

THERMAL EFFECTS OF VINES ON WALL TEMPERATURES- COMPARING LABORATORY AND FIELD COLLECTED DATA

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ABSTRACT

This paper summarizes some recent results from an ongoing series of experiments on the effects of vegetation on building surface temperatures and microclimate. For several years we have conducted experiments on the thermal effects of vines on wall surfaces at the energy laboratory of the UCLA Department of Architecture and Urban Design. Our experimental setup, which consists of a series of vertical aluminum plates in both south and west facing orientations with a variety of vines growing in front of them, allows us to simultaneously measure differences based on surface color, vine type, vine thickness and orientation. This work, reported on in previous papers (ASES 2000, TIA 2000) showed that vines grown against test panels at a thickness of 12-14 in (30-35 cm) reduced surface temperatures to, or just below, the level of the dry bulb temperature. The aluminum panels of the test modules are inexpensive, easy to handle and set up, but are not a common or typical building surface material. In this paper we will compare data from our test modules to data collected for vines growing against walls of stucco and brick and in configurations that were difficult to duplicate with the test modules.

One test is being done at the UCLA energy lab itself. We have placed vines in front of a south facing brick wall that is part of the Architecture building. Surface temperature is measured in several places in the shade of the vine and on the exposed brick surface. We have also placed thermocouples in holes drilled to the center point and the inside edge of the brick surface in order to track heat

transfer through the material. Another test is being done on a west facing stucco wall with a vine covering that is from 8 - 16 inches thick. In this test thermocouples were placed on the stucco surface in both sun exposed and vine shaded areas. At the same location we have conducted a test of the thermal conditions around a west-facing pergola covered with a Wisteria vine.

1. LABORATORY EXPERIMENT- DESIGN AND DESCRIPTION

The experimental set-up consists of a series of vertical modules, each with of 2 aluminum sheets mounted on styrofoam panels. In each module, one of the aluminum sheets is painted flat white and the other is painted flat brown. A thermocouple is attached to the back of each aluminum sheet at the center point (see fig.1). The experiment consists of five south facing modules and four west facing ones. One module in each orientation is left without any planting as a control. Test plants are grown in front of (or on) each experimental module. Plants are allowed to grow until they cover both panels of each module. Vining plants vary considerably in form and growth habit, so we have tested a number of different plant species including; Boston ivy, honeysuckle, jasmine, trumpet vine, wisteria, grape, peas, tomatoes and beans. At this time we are growing two different evergreen vines (Jasmine polyanthemum and Lonicera halliana), and one deciduous vine that is self-adherent (Parthenocissus tricuspidata or Boston Ivy) on each orientation.

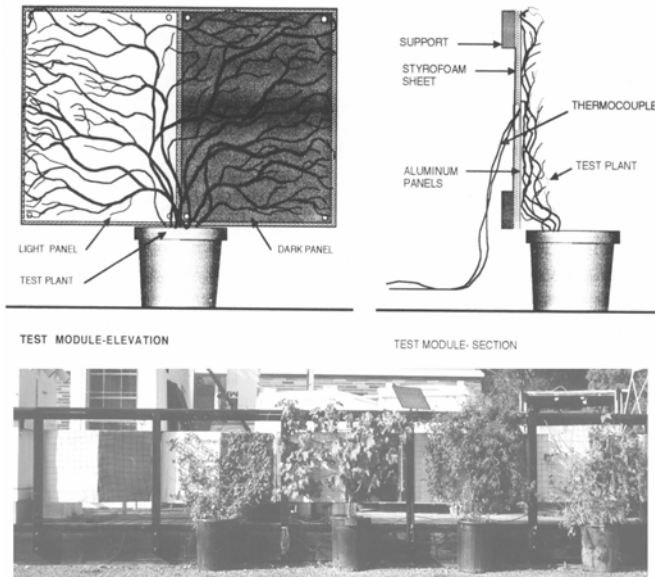


Fig. 1- Photo and diagram of experimental setup

In addition to the control and experimental module thermocouple data, basic weather data is collected at a weather station adjacent to the experimental panels. We monitor and collect data on air temperature, relative humidity, wind speed, wind direction, and solar radiation. Data is collected every 10 seconds and is averaged for 10 minute periods. We also process this data into hourly averages, daily maximums, daily minimums and daily averages.

1.1 Measuring Performance-

The heat capacity of the aluminum panels is very small, so their temperature responds to the instantaneous changes in the ambient air temperature (DBT) and solar radiation absorbed by the plates. Therefore, the elevation of the surface temperature above the DBT can serve as a substitute input data for the analysis of the shading effectiveness of the vining plants.

The suppression of the maximum temperature of the experimental panels above the maximum of the controls was evaluated as a ratio of the differences between the control and the shaded panel maxima to the control minus DBT. This ratio represents the shading effectiveness of the vines. This can be expressed in the following formula:

$$\text{Shading Effectiveness Ratio} = (\text{Control minus Shaded Panel}) / (\text{Control minus DBT})$$



Fig. 2- Campsis vine on a South facing brick wall

2. TEST OF VINES GROWING AGAINST A BRICK WALL

This test is not really a field test, but rather an additional test at our energy laboratory. Here we placed a red trumpet vine grown on a frame in front of the south facing brick wall at the edge of our lab space. Thermocouples were placed on the brick surface in three locations in the area shaded by the vine and on the brick surface that is exposed to the direct sunlight. We also placed thermocouples within the sun exposed brick at the center point and at the inside edge of the brick to monitor heat transfer through the material. A K&Z Radiometer was also placed on the wall to monitor solar radiation on the exposed wall surface. The vine was similar in thickness (12-16", 30-35cm) and foliage density to the Lonicera or the Jasmine on the South facing test panels. Data was collected on the laboratory Campbell Scientific CR-10 data loggers.

The chart in figure 3 shows daily maximum temperatures for the month of September, 2001. Data from the South facing experimental modules is combined with data from the South facing brick wall. The inputs included from the experimental panels are the dark control panel, the dark jasmine vine and dark Lonicera vine (honeysuckle) inputs. From the brick wall test, the inputs from the exposed brick surface, and three vine shaded locations are shown. Dry bulb temperature from the weather station is also shown. The three vines illustrated here were all approximately the same thickness and density; twelve to fourteen inches (30-35cm) with the jasmine being less dense than the

honeysuckle or trumpet vine. The color of the exposed brick and the color of the dark experimental panels is nearly the same. Based on daily maximum values, the performance of vines on the experimental panels and on the brick wall was nearly the same. The three shaded brick inputs and the dark lonicera form one line, which also closely follows the daily maximum DBT. The jasmine vine, which was thinner than the other two test plants, had readings that were two to five degrees above DBT and the other test plants. The dark control panel and the exposed brick surface also had very similar performance, with the daily maximums within one or two degrees of each other. During this period, the trumpet vine and the lonicera reduced the daily maximum surface temperature from twelve to twenty one degrees C each day and the jasmine reduced the daily maximum from eight to fifteen degrees C.

Sept 01, Daily Maximums- So. Dark Cont., Dark Jas. & Lon., South Brick Exposed and Shaded

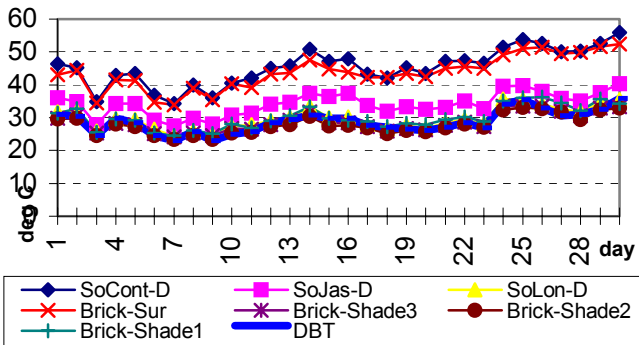


Fig. 3- Chart of Sept. 2001, daily maximums

Sept 30, 2001- DBT, South dark control, Exposed brick surface, Shaded panel and brick

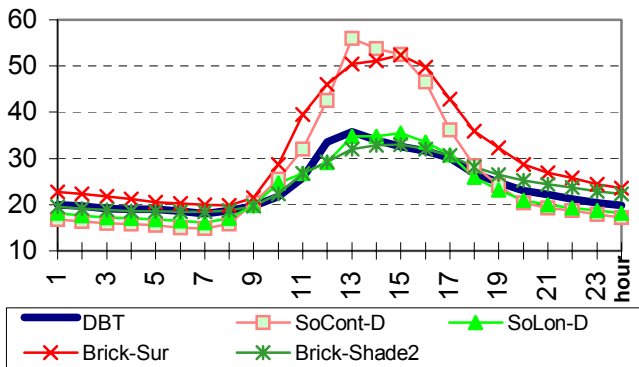


Fig. 4- Chart of Sept.30, 2001

Figure 4 shows the daily temperature patterns for Sept. 30, 2001 for the exposed brick surface, dark control panel,

shaded brick and shaded experimental panel, and dry bulb temperature. In general, there was very little difference in the results from the brick surface and experimental panels. The curve for the two exposed surfaces were similar, the dark control panel reached it's peak at the same hour as the DBT and the exposed brick reached maximum two hours later. The maximum on both of the brick surfaces shown here occur two hours later than those from the aluminum test panels. The difference between the temperature of the exposed and shaded surfaces was approximately 20 degrees C at the maximum for both materials. Shading effectiveness ratios for both were also similar, the honeysuckle shaded dark test panel had a ratio of 1.1 and the trumpet vine shaded brick had a ratio of 1.3 at the DBT maximum. Since surface temperatures for both were below the DBT, it is apparent that some of the surface temperature reduction in these cases was due to evapotranspiration by the plant

3. TEST OF A WISTERIA VINE GROWING ON A WEST FACING PERGOLA



Fig. 5- Photo of Wisteria covered pergola in Encino, Ca.

The west-facing pergola covered with Wisteria sinensis in the photograph above was monitored for a period of approx. one year. A pergola is a very common and practical use of vines. A pergola-grown vine has the advantage of being able to shade glazed as well as opaque building surfaces. The pergola also creates a vine shaded outdoor space adjacent to the building, increasing outdoor comfort on hot days and lowering the thermal load on the building envelope. The pergola in this test is 40 feet long, ten feet high and extends twelve feet from the west wall of this single-family residence. It is located in front of a two-story portion of the house so there is 9 feet of unshaded wall above the pergola. (see photo #1)

A “portable” Campbell Scientific data logger was installed at the site. Instruments to measure DBT, relative humidity, wind speed and direction, and light levels were set up and thermocouples were placed as shown in the section illustration below.

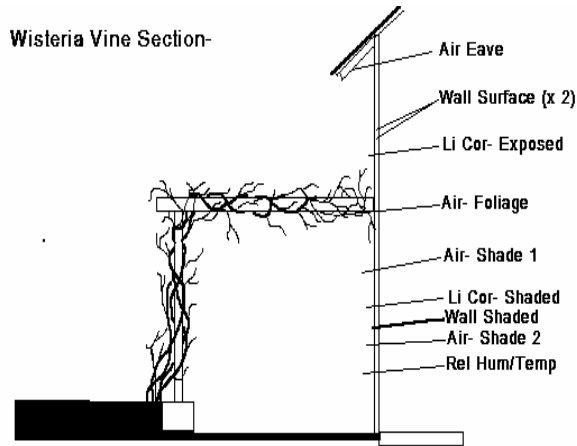


Fig. 6- Pergola section showing thermocouple locations.

Air temperature, wall surface temperature and light levels were all measured to determine the effects of the vine-covered pergola on the building envelope, and on the patio spaces adjacent to the building. Wall surface temperatures were measured above the vine covering and below. Air temperatures were measured above the pergola, within the foliage mass and at two levels below the foliage. Light levels were measured at the wall surface both above and below the vine covering. (See figure 6). The stucco surface of the house is painted light gray.

The site is in Encino Ca., part of the San Fernando Valley, just north of the Los Angeles basin. The climate here is marked by hot summers with daytime highs in the 90’s (32-37 deg C). Heat waves with temperatures in the range of 100-105 deg. F (37-40 deg C) are not uncommon. Afternoon and evening overheating is a particular problem here, especially in situations with large exposed west facades.

The homeowners were informally surveyed to determine how usage of the house has changed since the addition of the pergola and vines. One homeowner characterized the general thermal condition of the house before and after the addition of the pergola and vines as follows: “The house used to seem hot. We didn’t close drapes to block the sun, but we ran the air-conditioning a lot. Now it is actually cool. Many times I go outside and am surprised to find how warm it is”. The outside space adjacent to the house could be very uncomfortable on summer afternoons.

3.1 Results

The sample charts of some of the data below show the daily pattern of temperatures at the surface and of the air in several locations adjacent to the west side of the house during several days in July of 2001. Surface temperatures were reduced by up to 30 deg. C. Air temperatures in the foliage and below were reduced by 7-10 deg. C. The vine and pergola shading suppress both amplitude and timing of the daily patterns compared to the exposed west walls. Maximum temperature in the shaded locations was reached 3 hours earlier than at exposed locations.

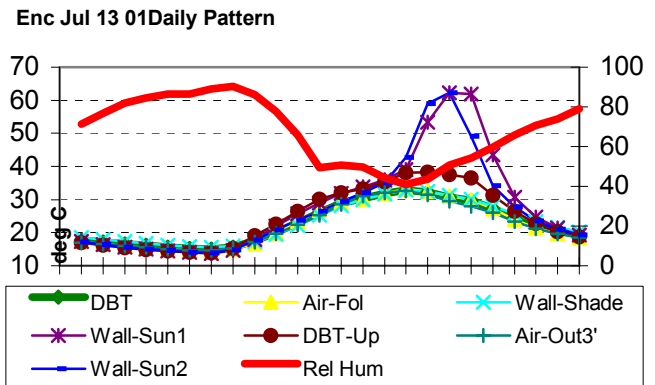


Fig. 7- Chart for Encino July 13, 2001 Daily Pattern

This graph shows a single day in July, 2001. A consistent characteristic of all of the charts from this site is that all of the temperature outputs show effects of the west wall microclimate of this location. All of the temperature measurements show peaks in the late afternoon, the thermocouples that were shaded by the Wisteria vine have peaks at 3-4 PM, while the thermocouples above the vines reached their maximums between 5 and 7 PM. Typical daily temperature patterns from weather stations would reach maximums much closer to noontime. The differences in temperature between the shaded and exposed wall surfaces are striking between the hours of 5 and 9 pm. The shaded wall reaches a maximum temperature of 32deg C at 5pm the exposed wall inputs reach maximums of approx. 62 deg. C near 7pm. The air temperature above the pergola between 5 and 8 pm was 5-7 degrees C higher than the air temperature inside and below the vines. During the earlier part of the day the air and surface temperatures above the pergola form one line and the air and surface temperatures below form another, approximately two degrees lower. At night, all of the inputs form one line, with a slight elevation (1 deg C) for the wall surface that is below the vines.

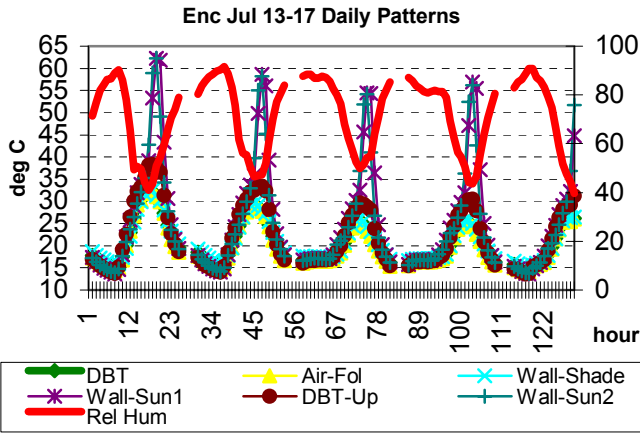


Fig. 8- Chart of Encino Daily Patterns, July 13-17, 2001

This graph shows typical output for several days in July 2001. The outputs displayed here are for air temperature above the pergola (DBT up), air temperature in the Wisteria foliage (Air-fo), wall surface temperature in the shade, wall temperature at two locations above the pergola (Wall-Sun 1 and 2) and relative humidity. This graph clearly illustrates the problem of exposed west walls. The daily peak surface temperatures occur in the late afternoon/early evening hours and ranged from 55-63 deg. C (131-145 deg.F) . The exposed wall surface temperatures were approximately 25 deg. C (45 deg F) above the air temperature at the peak, 30 deg. C above the shaded wall surface temperature and 34 deg. C (61 deg F) above the air temperature measured within the Wisteria foliage. Air temperature measured within the foliage of the Wisteria vines were several degrees below the shaded wall temperatures and 6 or 7 degrees C (12 Deg. F) below the air temperature measured above the foliage at the peak.

4. TEST OF GREWIA AND PYRUS ESPALIERS GROWING ON A WEST FACING STUCCO WALL.

At the same site as the pergola described in the section above, we also tested a section of west facing wall that was partially covered by a combination of two plants; Grewia caffra and Pyrus kawakami. These plants are not vines, but are shrubs grown as espaliers against this stucco wall. The foliage in this test was approx. 8-14" thick. One thermocouple was placed on the wall surface shaded by the plants and another was placed in a sun-exposed location. The stucco is painted a light gray color.

In Figure 10, data from the adjacent vine covered pergola is shown with the outputs from the shaded stucco wall. The

plants were approximately 10 inches thick at this point. The foliage was not as dense as the wisteria vine. The three exposed wall locations shown all have a similar pattern and temperature range. The maximums range from 54 deg. C to 58 deg C (129-136 deg. F). The surface shaded by the espalier plants had a maximum temperature that was 29 deg. C (52 deg. F) lower than the exposed surface.



Fig.9- Photo of a stucco wall and espaliers, Encino, Ca.

Encino Aug. 21,2001; Pergola and Espalier- Exposed and Shaded Stucco, Air t, Foliage t

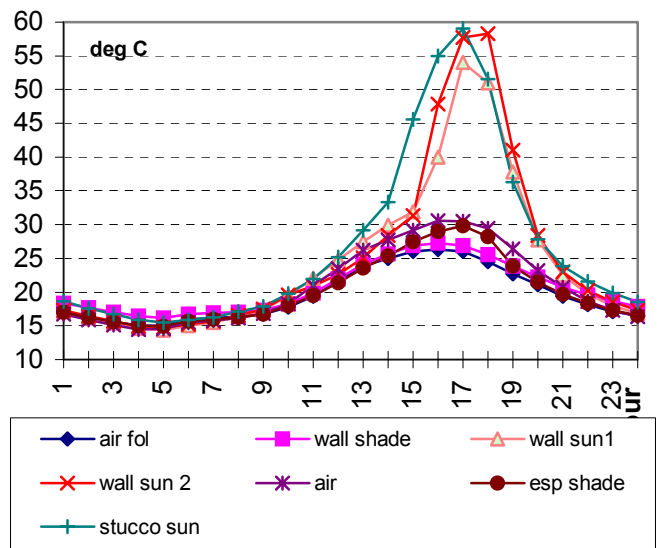


Fig. 10- Chart of espalier and pergola data

5. CONCLUSIONS

Reduction of heat gain is a prerequisite to an effective passive cooling strategy. In the introduction to Passive Cooling, Jeffrey Cook states: "In modern construction the various means of heat avoidance are by far the most economical energy conservation methods in spite of the availability of many technical or mechanical solutions." (Cook, p.8) Later, he mentions the state of research on the use of landscape for heating and cooling: "The potential of landscape to produce heating and cooling effects was also largely neglected. Although the general effectiveness of vegetation, especially trees, to provide low cost cooling was well known, there are few quantified studies..." (Cook, p.31) We hope that this work begins to provide quantified data to support the use of vines in producing effective cooling strategies for buildings. Vines are particularly suited to uses around buildings. They require little space, grow very quickly and can cover large areas of a building surface. Our laboratory work has shown, and the field tests presented here seem to confirm that:

- Vines grown against a building surface at a thickness of 12-14 inches (30-35 cm) can reduce surface temperature to the level of, or slightly below, the ambient air temperature.
- Vines grown to a thickness of 12-14 inches (30-35cm) can eliminate the effect of surface color. (Sandifer, p. 619)
- Vines growing directly on walls or on pergolas can be an effective means of reducing the problem of west wall heat gain.
- A vine covered pergola can; modify surface temperature as well as surface grown vines, shade glazed openings and provide more comfortable exterior space next to buildings.

Further work to be done includes: more careful analysis of data during non maximum daytime hours; analysis of nighttime performance data; tests on the effects of vines in combination with other landscape elements; producing better field test weather data inputs.

6. ACKNOWLEDGMENTS

We would like to thank Lee and Janet Dicker for allowing their garden to be used as a laboratory.

7. REFERENCES

- (1) Cook, Jeffery, ed., Passive Cooling, MIT Press, 1989
- (2) Sandifer, Steven and Givoni, Baruch, Thermal Effects of Vines on Wall Surfaces, Proceedings of the 25th National Passive Solar Conference, American Solar Energy Society, 2000