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ORIGINAL ARTICLE

Cooling and Warming Effects of a Grass Covered Area and Adjacent Asphalt Area in a Hot Day

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ABSTRACT

Knowledge of the warming or cooling effects induced by asphalt or grass covered areas, may improve our understanding of how thermal stress or thermal comfort is created for workers who have to work outdoors for long hours in warm seasons. For this purpose a field measurements were carried out to know the cooling and warming effects of two adjacent areas, one covered with grass and the other with asphalt. These two adjacent coverages were located in an open area, in Zanjan, a city in the north west of Iran. A calm and sunny day in June was selected to perform measurements. The temperature and relative humidity, on the grass and asphalt surfaces and also at a heights of 1.2 m above them were measured at 2 hours interval from 6 a.m. to 12 p.m. Results showed that in the measurement day, the grass surface temperature was less than asphalt surface temperature in the afternoon and in the before noon there was no significant difference between temperatures. Whereas, the temperature measurements at the height of 1.2 m above asphalt and grass, showed that the air temperature above grass was less than the air above asphalt during the measurements period, but in the afternoon, the difference between these temperatures was less than that of before noon. Both grass and asphalt surfaces, showed the cooling and warming effects, which are impressed on the air above them, due to thermal convection.

Keywords: *Cooling effect, Warming effect, Grass, Asphalt, Temperature*

INTRODUCTION

Today, climate in many cities have lost its natural characteristics. Temperatures in urban areas, due to the rapid growth of urbanization have increased heat generation by vehicles and buildings. Creating urban heat island, especially in the hot days of the year, is one of the most important issues in microclimatology and is the most important interest in the urban climate research [1]. This phenomenon is related to the temperature difference between urban and rural areas. Researchers have indicated that cities are warmer than their surroundings, and in this regard, researchers have been looking for solutions to reduce urban temperatures.

One of these solutions is to build green areas that have main role in the improving the anthropogenic created in modern cities. Green areas in towns and cities reduce the temperature somewhat. This process is called cold island phenomenon that create cooler and wetter air over green areas [2]. In addition, in many large cities, especially in the summer, the more electricity demand for air conditioning caused the more fuel consumption for power plants; consequently, increase of temperature within and around these cities is inevitable. One of the

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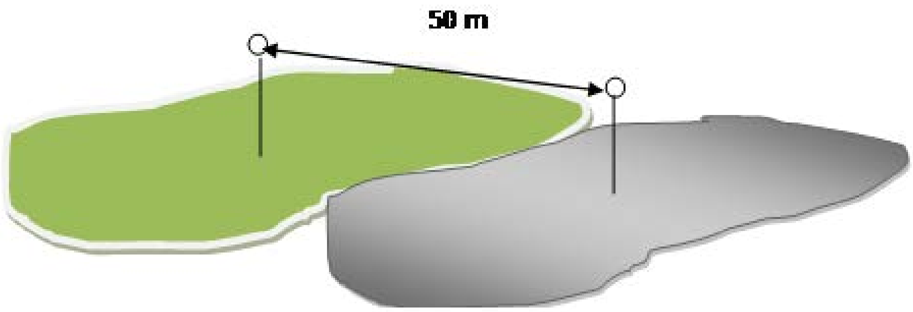

Fig 1. Configuration of 2 measurement points at adjacent grass and asphalt areas

main solutions to stop this vicious cycle is to cool the environment by green areas [3].

In recent four decades, studies have been done on the cooling or warming phenomenon of green areas, e.g. Hamada and Mikami found that the difference between the temperature of the grassy areas and their surrounding areas during the day is less than night. In the grassy places, during the day, the grass surface temperature increases due to direct sunlight, whereas, during the night, due to the loss of heat energy by the grass surface, the surface becomes cold [4]. The kind of vegetation covers (grass or trees) are important on the air temperature, e.g. the grass covered areas, are cooler than tree covered areas only in the early hours of morning [5]. The cooling effect is affected by soil and grass foliage moisture in a midday, and the cooling effect converts to warming effect in a humid and warm region [6]. The annual average temperature of earth's surface is highly dependent to evaporation, vegetation or snow cover. Besides, the difference of temperature between the asphalt surface and the air adjacent to the surface of the asphalt surface is maximum, whereas the difference between the grass surface and the air adjacent to surface is minimum [7]. Citraningrum by providing a mathematical model showed that the air temperature over pavement surfaces is models of their surface temperature [8].

In microclimatology, the horizontal transfer of momentum, heat and moisture from being non-homogeneous surfaces known as convection. Local convection theory has an important role in horticulture and hydrology and air pollution [9]. Cooling or warming effect of a green area (in this research, a grass covered area) and an adjacent asphalt area causes cooling or warming of the air over these surfaces and followed air stability or instability conditions [10]. Contrary to a asphalt covered area, the cooling or warming effect of a greenery area is, not only dependent to zenith angel, but also to evaportranspiration. Other factors may influence this phenomenon, e.g. the rate of evaportranspiration, soil moisture and time of irrigation [6].

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The main objective of the present study was to determine the air temperature and humidity variations, over a grass covered area and adjacent asphalt area. By comparison, these variations with each other in different times, the factors underlying on the cooling or warming effects are better understand. The selection of 18-hour period from 6 a.m. to 12 p.m. was due to that probably in the hot days, the most popular come to green area in this period.

MATERIALS AND METHODS

Temperature, relative humidity and wind speed measurements were conducted in a grass covered area and adjacent asphalt area in a residential complex of Zanjan City, west north of Iran, at 36.67 ^{o}N and 48.48 ^{o}E on a hot day in June from 6 a.m. to 12 p.m., in 2 hours interval. Since in this study, the time variations of temperature and relative humidity were important and no spatial variations of temperature and humidity, so only two fix points were selected in the center of grass and asphalt areas. The distance between selected points was approximately 50 m, temperature, and relative humidity measured simultaneously at these two points. Fig 1 shows the configuration of two measurement points in the adjacent areas.

For more realistic requirements, irrigation of grass that implemented almost every day at 7.3 a.m. in June was carried out in measurement day. Temperature and relative humidity were measured at the height of zero, 1.2 m, and 0.02 m, 1.2 m respectively for asphalt, and for grass at the height of 0.02 m, 1.2 m, and 0.02 m, 1.2 m respectively [6, 9]. Because the moisture content of asphalt is very low, when there are not snow or rain on the asphalt surface, measurements of relative humidity at height of 0.02 m above asphalt surface was performed (equivalent to the height above grass), because asphalt surface was completely dry.

Pre-test measurements showed that the air relative humidity at the height of 0.02 m above the asphalt surface is very different from the asphalt surface. For measurements, it was necessary to select a complete calm day, with sunny sky and almost without wind. By using weather forecasting sites, a calm day in June with

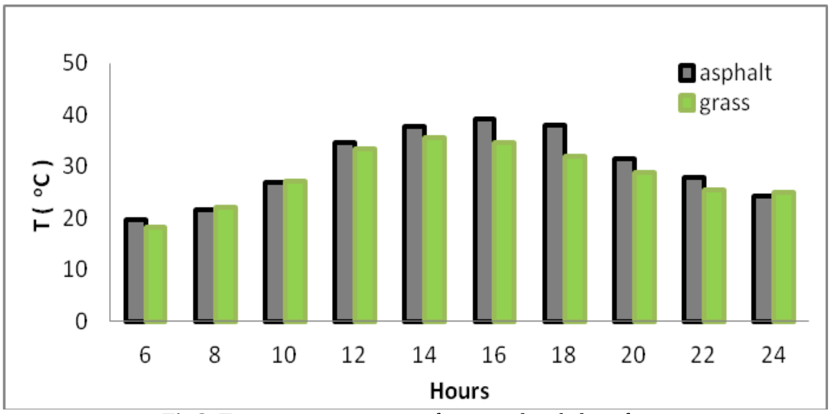

Fig 2. Temperature variations of grass and asphalt surfaces

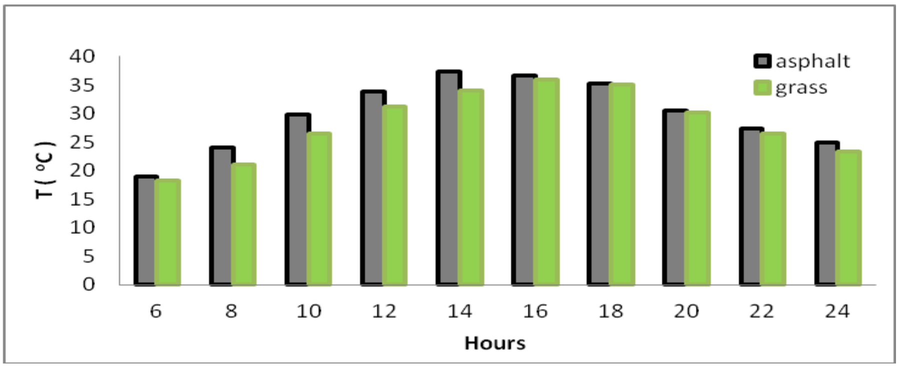

Fig 3. Air temperature variations at height of 1.2 m over grass and asphalt surfaces

above-mentioned characteristic was selected. The maximum wind speed was about 0.35 m/s. Temperature and Relative Humidity were measured by the thermo hygrometer model TESTO 625 with accuracy of ± 0.02 °C and the wind was measured by anemometer model KIMO VT100 with accuracy of ± 0.05 m/s. For more accuracy, the temperature and Relative Humidity were measured at the intervals of one minute, 5 minutes before and 5 minutes after each requested time, then the mean values at that time were calculated [11]. The mean values of temperature and relative humidity from 6 a.m. to 12 p.m. are listed in Table 1.

RESULTS

Temperature variations of grass and asphalt surfaces

Fig 2 depicts air temperature and relative humidity variations measured simultaneously at two points that are shown in Fig. 1. As depicted in Fig. 2, the temperature variations for both grass and asphalt surfaces are the same, however, the temperature increase rate for the asphalt surface is more than that of grass surface until 4 p.m., but after 4 p.m., the temperature decrease rate for grass surface is more than that of asphalt surface.

Air temperature variations above grass and asphalt surfaces

As Fig 3 shows, the rate of temperature variations for both grass and asphalt, in the height of 1.2 m, show the same patterns that are depicted in Fig. 2 for surfaces. At height of 1.2 m, the temperature increase rate for the air above asphalt is more than air above grass until 2 p.m. However, after this time, the less difference between them is observed.

Relative Humidity variations

Fig 4 shows the relative humidity variations in the grass and asphalt surface and above surfaces in the full measurement period.

The maximum relative humidity of grass surface was shown at 8 a.m. that was due to the grass irrigation at 7.30 a.m. The relative humidity at grass surface between 8 a.m. and 6 p.m. shows decrease rate, but again after 6 p.m., due to solar radiation, the relative humidity increases. As depicted in Fig. 3, at the height of 0.02 m above the asphalt surface, the relative humidity decrees between 6 a.m. until 4 p.m. and shows much difference with grass. The increase rate of relative humidity at the height of 0.02 m above asphalt surface is continued from 6 p.m. obviously, the relative humidity of air above grass at height of 1.2 m is less

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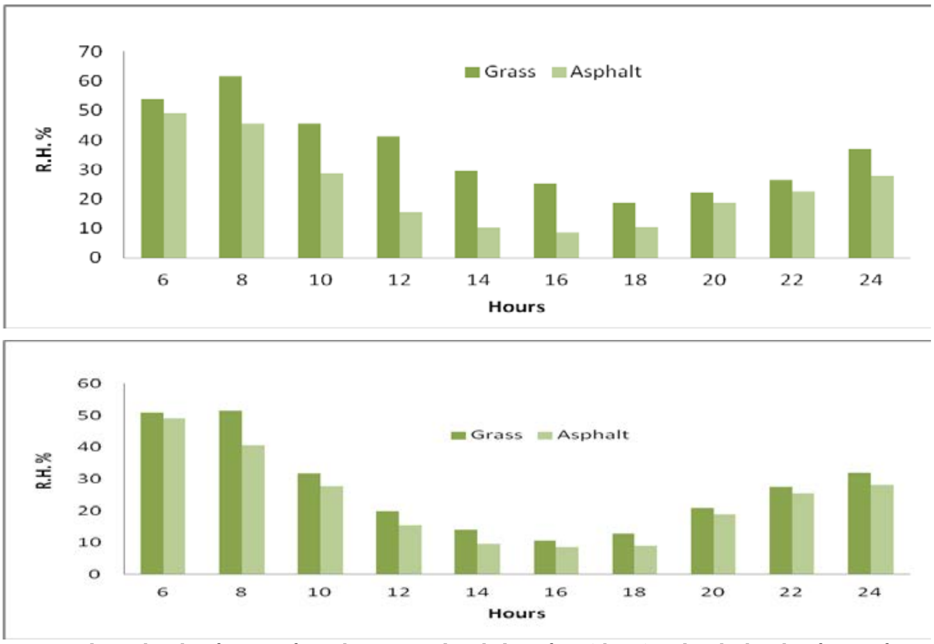


Fig 4. Relative Humidity at height of 0.02 m from the grass and asphalt surface (above) and at the height of 1.2 m from the surfaces (bottom)

than the relative humidity of the air adjacent to surface, that has higher levels of humidity due to evaportranspiration. Air relative humidity variations at the height of 1.2 m above grass and asphalt surfaces are completely similar to relative humidity variations in the surfaces, but with lower values.

Influence of the grass surface cooling or warming effect on the air above surface

Temperature variations for the grass surface and at height of 1.2 m above it, in different hours, showed that the temperature variations of air above surface followed the temperature variations of surface. Fig 5 depicts these

Table 1. Average measured values of temperature (T), relative humidity (R.H.) in the surfaces and the above surfaces (height of 1.2 m) of grass and asphalt

Hours / Quantities	6	8	10	12	14	16	18	20	22	24
Grass										
Mean T(s)*	18.3	22.1	27.2	33.5	35.6	34.6	31.9	28.9	25.5	21.3
Mean (a.s.)**	18.2	21.0	26.5	31.2	34.0	36.0	35.0	30.1	26.5	23.3
Mean R.H.(s)	54.1	61.7	45.5	41.2	29.7	25.4	18.8	22.3	26.5	37.0
Mean R.H.(a.s.)	51.0	51.4	31.6	20.0	14.0	10.7	12.7	21.0	27.5	31.9
Asphalt										
Mean T(s)*	19.6	21.5	27.0	34.6	37.7	39.6	38.0	31.5	27.8	24.9
Mean T(a.s.)**	19.0	24.1	29.8	33.8	37.4	36.7	35.2	30.6	27.3	24.9
Mean R.H.(s)	49.2	45.4	28.8	15.5	10.0	8.5	10.5	18.9	22.6	28.0
Mean R.H.(a.s.)	49.1	40.6	27.6	15.5	9.6	8.5	9.0	18.9	25.5	28.0

(s)* surface
(a.s.) ** above surface

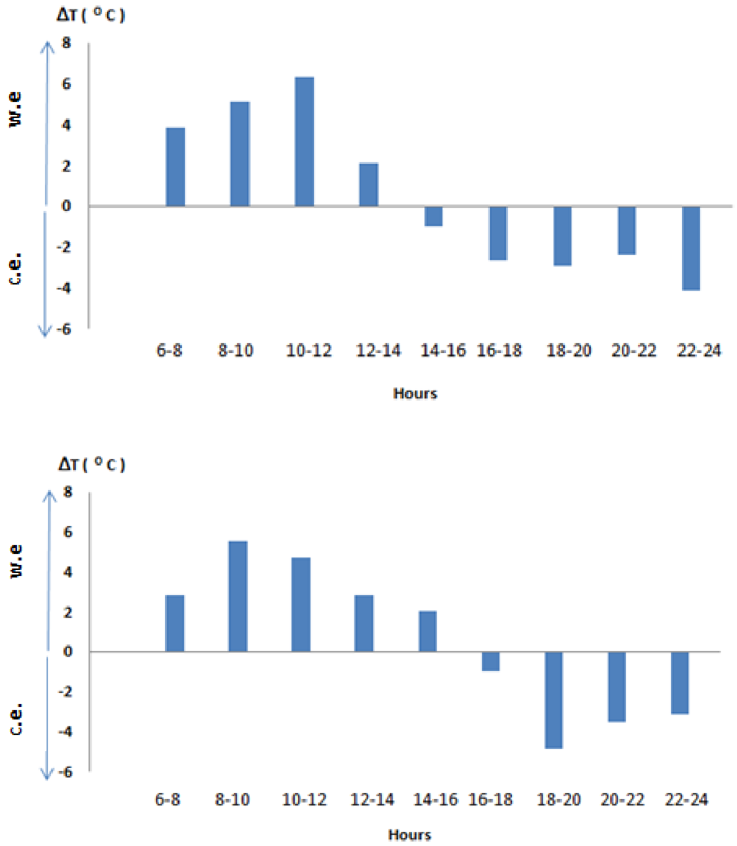


Fig 5. Variations of grass surface temperature (top) and air temperature above grass (bottom). Vertical plus values represent warming effect (w.e.) and vertical negative values represent cooling effect (c.e.)

temperature variations with plus or minus signs. Plus sign indicates Warming effect (w.e.) and minus sign indicates cooling effect (c.e.).

Fig 5 also shows that until 2 p.m., with intense sun radiation, especially between 10 a.m. and 12 a.m., the increase rate of temperature is completely positive. After 2 p.m. the temperature decrease rate of surface, due to decrease of solar radiation and increase of evaportranspiration has happened. So after 2 p.m. the grass surface showed cooling effect. Fig 5 shows the cooling effect of air over grass surface.

Influence of the asphalt surface cooling or warming effect on the air above surface

Fig 6 shows the air temperature variations in the surface and at height of 1.2 m above asphalt surface.

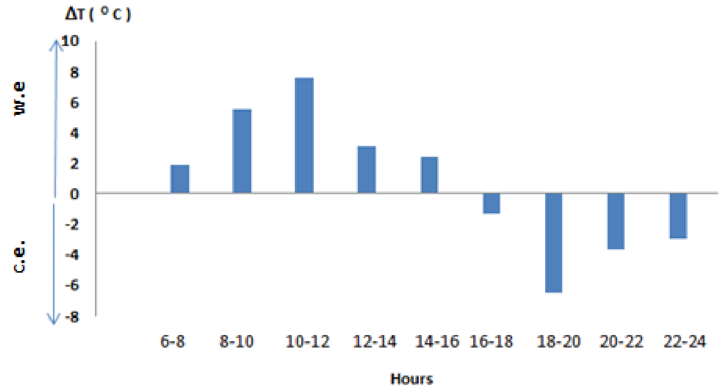
As Fig. 6 shows, the asphalt surface temperature, as the grass surface temperature, starts to warm up from 6 a.m., and the temperature increase rate of asphalt surface is continued until 4 p.m., which in the measurement day was more than that of grass surface for 2 hours. In general, the comparison of Figs. 5, 6 show that the warming and cooling effect of asphalt is more and less than that of grass, respectively.

Dependence of the Stability conditions of air above grass and asphalt to time

In this study, the Bulk Richardson number (*Rib*) was selected to determine of the stability or instability conditions of air at different times. This dimensionless number is the ratio of buoyancy force to inertia force due to the force of the wind and temperature differences and is expressed by the following equation [12]:

$$Rib = \frac{g\{Tv_{zr} - Tv_{z_0}\}(z_0 - z_{0,m})2}{T(z_{0,m}) \cdot u^2(zr) \cdot (z_0 - z_{0,h})}$$

Where $T_{V\,zr}$ and $T_{V\,z_0}$ are potential temperature at height z_r and z_0, also z_{0m} and z_{0h} are roughness length for momentum and heat respectively. g and $T(z_{0,m})$ and $u(zr)$ are gravity acceleration, air temperature at height z_{0m} and wind speed at height *zr*. Since the air potential temperature, is proportional to the measured temperature, thus the Bulk Richardson number is proportional to the temperature difference between surface and above surface. Based on the sign of



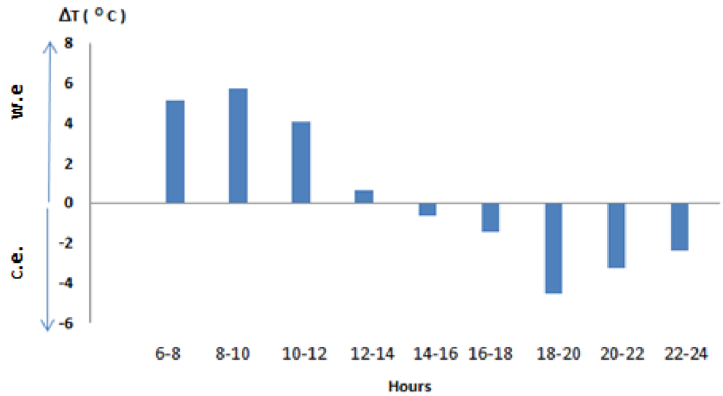


Fig 6. Variations of asphalt surface temperature (top) and air temperature above asphalt (bottom). Vertical plus values represent warming effect and vertical negative values represent cooling effect.

Bulk Richardson number, the warming or cooling effect of grass and asphalt surfaces could be determined at desired times. Fig 7 shows the stability conditions of air located on the grass and asphalt from 6 a.m.to 12 p.m.

As Fig. 7 depicts, the air above grass covered area, in a hot day in June, is unstable (Rib < 0) until 2 p.m. and in the afternoon, this unstable condition convert to stable condition (Rib > 0) and the cooling effect was happened. The stable mode shows signs of surface cooling effect and the unstable mode shows signs of surface warming effect.

DISCUSSION

In micrometeorology, creating green areas, such as grass covered park adjacent residential buildings, streets and highways are important in climate changes in cities.

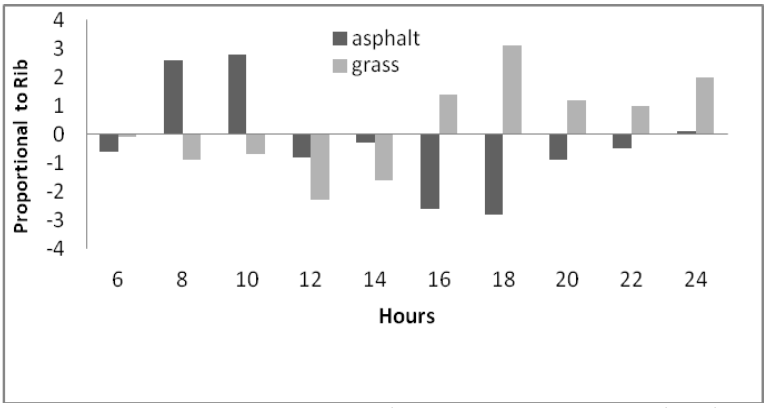


Fig 7. Stability (Rib > 0) and instability (Rib<0) conditions of air above asphalt and grass surfaces from 6 a.m. to 12 p.m.

It should be kept in mind that green areas show both warming and cooling effects. Also it is possible to show that green areas, even with a small area, can create cool air at the time of a hot day, and can increase humidity, especially in the arid and semi-arid areas. In this way, Aminu Sarat et al. (1985) showed that the temperature of asphalt-covered pavement, due to more absorption of solar thermal energy, is higher than the other coverages [13]. Yilmaz et al. (2008) in an investigation of the temperature distribution on the soil grass and cement surfaces and height of 2 m found that the difference between grass and asphalt is higher than others [14].

The results in present study showed that the overall temperature of the asphalt surface, in the most of time in the afternoon, was more than grass surface, whereas Fig. 2 and 3 show good agreement with the results of Aminu Sarat et al. [13], Yilmaz et al. [14] and Ca et al. [15]. The rate of air temperature variations for both grass and asphalt, in the height of 1.2 m, are shown in Fig. 3, have the same patterns that are depicted in Fig. 2 for surfaces. The temperature variation of air over grass surface could be as a result of convective heat flow from surface to height. At height of 1.2 m, the temperature increase rate for the air above asphalt is more than air above grass until 2 p.m. But, after this time, the less difference between them is observed.

The results in Fig. 5 show that the grass surface temperature at 6 a.m., before grass irrigation, due to the lower specific heat capacity of grass (0.00019 - 0.00035 cal/kg - ^{o}C) respect to air heat capacity (0.001cal/kg - ^{o}C) increased more rapidly [11]. Both grass irrigation and sun rising, caused increase of evaportranspiration. In this way the grass covered area encountered by increasing the surface temperature due to solar radiation and decreasing the surface temperature due to the increasing evaportranspiration [16], and As Fig. 5 shows, it clearly observed that the cooling effect of air over grass with a time delay, began from 6 p.m. and its maximum cooling effect occurred from 6 p.m. to 8 p.m. in the measurement day. For asphalt, due to less albedo, the warming effect is begun from 6 a.m. with a faster rate than that of the air above it. At 6 a.m., the initial temperature of the asphalt surface was less than the air temperature, which was located above it (Table 1), thus a heat convective flow from the asphalt surface is established. Temperature variations for the air above asphalt surface at height 1.2 m, was low between 12 a.m. to 6 p.m. and this matter shows that neutral stability condition is governed on the air above asphalt surface. Figs 5 and 6 show, that the temperature increase rate of asphalt surface, due to less albedo is more than that of grass with more albedo [16] until 12. After 12, the asphalt surface will be warmer than the grass surface, because there are not evaportranspiration phenomena on the asphalt surface. The cooling effect of asphalt surface, due to emitted long wave thermal radiation from the surface of the asphalt, is begun from 6 p.m., thus a heat convective from the surface to height [17] was formed, and hereby reduced the temperature of the asphalt surface. Although the sun radiation was lower after 6 p.m., and the rate of thermal energy gain for both air and asphalt was reduced, but due to the lower specific heat capacity of asphalt than air, asphalt surface would be cooled faster than the air above it. In general, the grass surface at the same solar radiation, due to more albedo than asphalt and having transpiration phenomena, is cooler than the surface of the asphalt. This matter shows that in the hot areas, asphalt surfaces must be reduced as possible, and will be added to the grass covered area.

The results of present study, especially showed that the cooler of grass surface than asphalt surface in the afternoon and the cooler air on the above grass surface in the before noon is quite sensible. Perhaps it is not unreasonable that in the hot days the most people go to the parks. Unlike the air located above grass surface, the air above asphalt, in a hot day, is stable in the before noon and unstable in the afternoon. The humidity of grass surface and the air above grass are more than similar values for asphalt, between 6 a.m. and 12 p.m. Also as depicted in Fig. 3 the increase of relative humidity from 6 a.m. to 8 a.m. on the grass surface is due to the increase of evaportranspiration [16]. More humidity production in the air of arid and semi-desert areas can be one of the factors in improving air quality. Obviously, if the measurements are repeated in the months of the year, the results may be different, because duration, power and angel of sun are different. Also if the measurements were conducted in other areas, with different longitude and latitude the results will be different. Another problem that plays a main role in the cooling effect of a grass covered park is the time of irrigation, which affect on grass evaportranspiration. Because if the irrigation time took place at another time, dependence of temperature to the soil moisture content, evaporation and transpiration, power and angel of sun, maybe caused the temperatures have not the same results that have obtained at the present study.

Consequently, the difference temperature between grass and asphalt in the hours of measurement may be different from present study. In the other words, the amount of evaportranspiration in hot seasons, due to irrigation, in a certain day is not the same as the other days, and it can affect the rate of cooling and also on the time of its occurrence. Finally, by doing further research on the basis of time variation on irrigation, under equal atmospheric conditions, it is possible to determine how to achieve the maximum cooling power of a grass covered park on a hot day.

CONCLUSION

The presence of the grass covered area instead of asphalt surfaces, even though small, can significantly improve the thermal environment in the small areas, e.g. outdoor of workshops and factories. In the other words, it is expected that with variation in coverage of the outdoor grounds, the level of thermal stress for workers who have to work outdoors varies.

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The authors declare that there is no conflict of interest.

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