VERNACULAR HOUSING, PAST AND PRESENT

Designer and Occupant: Roles in Residential Courtyard Cooling

John S. Reynolds
University of Oregon

Courtyards are a typical vernacular building type in many areas of the world. They allow rather dense settlement patterns, while preserving the privacy of outdoor spaces. As typically constructed a courtyard building's exterior walls are exposed only on the sides of the courtyard, and the side facing the street. All other exterior walls are common to neighboring buildings. Courtyard buildings are particularly suited to hot dry climates, where deep courtyards provide shade; major cooling strategies are evaporative and radiant cooling (to the cold clear sky); and wind velocity is not as critical to comfort as it would be in hot humid climates.

Courtyards utilize three heat sinks (sky, air, and earth) and four modes of heat transfer (convention, conduction, radiation, and evaporation). This presents a complicated set of cooling opportunities, with challenges both to the designer and the occupant. The designer determines, at the birth of the courtyard, its proportions and materials, strongly influencing both access to the heat sinks and the predominant modes of heat transfer. The occupant "thermally sails" the courtyard throughout its life, taking advantage of timely access to heat sinks and modes of transfer. As seen in Table 1, sinks and modes vary from cooling threats to opportunities, some better by day, others better by night.

It is difficult to identify either one primary heat sink or one mode of heat transfer, when so many sinks and modes are potentially at work. Martin (1) favors radiation:

"The courtyard mass (e.g., ground and walls) cools at night primarily because of radiative heat loss, and a volume of cool air is trapped within its boundaries if the wind is weak enough to not cause mixing. This air in turn may be effective in removing heat from the interior of the building and its massive structural elements so that internal coolness persists through part of the following day. Direct solar heat gain should be reduced by shading or vegetation, especially when it is incident on massive surfaces capable of storing heat."

Lowry and Lowry (2) emphasize evaporation and shading:

"The Hispanic courtyard is usually surrounded, and partially overhung, by pueblo-like, thick-walled chambers with small apertures...What is so distinctive in this kind of residence is the considerable list of means for fine-tuning both solar heating and evaporative cooling, the amount of fine-tuning depending on the season and the day's weather. For solar control in smaller courtyards, light-colored, canvas covers are mounted on supporting guides. The covers can be rolled out of the way against one wall, stretched over most of the courtyard, or places somewhere between. This *toldo* provides partial, diffusing shade that can be varied in both time and degree according to circumstances."

Givoni (3) also emphasizes evaporation, and observes:

"Many courtyards have areas that are paved with such materials as stone, tile, or bricks. The temperature of the pavement affects the radiant field in the courtyard and, if the yard's air volume is partially isolated from the general environment, it can also have some effect on the temperature of the air above. The temperature of the pavement in a private courtyard can easily be lowered if the pavement is regularly wetted during the hot hours of the day, because the evaporation from the surface of the moist pavement draws almost all the energy for the vaporization from the pavement. If the walls of the courtyard are cooled by a water cascade, the water flow can continue under the pavement of the courtyard into a pond, thus further lowering the environmental radiant temperature of the space."

From my observations, the designer's choice of courtyard proportions and flooring materials, combined with skillful thermal sailing by the occupants — shading, watering, and night ventilation — are the keys to successful cooling in a hot, dry climate.

I. The Designer

The designer's choice of courtyard proportions results in its aspect ratio, defined (4) as

$$\frac{\text{area of the courtyard floor}}{(\text{average height , surrounding walls})^2}$$

For reference, a courtyard in the form of a cube would have an aspect ratio of 1.0.

Higher aspect ratios indicate more sky exposure, thus more solar heat gain by day and also more radiant heat loss by night to the cold clear sky. Higher aspect ratios signify more shallow courtyards, more easily swept by the wind, and a floor area relatively great compared to wall area. They also offer a higher daylight factor. In sum, they are closer to the ambient conditions outside buildings.

Lower aspect ratios, then, depart more radically from the ambient conditions. With a lower aspect ratio, the courtyard floor sees less sky, and the earth heat sink is thus more influential. There is less wind through the courtyard, meaning less heat gain by day (when the air outside is hotter than in the courtyard) but also less heat loss by night. Less wind speed means less effective evaporation, further reduced by the lower daytime temperature of the courtyard floor and lower walls (because they receive less solar radiation).

A.Radiant Gain and Loss.

On a clear day at 36° north latitude (Córdoba, Spain) in August, an unshaded horizontal surface will receive about 6,140 W/m^2 (1,950 Btu/ft^2 hr) of solar radiation (5). How does this compare to radiant loss by night? Martin (6) establishes conditions of an ambient temperature of 27°C and dewpoint of 16° C (80.6°F and dewpoint of 60.8°F), with wind speed = zero. If a courtyard's floor surface temperature is 7C° higher than ambient temperature, then about 75 W/m^2 (24 Btu/ft^2 hr) of cooling is achieved. So the daytime radiant gain is about 8 times the nighttime radiant loss.

It is evident that some method is desirable for reducing daytime solar gain, while allowing nighttime radiant loss. The moveable horizontal fabric cover, or *toldo*, is a traditional such device. The designer can provide for this feature, but it is the occupant who must activate it.

B. Shallow or Deep.

Solar radiation in a shallow courtyard strikes a rather large area of the floor, at nearly normal angle of incidence during midday. A darker floor is well prepared to receive and store such heat. In a deeper courtyard, the solar radiation strikes mostly the walls, at angles of incidence that favor reflection more than absorption at midday. When the walls are white, even more of the solar radiation is diffusely reflected, some of it leaving the courtyard. Which is then better; shallow or deep?

The relationship between aspect ratio and courtyard floor area is graphed in Figure 1, for 40 courtyards in Andalucia and Mexico. In my measurements of courtyard temperatures, I found consistently lower daytime temperatures in the deeper courtyards (with lower aspect ratios). I measured 29 courtyards with a floor area of less than 750 ft^2 (or 70 m^2). In the old and densely settled courtyard

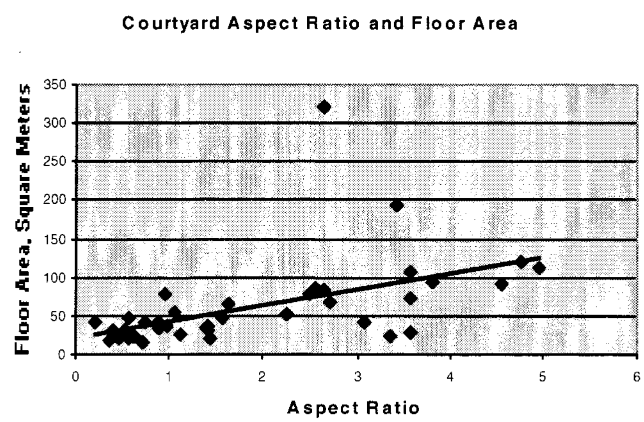

Fig. 1. Aspect ratios compared to floor areas of 40 courtyards in Andalucia and Mexico. Note that the smallest courtyards have a very wide range of aspect ratios; those with higher aspect ratios are in Mexico. The two large courtyards that depart from the trend line are in public buildings in Mexico.

neighborhoods of Andalucía, with two- or more story buildings, 12 courtyards averaged lower aspect ratios (0.71). In the Spanish colonial neighborhoods of Colima, Mexico, with mostly one-story buildings, 17 courtyards averaged higher aspect ratios (1.80). (This difference in sky exposure is all the more striking considering latitude. Andalucía at about 36° north has a maximum summer noon sun altitude of 77.5°, while Colima at 20° north has sun directly overhead, thus no shading at noon.)

C. Evaporative cooling at the floor.

Once the proportions are chosen, materials can become the design focus. Courtyard floors are unique opportunities to allow thermal properties, rather than durability, to dominate material selection. This is because they play no structural role, can be easily replaced, are able to be directly exposed to the weather, can be in direct contact with earth, and can be readily permeable to water (with the caveat that mold and mildew could become threatening to occupant health).

The courtyard floor is in contact with the earth and is the ultimate recipient of any water entering the courtyard either from the sky or from watering of plants or wall surfaces. Thus it is well situated to be an important surface for evaporation. Working against this evaporative potential are the lack of direct sun (especially in deeper courtyards) and a near absence of air motion, inherent in the courtyard's pit-like form.

Despite the disadvantages, a damp courtyard floor can lose significant heat by evaporation in the hot dry afternoon hours, if it can readily conduct both heat and moisture to its surface from the earth below. For this purpose, materials both porous and dense would be ideal. Such combinations are, of course, extremely rare (Figure 2). Instead, many courtyards utilize a floor surface made of many small, dense elements (for conductivity) set in a matrix that is highly porous to moisture. One typical surface consists of small pebbles, often in mixtures of black and light gray and set in geometric patterns, surrounded by sand or mortar (Figure 3). Another example is brick, fired at lower temperatures and thus less conductive but more permeable, set in a similar matrix.

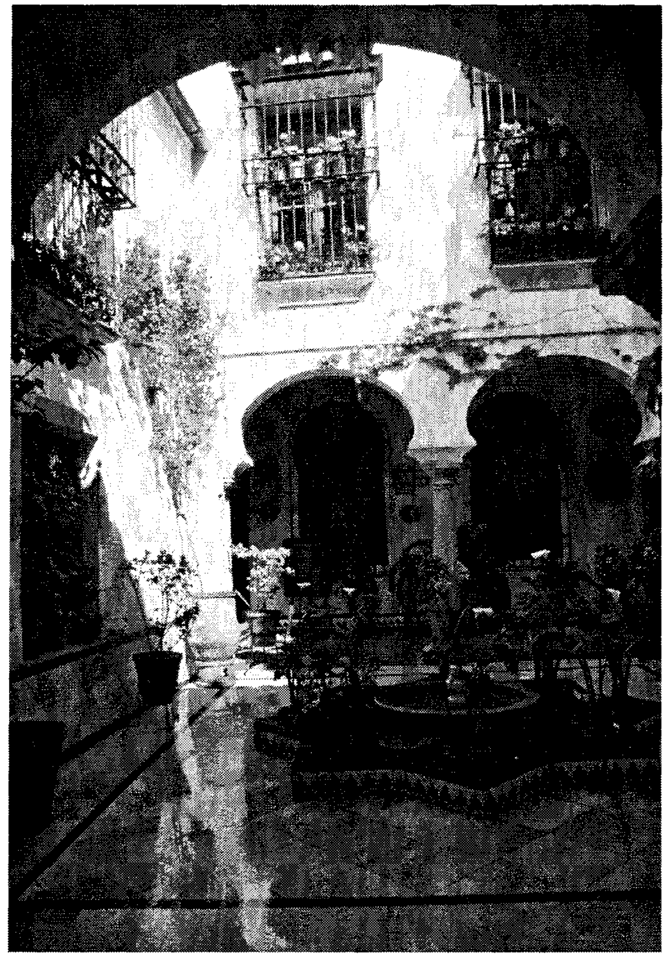

Fig. 2. Polished marble floors are very durable, connote wealth, and reflect light, but such non-porous surfaces do little to aid evaporative cooling. Cordoba, Spain, Calle Encarnacion. From John S. Reynolds, Courtyards: Aesthetic, Social, and Thermal Delight (New York: John Wiley and Sons, 2002; page 36.)

II. The Occupant

The courtyard's proportions and materials have been chosen, and the outdoor space constructed. Color is applied where appropriate (as in whitewashed stucco walls), and life within the courtyard begins. How successfully the place remains cool during the hottest and driest hours depends now on the occupants and their ability in thermally sailing the courtyard and its surrounding building.

A. Evaporation: Watering.

The great majority of residential Hispanic courtyards contain plants. A typical such courtyard will have many (sometimes hundreds) of potted plants, set on the floors and stairs, hung from the walls and from the arcades around the courtyard. These plants need regular watering during the hot dry season, and typically this is done in such a manner that spilled water runs down walls and drips from the pots onto the floor (Figure 4). In addition, many courtyards have rooted vines, shrubs, or trees that will need occasional watering. Plants, especially potted ones, thus act as a catalyst for the watering that guarantees a source for evaporation.

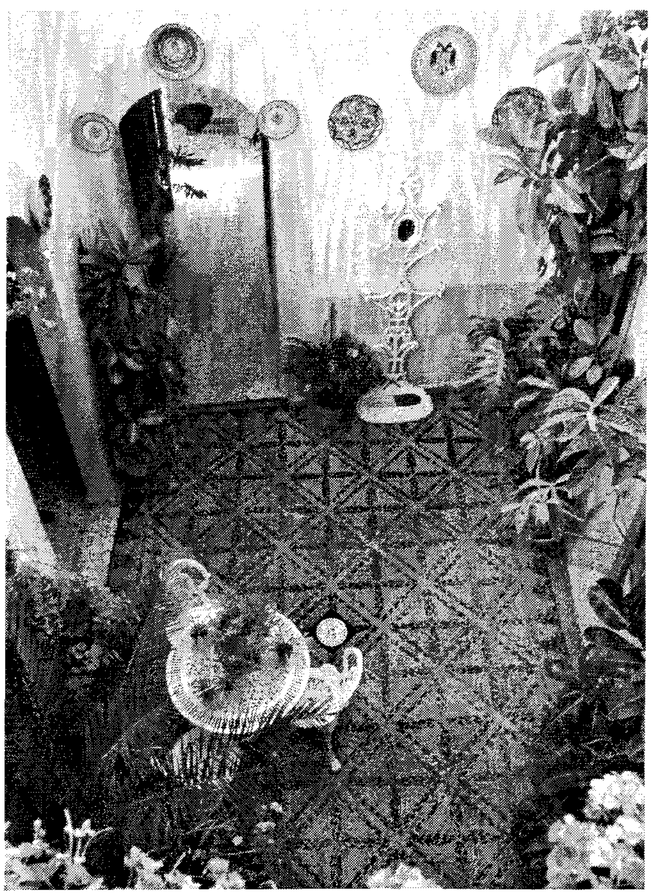

Fig. 3. Black and white pebbles, set in a porous mortar, can be wetted repeatedly during hot weather for nearly continuous evaporative cooling. Cordoba, Spain, Calle Zarco. From John S. Reynolds, Courtyards: Aesthetic, Social, and Thermal Delight (New York: John Wiley and Sons, 2002; page 35.)

Fountains are another source of evaporative cooling, and the continual sound of splashing water adds a psychological cooling reinforcement (Figure 5). Sometimes these fountains are allowed to splash or overflow onto the courtyard floor, further expanding a wetted surface with evaporative potential.

B. Radiation: the *Toldo.*

If solar radiation by day is to be diminished while radiation to the cold clear night sky is encouraged, a courtyard will need a moveable shading device. Trees are superb at daytime shading, but they block nighttime radiative transfer. Instead of trees, many courtyards use a *toldo,* a large sheet (or adjacent sheets) of fabric deployed horizontally near the eaves of the courtyard. These sheets are suspended by small metal rings that ride along wires across the courtyard, often about 1 meter on center. They are pulled open and closed by sets of ropes that are suspended below the *toldo,* usually two ropes for every wire — one to pull the *toldo* open from one end, the other to pull it closed from the other. Thus many meters of ropes are installed for each *toldo,* and these ropes are gathered into graceful lines and elaborate knots that are looped around columns, on the grillwork of gates, or on large wall hooks.

The opening and closing of the *toldo* becomes a ritual, marking the sun's rise and set. The quality of light and the exposure to wind in the courtyard change quite markedly with each deployment of the *toldo.* Dark, nearly opaque *toldos* are most common (Figure 6), because they show less accumulated dirt on the surface, and because in hot dry weather the deep shade they provide is seen as a cooling influence. Translucent *toldos* are most often white or nearly so (Figure 7), and the diffused light they provide is nearly ideal for the potted plants that so often adorn the walls and floors of the courtyard below. Sometimes the *toldo* is a translucent blue, green, or orange, but the psychological impact of such colors is of questionable value.

To my surprise, I found that the shallow courtyards that could benefit greatly from daytime shading were less likely to have a *toldo* than were the deeper ones. I believe that this is primarily due to the radiant heat generated by a *toldo* by day. As it intercepts sun, a *toldo* will rise rather sharply in temperature. In a shallow courtyard, this hot surface represents a high percentage of the radiant field for a courtyard occupant, and thus it becomes an unpleasant influence despite its shading role.

C. Night Ventilation: Windows.

In hot dry climates, windows are kept closed by day because the air outside is hotter than the air indoors. With evening, the outside air temperature descends rapidly, and shortly after sunset it drops below the indoor temperature. At this point, a skilled thermal sailor opens the windows, both to street and to courtyard, encouraging the cool air to scour the room (and courtyard) of its accumulated heat. This also requires closing the windows the next morning as the outdoor air temperature rises.

When a courtyard has unfettered access to the sky (because the *toldo* is open) and access to breezes through open windows in its walls, the chances of cooling by convection are greatly increased. This can be used to advantage during the cool nighttime hours. In Figure 8, the temperature in a living room near Seville, Spain, is compared to the outdoor (roof terrace) temperature on a series of very hot dry days. Note how, except for the last evening,

Fig. 4. A simple can on the end of a long pole is used to water the many pots hanging on the courtyard wall. Spilled water adds to evaporative cooling. Cordoba, Spain, Calle Pintor Bermejo. From John S. Reynolds, Courtyards: Aesthetic, Social, and Thermal Delight (New York: John Wiley and Sons, 2002; page 45.)

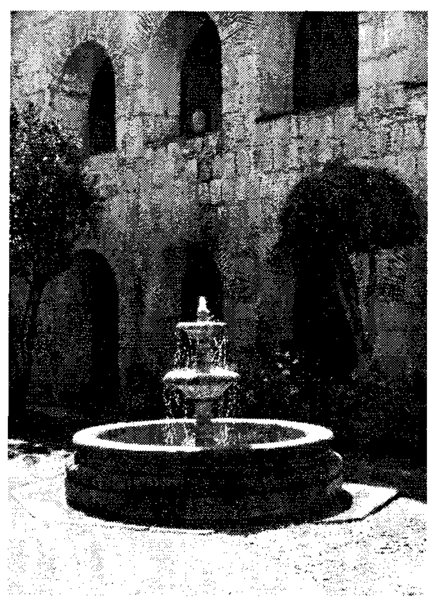

Fig. 5. A splashing fountain, backlit by the sun, adds psychological cooling through sight and sound. Oaxaca, Mexico, Hotel Camino Real. From John S. Reynolds, Courtyards: Aesthetic, Social, and Thermal Delight (New York: John Wiley and Sons, 2002; page 55.)

Fig. 6. The nearly opaque toldo darkens the courtyard by day, protecting everything below from direct sun. The small holes prevent accumulated rain from adding unsupportable weight. Cordoba, Spain, Calle Osio. From John S. Reynolds, Courtyards: Aesthetic, Social, and Thermal Delight (New York: John Wiley and Sons, 2002; page 87.)

windows were opened almost at the moment that the falling outdoor temperature dropped below the indoor temperature. And note the consequences for the room's temperature of the delayed opening on that last evening. Note also that each morning the windows were closed rather later than would have been ideal.

III. Summary.

Designers of courtyard buildings must consider the aspect ratio as they choose courtyard proportions. Deeper courtyards (smaller aspect ratios) favor cooling performance in hot dry summers, but at the expense of daylight and wintertime access to sun. Designers can choose floor materials that encourage evaporative cooling: small dense paving units in a generous matrix of absorptive sand or mortar. Occupants of courtyards are the real arbiters of cooling comfort, as they thermally sail the space, taking advantage of hot dry days and cool clear nights and the resulting the shifts of available heat sinks and modes of heat transfer.

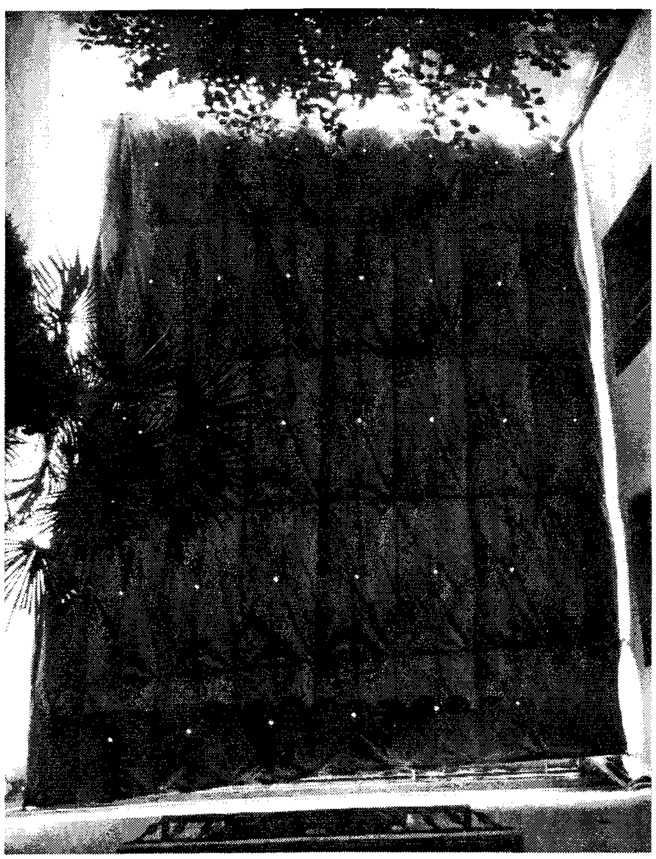

Fig. 7. The translucent toldo diffuses sunlight, and absorbs less heat than the darker opaque version. Bornos, Spain, Calle Alta. From John S. Reynolds, Courtyards: Aesthetic, Social, and Thermal Delight (New York: John Wiley and Sons, 2002; page 144.)

Notes

1 Martin, Marlo. "Radiative Cooling" in Jeffrey Cook (ed.) *Passive Cooling.* Cambridge: MIT Press, 1989, p.171.

2 Lowry, William P. and Porter P. Lowry II. *Fundamentals of*

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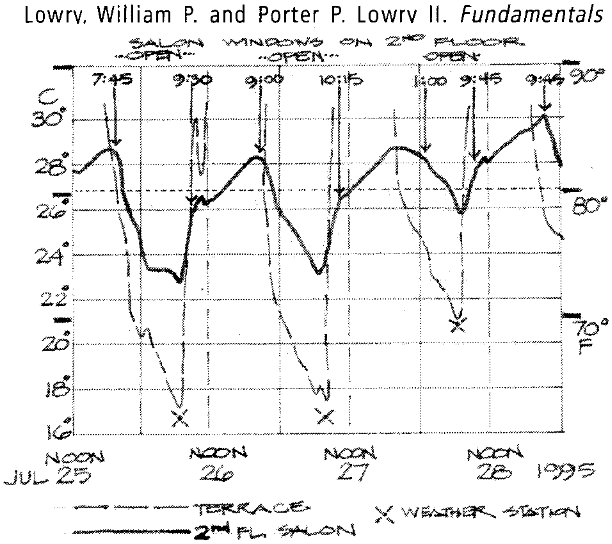

Figure 8. Temperature comparisons between ambient (terrace) and the living room (salon), showing the impact of night ventilation. July 25-28, 1995, Bornos, Spain. Daytime temperatures reached 42° C (108° F). The moment of window closings by day, openings by night are clearly visible by the change in salon temperature. From Carrasco, Victor and John S. Reynolds, "Shade, water and mass; passive cooling in Andalucia" in Proceedings of the 21st Annual Passive Solar Conference (Boulder: American Solar Energy Society, 1996).