Ponds, Green Roofs, Pergolas and High Albedo Materials; Which Cooling Technique for Urban Spaces?

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ABSTRACT: In this paper the effect of vegetation, water and high-albedo coating on the mitigation of raised urban temperatures are examined. With the hypothesis that raised urban temperatures are mostly formed by the high heat capacity and absorptivity building materials, this paper looks into the thermal effect of covering these surfaces with materials which either control the energy absorbed by the system or lower temperature with evaporation. Roofs with ponds, pergolas, high-albedo coating and green roofs are investigated and compared for three basic types of hot climates (hot and arid, hot and dry and hot and humid). Guidelines are drawn about which solution is the most effective one for mitigating the raised temperatures of cities with different climatic characteristics and creating a more human-friendly environment around urban buildings. Emphasis is given on the outdoors thermal comfort for the four different types of roof covering investigated in this paper.

Keywords: green roofs, pergolas, ponds, high-albedo coating, urban temperature, thermal comfort

1. INTRODUCTION

Most cities, especially the ones in hot zones, suffer from raised urban temperatures and other climatic alterations, generally known as the heat island effect. Although raised temperatures might be beneficial during cold periods, for warm and hot periods they are responsible for larger amounts of energy consumed for cooling city centres. In the instance of Athens, the heat island effect is responsible for 50% larger cooling loads in the city centre than in the suburban areas [1]. It is impossible to argue about designing with passive cooling techniques in city centres or about creating sustainable urban spaces, unless these raised urban temperatures are mitigated.

In this paper traditional techniques of lowering temperatures around buildings, such as controlling the amount of insolation absorbed by the surface or placing transpiring surfaces, are explored theoretically, for different climatic characteristics, in order to perceive which technique would be more beneficial, for different climates and needs.

2. COMPARISON OF COOLING TECHNIQUES

The heat and mass transfer prognostic (dynamic), one-dimensional model used and the methodology followed to validate these techniques are as suggested by [2] and have been presented in [3] and [4]. Humid air is considered to be a binary gas mixture (air and moisture), in a system of zonal calculation, with constant properties of both components and without any air movement apart from molecular diffusion, near the surface. Due to the great temperature gradients near the surface, the enthalpy transfer resulting from vapour diffusion is taken into account in the heat transfer equation, leading to much greater accuracy. This method has been solved with finite differences approximations; the forward Euler scheme, the first order forward approximation and the second order central approximation are used for solving the heat and mass transfer equations in solids, liquids and the boundary air nodes. The fourth order in space solution is used for the air nodes well away from the surface. The model's accuracy has been validated with an experiment, as discussed in [4]. The method's error is only 0.4^{o}C. When the water vapour gradient is not taken into consideration in the heat transfer equation, for the same finite differences approximations, the error reaches up to 0.7^{o}C.

The temperature of the surface of the roof as well as the air temperature above the surface are examined for five types of roofs, for the cases of three hot climatic types. A plain concrete roof is examined (fig. 1a), and a concrete roof covered with high albedo coating (fig. 1a). The high-albedo coated roof is also examined three years after the coating has been applied, when it has lost at least 25% of its albedo [5]. Air and surface temperatures are also investigated at a green roof, with 20cm vegetation (fig. 1b), a pond roof with 20cm water, where water is at 20^{o}C, at midnight (fig. 1c) and a "green sky", a pergola with 20cm vegetation, placed 2m above the concrete roof (fig. 1d). All temperatures of the four cool techniques are compared with the temperatures of the "base case", the plain concrete roof. Air temperature is examined 1m above the roof for each case (node air', fig. 1). The three climates examined are the Mediterranean climate (hot and dry), with climatic data from Athens, the rain forest climate (hot and humid), with Mumbai's climatic data and the desert climate (hot and arid), with the climatic data of Riyadh, as have been presented in [6]. The climatic data of temperature and humidity are input at the "urban" node (fig. 1), while the short and the long wave radiation are input at the surfaces.

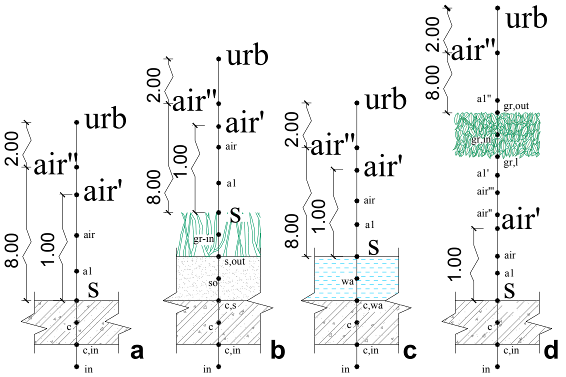

Figure 1: (a) Concrete roof model, (b) green roof model (c) pond roof model and (d) green sky model

2.1 Hot and Dry Climate; July in Athens

It can be observed in fig. 2 and 3 that for the hot and dry summer of Athens, all four techniques can lower raised urban temperatures, quite significantly. The white-coated concrete roof can lower surface temperatures to a maximum of 20.9°C, with a day-time average of 12.4°C. The air temperature 1m above the roof lowers by 4.1°C maximum and 2.2°C day-time average. After three years, when the white roof's albedo lowers by 25%, this temperature decrease lowers by 57%. Surface temperature decrease reaches a maximum of only 11.9°C, with a 7.1°C day-time average. For the air 1m above the roof these decreases lower to 2.3°C and 1.3°C, respectively.

The green roof shows greater temperature decreases than the white concrete roof. For the surface temperature, the maximum temperature decrease reaches 26.2°C, with a day-time average of 14.4°C. The temperature decrease is more significant at the air layer above the roof, reaching 7.3°C for the maximum and 2.7°C for the day-time average. The maximum temperature decrease of the green roof is 3.1°C larger than the maximum air temperature decrease of the high albedo roof. Due to the dryness of Athens, the evapotranspiration from plants is able to lower air temperatures to greater levels than a non-transpiring surface, which absorbs lower amounts of solar radiation. It can be observed in fig. 3 and 4 that both the surface temperature of the green roof and the air temperature are higher than the white concrete's temperatures in the morning, for 7 hours, with a 3.5°C average difference for the surface. For the air layer 1m above the roof, this difference reaches only 1.3°C. Later on during the day, as heat is stored up in the white concrete roof, its surface and air temperatures become higher than those of the green roof's, reaching a much larger average difference of 8.8°C for the surface and 2.7°C for the air layer 1m above the roof. Three years after the coating has been applied ([old-wh-con] case), surface temperature of plants exceed that of the roof's only by a negligible 0.2°C (fig. 3), while the air above it slightly exceeds it by 0.6°C, in the morning (fig. 2). The rest of the day, the green roof shows much lower temperatures than the white roof, by an average difference of 10.1°C for the surface and 3.2°C for the air layer 1m above the roof.

Regarding the pond roof (case [water] in fig. 2 and 3), it has more stable temperatures than the two types of roofs examined, due to water's high heat capacity. The difference between the maximum and the minimum surface temperatures reached is only 7.9°C. In comparison, this discrepancy is 26.2°C for the green roof, 18.0°C for the white roof and reaches 38.8°C for the plain concrete roof. The surface temperature of the pond roof reaches a maximum decrease, when compared to the plain concrete roof of 28.1°C, with 14.8°C day-time average. Temperature decrease at the air layer 1m above the roof is much lower, reaching a maximum of the magnitude of 5.5°C, with 2.6°C day-time average. The pond roof has lower temperatures than the green roof during the late morning and early afternoon hours (fig. 2 and 3), reaching a maximum difference of 10.0°C for the surface and 2.7°C for the air, with respective averages of 6.9°C and 1.7°C. However, due to the heat stored in water, temperatures are much lower on and above the green roof in the late afternoon and evening hours. The surface temperature of the green roof is lower than that of the pond roof by 14.1°C maximum and 11.4°C average during that period. The respective values for the air are 4.2°C and 3.1°C, much larger than the differences between the two cases for the 8 hours when the pond roof is cooler than the green roof.

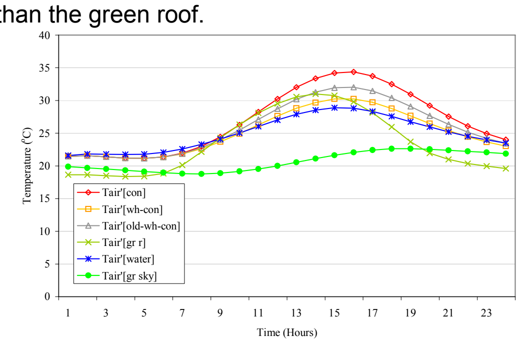

Figure 2: Air temperature 1m above the roof for the plain concrete roof [con], the white-coated concrete roof [wh-con], the white-coated roof with 25% smaller albedo [old-wh-con], the green roof [gr r], the pond roof [water] and the pergola [gr sky], for Athens

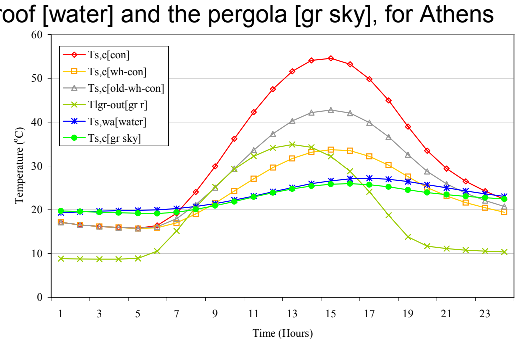

Figure 3: Roof surface temperature for the plain concrete roof [con], the white-coated concrete roof [wh-con], the white-coated with 25% smaller albedo [old-wh-con], the green roof [gr r], the pond roof [water] and under the pergola [gr sky], for Athens

Pergola (green sky) acts as a buffer space between the roof and the sky's long and short wave radiation. The solar radiation that reaches the concrete roof under the green sky is only a fraction allowed by the penetration fraction of the pergola's canopy. Due to this shading, combined with the evapotranspiration from plants, the green sky temperatures show the smallest discrepancies between maximum and minimum, reaching only 6.8°C for the surface temperature of the roof and 3.9°C for the air layer 1m above the roof. When compared with the plain concrete roof, it reaches the greatest decreases than any other case, with 12.6°C maximum and 8.1°C day-time average for the air, while for the surface these values become 28.8°C and 15.6°C, respectively. It can be observed in fig. 3 that the surface temperature of the roof of the green sky has very similar distribution as the surface temperature of the pond roof. For the lower insolation of Athens (when compared with that of Mumbai or Riyadh), the difference between the surface temperatures of the two cases reaches only an average of 0.8°C. Nonetheless, as can be observed in fig. 2, the difference between the two cases for the air temperature is much greater. The air temperature in the green sky case is smaller than that in the pond roof by an average of 5.5°C.

2.2 Hot and Humid Climate; May in Mumbai

For Mumbai with its higher amounts of solar radiation, the effect of high-albedo coated roof on temperature distributions is similar, but slightly smaller than for Athens. Temperature decreases due to the newly coated high-albedo surface reach 20.8°C maximum and 11.7°C day-time average for the surface and 4.1°C and 2.1°C, respectively, for the air layer 1m above the roof. Surface and air temperatures on and above the white-coated concrete roof are much lower than those of the concrete roof during day-time are, but their difference is not so significant during night-time (fig. 4 and 5). Three years after the coating has been applied, these decreases lower again by 57%, to 11.8°C for the maximum and 6,6°C for the day-time average on the surface and only to 2.3°C and 1.2°C, respectively, for the air layer 1m above the roof.

Regarding green roofs in Mumbai, because of the larger amounts of solar radiation and higher air temperature, the effect of green roofs is greater than that of high-albedo coating. Surface temperature decrease reaches a day-time average of 15.0°C, with 27.6°C maximum. For the air layer 1m above the roof these values become 3.1°C and 8.0°C, respectively. This great difference between the maximum and the average is due to the fact that because of the elevated temperatures of Mumbai, air temperature above the plain concrete and the green roof are of a similar magnitude from 9:00 to 11:00 in the morning. As the day proceeds, heat is stored in the concrete roof, raising its temperature up to 57.3°C, while plants keep their surface temperature to less than 37.2°C. When compared with the high-albedo roof, the green roof shows generally lower temperature distributions. During the early morning hours the green roof has higher surface temperatures than the newly coated white concrete roof. The average difference between the surface temperatures reaches an average of 3.1°C and 1.1°C for the air layer 1m above the roof, slightly smaller than those of Athens. The rest of the day the differences between the lowered temperatures above the green roof and those above the white concrete roof are even larger, reaching an average difference of 10.5°C for the surface and 3.4°C for the air layer 1m above the roof. Three years after the coating has been applied, green roofs in Mumbai have a far cooler behaviour than the old, white-coated concrete surface. Green surface temperature is lower than that of the old, white concrete roof, while the air temperature above the green roof exceeds that above the old, white concrete roof by an average of 0.5°C at 1m height, for only 4 hours. For the rest of the day, air temperature above the green roof is lower than that above the old, white roof by an average of 3.8°C (fig. 4). Regarding surface temperature, plants have a lower surface temperature than the old, white roof throughout the whole day, by an average of 13.2°C (fig. 5).

For the climate of Mumbai, the effect of the pond roof is close to that of the green roof, but slightly smaller. For the surface temperature, the decrease when the roof is covered with 20cm water reaches a maximum of 27.8°C, with 13.4°C day-time average, while for the air 1m above the roof, it reaches 5.5°C and 2.4°C, respectively. For the 7 late morning-early afternoon hours, when the pond roof has lower temperatures than the green roof, the average temperature difference between the two reaches 5.2°C for the surface and 1.5°C for the air layer 1m above the roof. In the late afternoon and evening hours, as the heat stored in the water makes its temperature rise, the pond roof has much greater temperatures than the green roof (fig. 4 and 5). The differences of temperature distributions between the two cases reach averages of the magnitude of 10.9°C for the surface and 3.8°C for the air.

As has been the case for Athens, green skies offer the most protected environment, from a thermal point of view, on a roof in a hot climate. The maximum surface temperature of the roof under a pergola is only 26.5°C, with 23.2°C day-time average (fig. 5). For the air layer 1m above the roof a maximum of 23.4°C is reached and a day-time average of 20.8°C (fig. 4). When compared with the plain concrete case, the green sky case has the greatest thermal effect in Mumbai, reaching a maximum air temperature decrease of 15.4°C, with 10.6°C day-time average and 30.9°C and 16.8°C, respectively, for the surface. When compared with the pond roof, it can be observed that the differences between the pond and the green sky roofs are greater in Mumbai than in Athens. The difference between the surface temperatures of the two cases reaches a maximum of 4.4°C (greater by 2.6°C than Athens) and an average of 3.3°C (greater by 2.5°C than Athens). For the air layer 1m above the roof the difference between the two cases is much greater. The air temperature under the pergola is smaller than that above the pond roof, with a maximum difference of 10.4°C (3.0°C greater than Athens) and an average of 6.9°C (1.4°C greater than Athens). Due to the high humidity concentrations of Mumbai, a self-adjusting buffer space may prove much more beneficial than an evaporating surface.

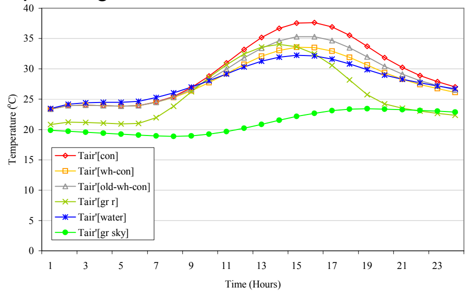

Figure 4: Air temperature 1m above the roof for the plain concrete roof [con], the white-coated concrete roof [wh-con], the white-coated roof with 25% smaller albedo [old-wh-con], the green roof [gr r], the pond roof [water] and the pergola [gr sky], for Mumbai

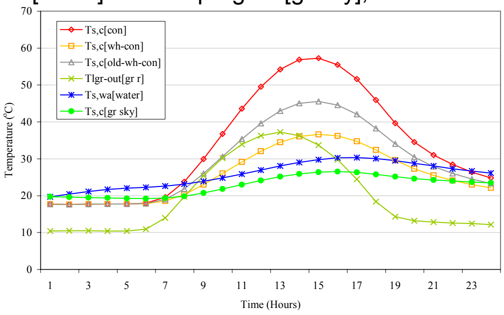

Figure 5: Roof surface temperature for the plain concrete roof [con], the white-coated concrete roof [wh-con], the white-coated roof with 25% smaller albedo [old-wh-con], the green roof [gr r], the pond roof [water] and under the pergola [gr sky], for Mumbai

2.3 Hot and Arid Climate; July in Riyadh

For the extreme heat and aridity of Riyadh, evaporating surfaces are more beneficial than high-albedo surfaces. The white concrete roof has the smallest temperature decreases, when compared with Athens and Mumbai. The surface temperature decrease of the white, concrete roof reaches a maximum of 17.9°C (while it reaches a maximum of 20.9°C in Athens and 20.8°C in Mumbai), and 10.4°C day-time average. The air above the roof lowers less than in the other two cities, reaching a maximum of 3.5°C and a day-time average of 1.9°C (the latter being 2.2°C in Athens and 2.1°C in Mumbai). Three years after the white coating has been applied, temperature decreases lower to more than half; for the surface, the maximum temperature decrease is 10.1°C, with a day-time average of 5.9°C, while for the air 1m above the roof 2.0°C and 1.1°C, respectively.

The greatest temperature decreases of the green roof are observed in arid Riyadh. Surface temperature decrease reaches 18.5°C day-time average and 29.5°C maximum. For the air layer 1m above the roof these values become 4.7°C and 8.8°C, respectively. The surface temperature of the green roof does not exceed the surface temperature of the white concrete roof (fig. 7), nor does the air temperature above it (fig. 6). For the white-coated roof, the day-time average difference between its surface temperature and the surface temperature of the green roof reaches 8.8°C and 5.2°C at the air layer 1m above the roof. After three years, when the white paint's albedo has been reduced by 25%, these differences become even larger, with the green roof having a smaller surface temperature by a day-time average of 14.1°C. For the air layer 1m above the roof the day-time average becomes 3.9°C.

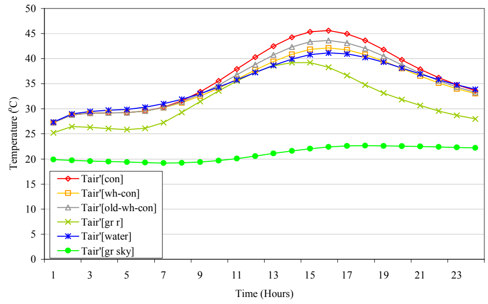

Figure 6: Air temperature 1m above the roof for the plain concrete roof [con], the white-coated concrete roof [wh-con], the white-coated roof with 25% smaller albedo old-wh-con], the green roof [gr r], the pond roof [water] and the pergola [gr sky], for Riyadh

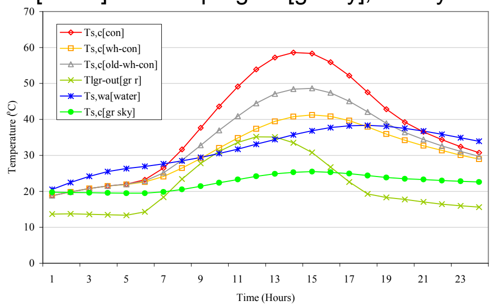

Figure 7: Roof surface temperature for the plain concrete roof [con], the white-coated concrete roof [wh-con], the white-coated roof with 25% smaller albedo [old-wh-con], the green roof [gr r], the pond roof [water] and under the pergola [gr sky], for Riyadh

Due to the raised temperatures of Riyadh and its high solar radiation, the pond roof is not as beneficial as in the Athens and Mumbai. Although evaporation manages to lower air temperature quite significantly (fig. 6), the heat stored in water, in combination with the raised temperatures of Riyadh, raises the surface temperature of the pond roof significantly during the late evening hours (fig. 7). Nonetheless, the pond roof lowers air temperature to a maximum of 4.6°C, with a day-time average of 2.1°C. For the surface, these values become 22.9°C and 11.1°C, respectively. When compared with the green roof, the pond roof has, in general, larger temperatures. Only for 4 hours in the late morning does the surface temperature of the green roof exceed that of the pond roof by an average of 1.9°C. The rest of the day, the surface temperature of the green roof is lower than that of the pond roof by an average of 15.4°C. For the air 1m above the roof this difference becomes 4.7°C.

For the extremely raised temperatures of Riyadh, the buffer space created in the green sky is the optimum solution for outdoors use. In the protected from the sun and the climatic conditions of Riyadh air layer under the pergola, the maximum temperature decrease reaches 23.3°C, with 17.6°C day-time average. For the surface, these numbers become 33.3°C and 21.0°C, respectively. When compared with the pond roof, the green sky has lower temperatures throughout the whole day by an average of 9.9°C for the surface and 15.5°C for the air layer 1m above the roof (fig. 6 and 7). With the use of a two or a three-dimensional model, these differences observed in the green sky would be smaller, due to advection. Nonetheless, a one-dimensional model can estimate quite satisfactorily the thermal exchanges in the middle of a relatively large roof, under small wind speeds.

3. THERMAL COMFORT ON THE ROOF

Both air and globe temperature, which have been altered with all four roofing techniques, have a very significant effect on the thermal comfort of outdoors spaces [7]. By altering both of them, new energy balances affect the thermal comfort in the same space. When a space becomes more attractive for people, from a thermal, an aesthetics or from a facilities point of view, its use tends to change. Abandoned spaces, such as roofs in hot climates, may turn into active spaces of buildings, when the thermal comfort is improved, becoming an additional space to the building, as Le Corbusier was considering them to be. With the use of the Physiological Equivalent Temperature (PET), as defined by [8] and [9], and its relationship to thermal perception as determined in [10], the thermal comfort of a standing man on all five types of roofs is examined. Especially for the green sky, the solar radiation received is the one allowed to penetrate by the penetration fraction of the pergola's canopy. This shading from the sun makes the green sky the most efficient technique, from a thermal comfort point of view, in all three climates.

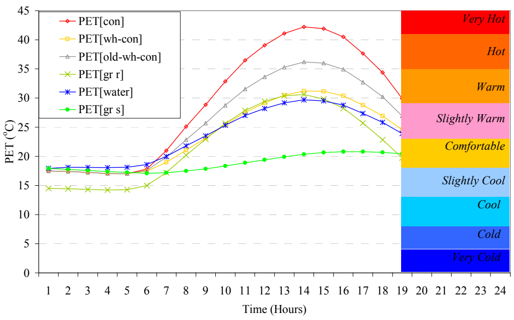

Figure 8: Physiological Equivalent Temperature for a man standing on a plain concrete roof [con], a white-coated concrete roof [wh-con], an old, white-coated roof [old-wh-con], a green roof [gr r], the pond roof [water] and under a pergola [gr sky], in Athens

For a man standing under a green sky in Athens (fig. 8), he is in the "comfortable" zone for 15 hours and for 8 hours (in the late night and early morning hours) in the "slightly cool" zone. In Mumbai (fig. 9), the green sky results in a 24-hour "comfortable" zone, while in Riyadh (fig. 10) 17 hours in the "comfortable" zone and 6 hours in the "slightly cool" zone (again in the late night and early morning hours). The second coolest roof is the green roof, ranging from the "slightly cool" to the "warm" zone for Athens and Mumbai and reaching the "hot" zone in Riyadh. The pond roof is cooler than the concrete roofs, ranging from the "comfortable" to the "warm" zone in both Athens and Mumbai. In Riyadh the pond roof is never in the "comfortable" zone, but extends from the "slightly warm" to the "hot" zone.

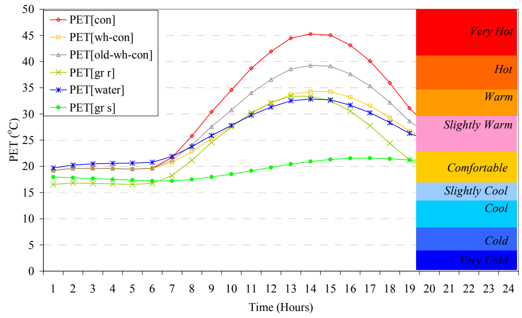

Figure 9: Physiological Equivalent Temperature for a man standing on a plain concrete roof [con], a white-coated concrete roof [wh-con], an old, white-coated roof [old-wh-con], a green roof [gr r], the pond roof [water] and under a pergola [gr sky], in Mumbai

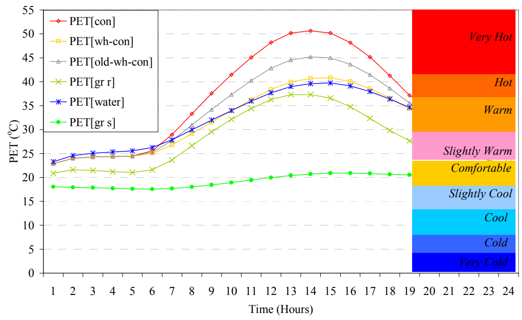

Figure 10: Physiological Equivalent Temperature for a man standing on a plain concrete roof [con], a white-coated concrete roof [wh-con], an old, white-coated roof [old-wh-con], a green roof [gr r], the pond roof [water] and under a pergola [gr sky], in Riyadh

The concrete roofs offer a less perceivable cooling sensation. The thermal sensation on the white-coated roof ranges from "slightly cool" to "warm" in Athens. In Mumbai the same roof creates a thermal perception from "comfortable" to "warm" while in Riyadh its effect is from "slightly warm" to "hot". After 3 years, the thermal sensation on this roof is not so pleasant, reaching "warm" for 8 hours in Athens and "very hot" for 5 hours in Mumbai and 6 in Riyadh. As can be observed in fig. 8-10, the thermal perception on the plain concrete roof is very unpleasant, reaching the "very hot" zone, with its extreme heat stress for 3 hours in Athens, 5 in Mumbai and 9 in Riyadh.

It is obvious that for all three climates examined, the most effective techniques for creating more thermally comfortable spaces are the transpiring ones and especially the evapotranspiring ones (green roofs and green skies). High-albedo materials can improve the thermal sensation only for a few hours. In particular, the green sky where the space is shaded and cooled with evapotranspiration from above, the thermal perception is phenomenally improved in all cases of different humidity concentrations and solar radiation. If roofs are perceived as the fifth element, a space of use by the inhabitants of the building, one should bear in mind that the thermal protection of green skies is the most efficient method of creating thermally comfortable roofs in hot climates.

4. EFFECTS ON THE URBAN CLIMATE

Although a one-dimensional model is not sufficient to describe heat and mass transfer exchanges at the city meso-scale, it is interesting to observe how the different types of roofing affect the air temperature well above the roof. If a city is considered to have a homogenous roof type, and that the roof type is altered for the whole city, the thermal effect of the different types of roof on the urban climate could be estimated by a one-dimensional model. This is done by comparing the air temperature at the node air'' (fig. 1) with the input air temperature at the "urban" node. The node air'' is set 2m below the "urban" node and 8m above the roof, for all the cases examined, describing the temperature of the air zone of the upper part of the "urban plume" in the small scale of the cases examined in this paper.

Table 1: Average air temperature differences (in ^oC) with the input "urban" temperature at the node 2m below the "urban" node and 8m above the external surface of the roof (node air'' in fig. 1), for all the types of roofs examined, in Athens, Mumbai and Riyadh

Case	Athens	Mumbai	Riyadh
Concrete roof	3.4	3.6	2.3
White roof	-0.8	-1.0	-1.6
Old white roof	0.3	0.3	-0.3
Green roof	-1.0	-2.2	-3.3
Pond roof	-1.4	-1.6	-2.0
Green sky	-1.6	-2.3	-2.9

As can be observed in table 1, even 8m above the concrete roof, the air temperature is greater than the "urban" temperature for all three climates, ranging from 3.6^oC average difference in Mumbai to 2.3^oC in Riyadh. The white, concrete roof manages to lower air temperature by 1.6^oC in Riyadh to 0.8^oC in Athens. Three years after, the difference between the "urban" and the air'' temperature ranges from 0.3^oC in Mumbai and Athens, to -0.3^oC in Riyadh. The green roof achieves the greatest temperature decreases in Riyadh and Mumbai, with average differences from 3.3^oC in Riyadh to 2.2^oC in Mumbai and 1.0^oC in Athens. The other evaporating roofs are also more effective than the white roofs, with differences from 2.0^oC in Riyadh to 1.4^oC in Athens for the pond roof and 2.9^oC to 1.6^oC, respectively, for the green sky. It can be observed in table 1 that even the upper parts of the "urban plume" suffer from greater temperatures when the roofs are plain, concrete ones. Air well above the roof is more affected by transpiring roofs, rather than roofs with altered albedo. From this rough estimation of the one-dimensional model, it can be observed that evaporating surfaces can be more effective on lowering raised urban temperatures than high-albedo coated surfaces.

5. CONCLUSION

It has been shown in this paper that high-albedo surfaces, ponds, green roofs and pergolas can mitigate the raised temperatures on and above a roof quite significantly. Which technique should be applied is a question of where and the type of buildings these techniques are going to be applied. In general, evaporating surfaces are more capable of lowering temperatures than high-albedo roofs, in all three climates examined, both at roof level and for the air layer well above the roof. Pond roofs could work better for office and school buildings, or generally buildings with day-time use, provided water is renewed. On the other hand, green roofs and pergolas have a constantly lower temperature, making them more appropriate for buildings with 24-hour use, such as residencies and lodging places. If the roof is designed as an additional space to the building, in all climates examined, the green sky offers the ideal outdoors thermal comfort conditions, as it offers shading in the buffer space created underneath the plants. The largest temperature decreases for all climates are created in the buffer space of the green sky, where average air temperature decrease ranges from 17.6^oC in Riyadh to 8.1^oC in Athens. The lowest decreases are noted for the three-year-old, high-albedo coated roof, with average air temperature decrease from 1.3^oC in Athens to 1.1^oC in Riyadh. Nonetheless, all four cooling techniques examined in this paper are capable of lowering temperatures at roof level and, if applied to all or the majority of roofs in a city, at a city scale. In all cases, plants and water are more efficient in lowering urban temperatures than white-coated roofs, in all arid, dry and humid hot climates.

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