shows the temperatures at the three levels of the cooled soil under the shack that was raised above the ground, in Tallahassee, Florida. Even the soil at 5 cm below the surface was near the outdoors' minimum temperature. This pattern was consistent throughout the summer.

It is of interest to note that whenever a rain started the shaded soil temperature under the shack rose abruptly. Figure 6 shows the outdoor air and soil temperatures on a day with rain starting after 12 noon.

Note in figure 6 the sudden rise of the soil's temperature after the start of the rain. This rise resulted apparently from the flow of warmer water, flowing from the warmer, un-shaded, soil to the permanently shaded soil under the shack. It can be assumed that preventing the flow of the rain water into the area of the cooled soil would further lower its temperature.

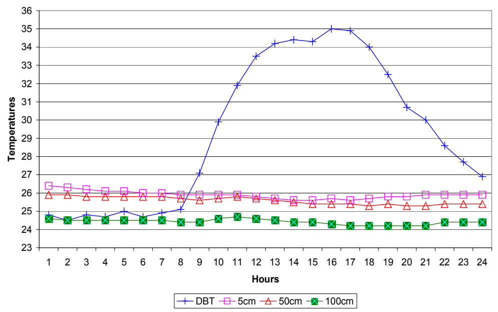

Figure 5: Cooled soil under a shack, raised above the ground, in Tallahassee, Florida.

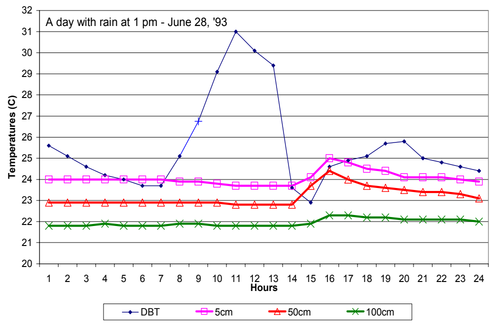

Figure 6: Outdoor air and soil temperatures on a day with rain after 12 noon.

The pattern of cooled soil temperatures near the outdoors minimum temperature was consisted throughout the whole summer.

Figure 7 shows the cooled soil's temperatures at depths of 5, 50 and 100 cm, over the background of the outdoor air's maximum, average and minimum, during the whole summer period, from June 1st to August 7th, with some missing days due to data logger's problems.

It can be seen in figure 7 that even during the peak of the summer the cooled soil's temperatures had followed the outdoors' minimum temperature, and at depth of 1 meter was actually a little below the outdoors' minimum. It can be assumed that preventing the flow of the rain water into the cooled soil would further lower its temperature.

4. ARCHITECTURAL OPTIONS FOR USING THE COOLED SOIL

The ways in which the cooled soil can be utilized as a cooling source for buildings

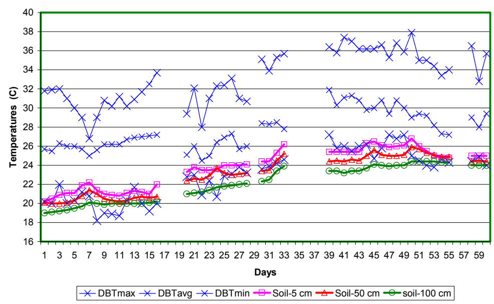

Figure 7: Outdoors' and cooled soil's temperatures at depths of 5, 50 and 100 cm, during the whole summer period.

depends in part on the relationship between the building and the cooled soil – whether they are coupled thermally or are "separated". This relationship depends in part on the climate, mainly on the severity of the winters. In regions with cold winter the building has to be insulated. Consequently, it can not be thermally coupled with the soil. In such cases the coupling between the cooled soil and the building has to utilize "active" heat transfer systems, using fans (with air tubes in the soil) or pumps (with water pipes in the soil).

4.1 Earth Covered Roofs and Buildings

The system of soil cooled by a gravel layer can be applied in several ways. In the case of a single story building, or the top story of multiple story buildings, with a flat roof structurally capable to support the load of the soil and gravel, the application of this cooling system is directly over the roof.

It should be noted that the cooled soil should be in direct thermal contact with the roof, without any insulation layer in between. It means that this system is applicable only in regions with mild winters with very scarce rains, and/or when the rainy season is in summer

In the case of single story buildings also the walls can be bermed by soil covered by a gravel layer. Figures 8 and 9 show front and back views, respectively, of a domed building I have designed at the Sde Boqer Campus of Ben Gurion University in Israel. The front (South) wall is mostly glazed, for passive solar heating in winter, with overhang and shutters providing shade in summer. The walls are completely covered by the soil with the windows projecting

Figure 8: Earth Covered Building in Sde Boqer, Israel. South View.

Figure 9: Earth Covered Building in Sde Boqer, Israel. North View.

through the soil.

Because of budget cut the gravel layer was not applied over the soil. Still the building provides reasonably comfortable conditions year round.

4.2 Soil Under Buildings Raised Off the Ground

In this case there is no direct thermal contact between the cooled soil and the building. The cooled soil can be used only with the applications of air or water heat exchangers. When air tubes are embedded in the cooled soil they serve as the heat exchangers. Either indoor or outdoor air can be circulated in the pipes and introduced in the building.

When water pipes are embedded in the soil the water have to circulate in water to air heat exchangers within the indoor space.

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