COOL ARCHITECTURAL MATERIALS AND ASSEMBLIES FOR OUTDOOR URBAN SPACES

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ABSTRACT

This paper is concerned with providing thermal comfort for waiting passengers in open or semi-open urban spaces based on research carried out for the Valley Metro Rail Project in Phoenix, focusing on cool architectural materials and assemblies for outdoor urban spaces. The effectiveness of microclimatic modification of architectural shelter, for the purposes of climatic mitigation is an accepted fact. Although design strategies should attempt to lower ambient air temperatures, this approach has limited possibilities. The fundamental opportunities are in controlling the radiant temperatures of the building material surfaces that impact users and hence controlling the Mean Radiant Temperature (MRT). Local field measurements of a number of outdoor shading structures such as the ones over walkways, bus stops and car parking canopies have demonstrated that it is not uncommon on a summer day to have surface Sol-Air temperatures of 150°F (65°C). Such a high temperature on such a large radiant plane six to eight feet above a user creates significant thermal discomfort and health stress.

Our thermal goal was to document which materials and details can provide the lowest surface temperature when the ambient air temperatures are at their highest. Climatic data analyses, health and comfort evaluation, architectural and city planning choices and environmental recommendations included methods of measuring, calculating, simulating and/or testing the guidelines. The primary aim was to investigate alternative choices, examine current field applications in Phoenix climates, conduct data collection and analysis, including thermal measurements, costs, durability, maintenance, range of performance and comparative criteria. The final objective was to provide recommendations for the same to the Valley Metro Rail Station Design Teams as to their feasibility and application and to enrich the design opportunity by prioritizing materials choices.

1. RESEARCH PARAMETERS

The research focused on the summer-overheated condition as a design stimulus to promote comfort and avoid health risks within open stations. August 21 at 4 PM is identified as the critical time. Following earlier recommendations about shading, and establishing the upper thresholds of discomfort including the health risks[1], the research emphasizes the design opportunities and techniques of materials choice, architectural detailing, and specially designed devices such as cooled seating and radiant walls. Preliminary proposals identify particular devices of promise.

The investigations were focused in the following major areas: paving materials, canopy materials, landscape and vegetation, water features and cooled seats. Actual construction was simulated by performing full-sized outdoor fabrication and testing. The particular method employed here for outdoor testing during local summer-overheated conditions reinforces recommendations based on thermal performance expectations, and published or calculated data. Custom performed calculations and published manufacturers' specifications were only used to confirm first hand observations. By showing the range of performance and the simultaneous thermal advantage of material surface temperatures over air temperatures, a cooler architectural configuration can be designed.

2. TESTING OF MATERIALS

Materials and assemblies were tested under the broad categories are paving materials, landscape and vegetation, canopy materials, water features and cooled seats. The following give a brief account of the experimentation and the significant findings from our investigations. The surface temperature of the materials was recorded at different times of the day with a 'Raytek Raynger ST' infrared thermometer. The readings were recorded under actual summer outdoor conditions on days with full sun. Five readings were taken for each material at any time and then the average was taken. The materials had been exposed to the sun for 30 minutes before the readings were taken.

2.1. PAVING MATERIALS

The thermal performance of the paving materials was evaluated by recording the surface temperatures and the dry bulb temperature for the following conditions:

- Paving materials in outdoor application settings.
- Paving materials kept in sun
- Paving materials made moist with pouring water over them.
- Paving materials made wet by allowing for gradual wicking up of water to the surface by capillary action, using a soaker hose.

The materials tested under this category were Clay tiles, Concrete pavers, Epoxy Concrete tiles, Autoclaved Aerated Concrete, Asphalt and Foam (Polystyrene). The material categories covered parameters like different colors and thickness.

2.1.1. Paving materials in natural settings

Testing Procedure

The thermal performance of paving materials at different locations in outdoor application settings was observed and documented both in sun and shade.

Results

The trends in the measurements taken reflected that the thermal performance of the concrete paving was better in shade as compared to that in the sun, thus as far as possible shading of paving must be incorporated in the design. Color influenced the performance of the material. Lighter colored concrete performed better than the darker one. Black asphalt shows higher surface temperatures than concrete. Since the station platforms will always have some sun, and never be shaded throughout the day, so the study recommended that for the platform material black asphalt should not be considered anywhere and dark materials should be avoided.

2.1.2. Paving materials kept in sun

Testing Procedure

The surface temperatures of several paving materials were taken at different times of the day with materials laid side by side on the steel grating at the Solar Laboratory at Arizona State University.

Results

The Beige color Epoxy concrete tile performed the best when the paving materials were exposed to sun.
The color of the paving material did not make a substantial difference in surface temperature in case of concrete. The lighter color clay tile performed better, the

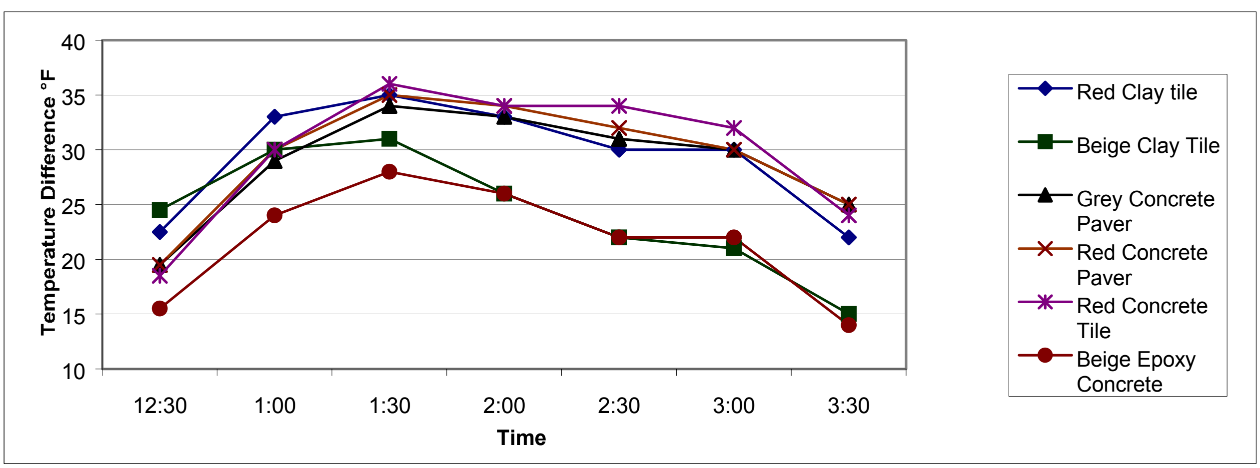

Fig. 1: Surface Temperatures of Paving Materials in Sun

surface temperature of the tile being 15 to 30°F higher than the ambient air temperature.

2.1.3. Paving materials made moist by pouring water

Testing Procedure

The samples were kept in a wet sand bed and water was poured over it and then allowed to evaporate in a bright sun condition. The surface temperatures were recorded with an infrared thermometer at different times of the day.

Results

Wetting the samples had a considerable impact on their thermal performance in case of clay tiles. Within 15 minutes after pouring the water the surface temperature dropped by 30 degrees and went down up to 10 degrees below the ambient air temperature. The tiles showed the effect of gradual evaporative cooling and remained damp throughout the day once the water had been poured. The concrete pavers had a problem of efflorescence and a white crust deposited on the surface. In case of epoxy concrete the wetting did not have any significant impact on the performance since the tile became dry within 5 minutes after pouring of water because of the epoxy seal.

2.1.4. Paving Performance- Soaker hose Experiment

Testing Procedure

A ¼" porous soaker tubing was embedded in a 6"sand bed and the paving materials were placed over it. Water was allowed to seep through the sand bed and wick up to the tile. The tile surface was kept damp throughout the day. The surface temperatures were recorded at different times of the day.

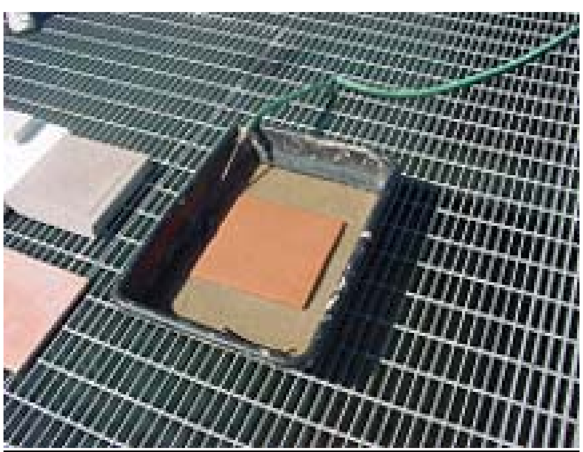

Fig. 2: Soaker hose Experiment

Results

The experimental set-up turned out to be a potential water-cooled assembly for reducing surface temperatures of paving materials. The sand bed on which the sample was kept became wet within 5 minutes after the water was supplied. The surface of the Clay tile was damp within 6 minutes after the water was supplied and after that there was no need for water to be supplied throughout the day. The temperature drop of the surface ranged from 33 to 37 degrees as compared to that of the same sample kept in the sun in the dry condition. The cooling performance was consistent throughout the day. The next day also the temperature of the tile that was wetted the previous day showed a temperature drop of 30 degrees as compared to the dry tile (both being exposed to the sky during the night). Concrete samples did not show good wicking property and the surface remained partially dry even after several hours.

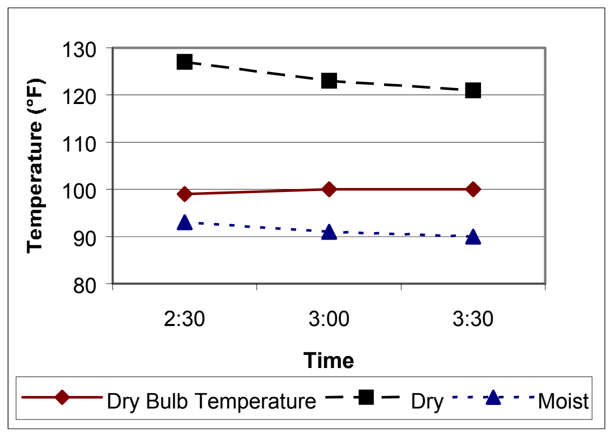

Fig. 3: Cooling Performance of Red Clay Tile

2.1.5. Findings

Paving materials documented in outdoor applications had the benefit of being backed by concrete slabs approximately 4" thick and earth contact, which provides both thermal storage and thermal lag. This allows nighttime cooling to be continued into the next day with a time delay and thermal dampening. A rule of thumb is that it takes one hour for heat to penetrate one inch of concrete of dense masonry material.

The unmounted paving material samples had no concrete or earth backing but were laid on the metal grid of the lab platform that is suspended above an exposed concrete roof. The sample pavers were exposed to the sun continuously and ranged in thickness from 5/8th to a 1-1/4 inches. Therefore surface temperatures approximate an instant reading with only a small thermal lag. Thus surface temperatures of these paving materials permanently installed would show lower readings and thus would be more advantageous than as observed in the testing. Water acts as a potential medium for lowering the surface temperatures of paving materials and wetted samples show a surface temperature 10 degrees below the ambient air temperature.

2.2. LANDSCAPE AND VEGETATION

2.2.1. Materials List And Test Descriptions

The thermal performance of plants at different locations in a natural setting was observed and documented under actual summer outdoor conditions to verify assumptions in the calculation of thermal performance of proposed station designs.

Tests were carried out on grass, plants and shrubs. Multiple readings of surface temperatures were made in the center of individual leaves. The vegetation had 2 hours of shade before the readings were taken. The plants were in damp soil, but they had not been watered for several days. The problem with this method of evaluating vegetation performance is that measurements are difficult to make because the area of the leaves is very small.

2.2.2. Results

The grass-covered surfaces had the lowest surface temperature as compared to any other paving material. The surface temperature ranged from 7 to 20 degrees below the ambient air temperature. Unlike the paving materials, the grass in shade showed a small temperature difference as compared to the grass in sun. Medium sized shrubs and plants also showed a temperature difference of 8 to 20 degrees below the ambient air temperature.

2.2.3. Findings

The results showed that the surface temperatures of vegetation are always slightly below the ambient air temperature. Typically surface temperatures will be 4° to 12 °F below, and sometimes considerably cooler, showing that they can contribute considerably in controlling the microclimate of a place.

Vegetation and leaf surface temperatures are always variable. They are dependent on species, health, maturity, and watering schedule. As air temperature rises evaporation of some plants close down, and thus allow their temperatures to float to ambient, as an act to conserve water. So, plant selection becomes an important criterion for determining cooling effect. At night, plants do not evapotranspirate but follow ambient air temperatures. Thus plants have a neutral effect on MRT at night. All measurements were made in midday when maximum temperature differences can be observed.

2.3. CANOPY MATERIALS

A canopy material that gets hot can become a very effective radiative plane transmitting its heat down to the passengers below. On the other hand, a well chosen canopy material will allow as little heat as possible to radiate down to the platform, thereby acting as a true shading device, and will protect passengers from the hot valley sun while they wait at the station. The materials for canopy were classified into two categories and tested as follows:

- Translucent materials- Fabrics
- Opaque Materials – Metals

2.3.1. Fabrics

Although several samples of materials have been received, discussed and tested, only one has been carefully reviewed for potential recommendation. That material is “SHEERFILL V H.T.” manufactured by Saint Gobain. SHEERFILL uses a woven fiberglass substrate with polytetrafluoroethylene (PTFE) coating on top and bottom for superior weather resistance. The size of the two samples was 1 x 1 meter (40”x 40”). Tested was done in June 2002 and again in August 2002.

Testing Procedure

A series of radiation thermometer readings were made outdoors on the solar test roof, using the same sample in two positions. The goal was to measure performance characteristics at characteristic Phoenix summer weather conditions low angles of incidence, especially late in the day, on a hot summer day. This should verify and extend manufacturers claims, and provide first hand input for comfort calculations.

In the first position the fabric sample was kept at 18º to the sun’s path, which is the position of the sun at 4 PM on 21 August. Multiple reading were made on a hand held ‘Raytek Rayngner ST’ infrared thermometer, over a period of 10 minutes.

Readings were made on the sun side, the Outside; and on the shaded undersurface, the Inside. In the second position, the fabric sample was mounted at a tilt angle of 42º, facing due south. But at each test time, the sun’s position had changed, so the incident angle changed. Thus each set of readings represented a different set of incident sun angles. In the previous test, the sample was mounted in a deep polystyrene frame and the inside readings were vented but shielded from the radiant influences of adjacent materials. In this second test, the solar heated metal grating of the platform floor was influencing the inside temperature, thus emphasizing the important thermal contributions from the floor that reduce the fabric effectiveness as a cool surface.

Results

The SHEERFILL fabric seems to have a high infrared emittance, because surface temperatures are always below that of ambient air temperature. In other words this material is a very good radiator, emitting high levels of both incident and ambient energy.

The superiority of the SHEERFILL fabric in terms of low radiant temperature was demonstrated by side-by-side comparisons with other fabrics. At high solar angles (near normal to the surface) there is little difference between temperatures on each side of the fabric, and both are close to the ambient temperature. Thus re-radiation was less effective because it was facing directly towards the sun. At low incident solar angles, such as early and late in the day, both sides of the fabric are significantly lower in temperature than ambient temperatures. Thus the surface presented a cool radiant temperature. However at low sun angles, a flat canopy provided little shade because of the geometrical relationship.

2.3.2. Metals

In this category several samples of perforated metals were tested. Perforated metal has many applications, including screening, ventilation, protection, or decoration. They come in a wide array of perforation designs as well as metal types, gauge and openness factor.

Testing Procedure

The experiment covered seven different perforated panels made from four different metal types, six different openness factors, three different hole shapes, and three different known gauges.

Perforated metal panels were mounted on a wooden frame sloped at 32° approximating the Phoenix latitude. The panels were 24"x24" sizes conforming to ASHRAE standards for product evaluation. The surface temperature and the mean radiant temperature were recorded for each of the perforated panels. The additional sets of data collected were the ambient air temperature and the total solar incident radiation. The readings were taken at ten-minute intervals over the course of several days.

Results

Surface temperatures were always higher than the ambient. The lab test showed that the smaller the openness factor, the lower were the temperature differentials. However, keeping in mind the multiple variables it was difficult to discern whether this was due to the hole size, the metal types or spacing. More testing in the area is planned.

2.3.3. Findings

Among the three categories of canopy materials tested the fabric "SHEERFILL V H.T." performed the best and because of its demonstrated thermal and optical properties this material is strongly recommended as a standard for canopy shade structures for Valley Metro Rail Stations.

2.4. WATER FEATURES

Several existing water featured were studied and the concept of wet walls tested for use in Valley Metro Rail stations. Wet walls are a concept of robust water features that could become a signature of the Valley Metro Rail system. Aside from the significant symbolic and aesthetic opportunities, such an idea could provide two primary cooling functions as shading walls and as surfaces cooled by evaporation, without being compromised by security or high maintenance.

The wet wall concept utilizes the cooling capacity of water to cool down the surface of the "wall" or column. The surface temperature is influenced by water temperature (by conduction) and by evaporative cooling based on the relative humidity of air. This wall can then act as a radiative surface to help cool down objects in its proximity.

2.4.1. Test Description

The aim of this experiment was to build a scaled down prototype of a wet wall and measure its surface temperatures when dry and wet while under varying conditions such as; exposure to direct solar radiation, level of wetness etc. Knowing the surface temperatures will allow us to know the contribution of such a wet wall to the radiant field.

The walls/columns are constructed of standard hollow concrete blocks 6" x 6" x 8" in dimension. The blocks were stacked in two columns of five blocks each and the joints sealed. Water was filled in one column and it could pass through to the other column via a connecting pipe at the top of the columns. Water was filled from the top of one of the columns, and flowed onto the other column via a pipe connecting the two columns at the top. Excess water dripping down the columns was collected in a trough below the columns. The study covered three stages of "wetness" for the column: overflow – when water cascades down from the top of the column, wet – when water seeps through the concrete and keeps the surface continually wet with water trickling down the outside of the column, and damp – when the surface is wet enough just to allow evaporation to take place, but no trickling of water.

2.4.2. Results

The nearby shaded dry bulb air temperature remained unaffected by the experiment. Also the temperature of the water was uncontrolled, thus initially it was warm and was further heated by the solar heated surfaces, and then as evaporation began the temperatures naturally dropped.

When water was filled into the columns, the temperature drop was not very significant, but temperatures recorded when wet were comparable to those of the previous days. However, when water was allowed to overflow, surface temperatures were the highest recorded for the day.

2.4.3. Findings

The lowest temperatures were recorded in the last experiment when water that was filled in the column cavity was allowed to seep through the concrete blocks and dampen the column surface. This water then evaporated from the surface, thereby cooling it.

In the case where a continuous flow of water was allowed to run down the column surface, the temperature readings were reduced only to the temperature of the water itself, since the radiative cooling/heating coming from the continuous film of water on a surface was from the sheet of water, and not from the hard architectural surface that was behind it.

Water for this experiment came continuously from the main supply and was not looped back into the columns from the trough. Looping the water might have cooled it down, since every time the water flows over the column surface, some of it evaporates, leaving the rest of the water cooler.

2.5. COOL SEATS

This strategy was developed and tested in the form of two prototypes for mechanically cooled seats, which provide personal cooling by conduction. The details of this category are presented in a separate paper, which is also being presented at this conference.[2]

3. CONCLUSIONS

The goal of architectural material selection for station design for the Valley Metro Rail System, VMR was to identify those materials that offer the lowest surface temperatures during the summer-overheated period, although complete shade was the first best strategy for all materials. Thus the thermal merit was expressed as a numerical value (ΔT). The lowest number was the best performer. That number also represents the difference in surface temperature related to ambient or dry bulb temperature. Since readings were taken over many days and varying conditions these values were within 5% plus or minus expected performance. The goal was to use materials; assemblies and locations that provide surface temperatures below ambient during summer days between noon and 4 pm.

The study came up with a guideline for recommending the materials for the Valley Metro Rail Station designs for achieving outdoor thermal comfort condition.
Based on the measurement program under local summer conditions as well as published data about the solar thermal performance of building materials the guide proposed priorities in selecting materials. These recommendations have been incorporated in the proposed Valley Metro Rail station designs. But there are many other criteria aside from thermal performance that influence such design decisions, which are normally part of an architect's design process. Thus the guide was intended to add another layer of information to professional decision making; not to replace it.

ACKNOWLEDGEMENTS

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