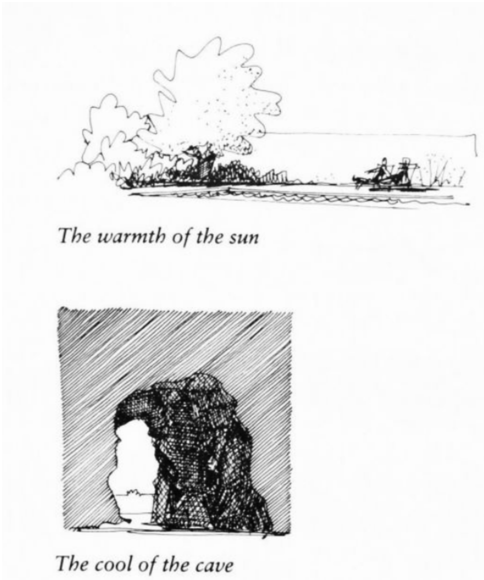


Figure 3[1] (Moore, Mitchell and Turnbull Jr.)

III. Taxonomic Investigations

In the Medieval Islamic world, sophistication and refinement were defined by satisfaction and well-being.[1] The key to unlocking how the Nasrids is the skilled production of a passive climate control system, or comfort zone, designed to help the body achieve thermoregulation. Exploiting territory, managing water, and structuring the Alhambra were essential to this process, as they helped the Nasrids control the flow and humidity of air. While paradisiac engravings in the Alhambra's walls provide fragments of the Nasrids' bioclimatic recipe, the most complete formula is a very literal poem authored by Granada Ibn Luyun in 14th Century Granada:

With regard to houses set amidst garden an elevated site is to be recommended, both for reasons of vigilance and of layout;
and let them have a southern aspect, with the entrance at one side, and on an upper level the cistern and well,
or instead of a well have a watercourse where the water runs underneath the shade.
And if the house have two doors, greater will be the security it enjoys and easier the rest of its occupant.
Then next to the reservoir plant shrubs whose leaves do not fall and which [therefore] rejoice the sight;
and, somewhat further off, arrange flowers of different kinds, and, further off still, evergreen trees,
and around the perimeter climbing vines, and in the centre of the whole enclosure a sufficiency of vines;
and under climbing vines let there be paths which surround the garden to serve as margin.
And amongst the fruit trees include the [common] grapevine similar to a slim woman, or wood-producing trees;
afterwards arrange the virgin soil for planting whatever you wish should prosper.
In the background let there be trees like the fig or any other which does no harm;
and any fruit tree which grows big, plant it in a confining basin so that its mature growth
may serve as a protection against the north wind without preventing the sun from reaching [the plants].
In the center of the garden let there be a pavilion in which to sit, and with vistas on all sides,
but of such a form that no one approaching could overhear the conversation within and whereunto none could approach undetected.
Clinging to it let there be [rambler] roses and myrtle, likewise all manner of plants with which a garden is adorned.
And this last should be longer than it is wide in order that the beholder's gaze might expand in its contemplation.

Figure 3[2], 3[3] Aerial plan showing wind tunnel simulating prevailing wind velocity over Digital Elevation Model of Granada at 5 meter LIDAR accuracy

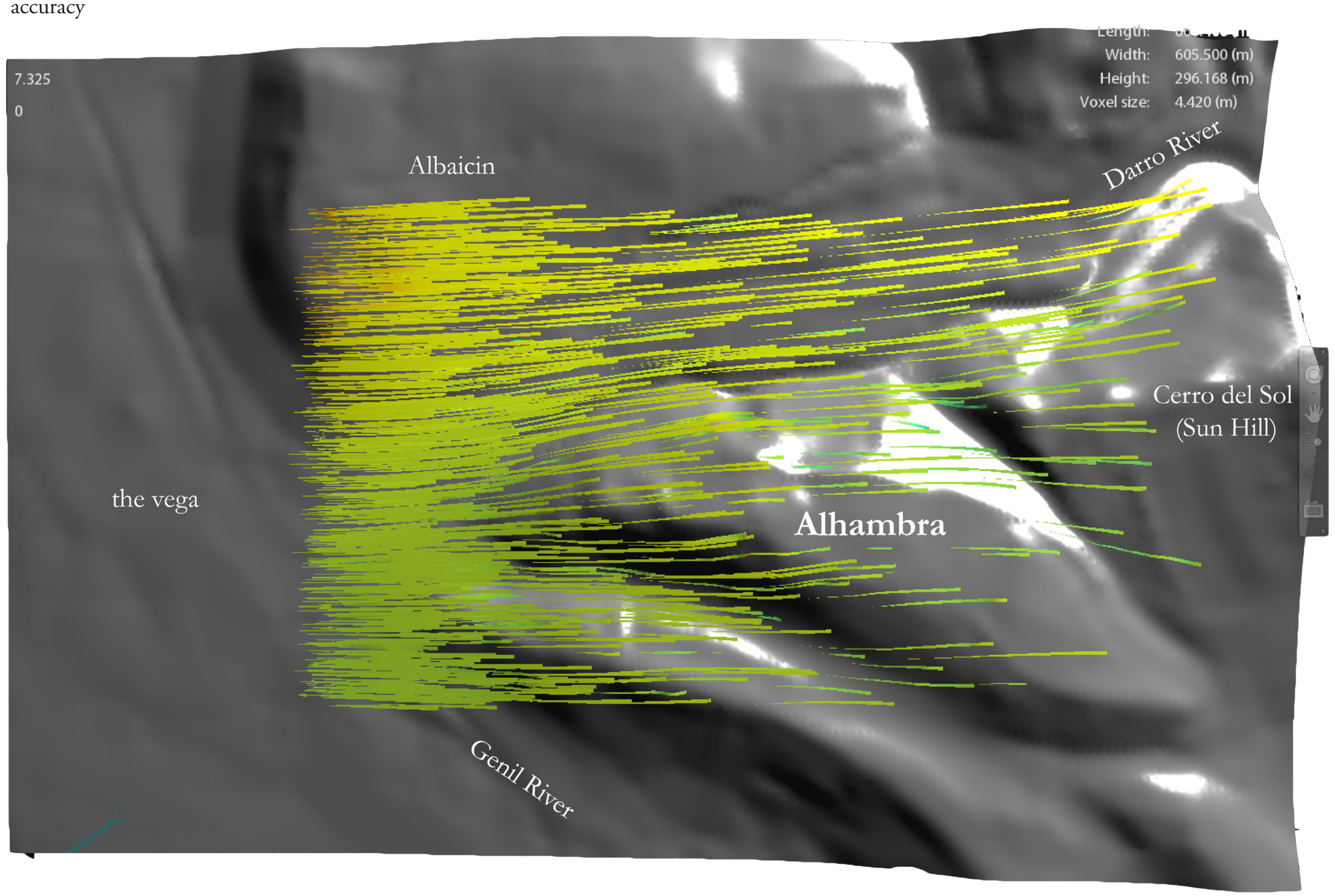



Figure 3[4] Main garden (Patio de la Acequía) in the Generalife

While Luyun's poem was intended for house building, it very closely resembles the main courtyard garden at the Generalife, which most certainly inspired the later courts of Muhammad V. So many elements appear in Ibn Luyun's poem—elevation, orientation, climate, irrigation, shade, plantings, water basins, pavilions, enclosure, and overall shape—that it helps to understand their individual functions in two different sequences: *summer cooling* and *winter warming*.

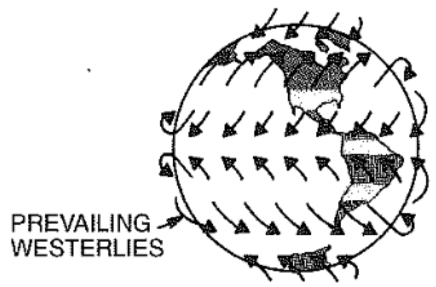


Figure 3[5]

Granada experiences an arid Mediterranean climate, with hot, dry summers and relatively cool winters. Because of its location in Europe, Granada sits in the course of the Prevailing Westerlies that cross the Atlantic. The most common and strongest wind speed in Granada is two meters per second from the west, occurring on an average of 1677 hours out of 8670 total hours in the year. Using a digital elevation model of Granada's landscape, I simulated the wind's interaction with the Sabika by constructing a wind tunnel from the floor

Figure 3[6], 3[7] Horizontal section of wind tunnel simulating prevailing wind velocity over Digital Elevation Model of Granada at 5 meter LIDAR accuracy

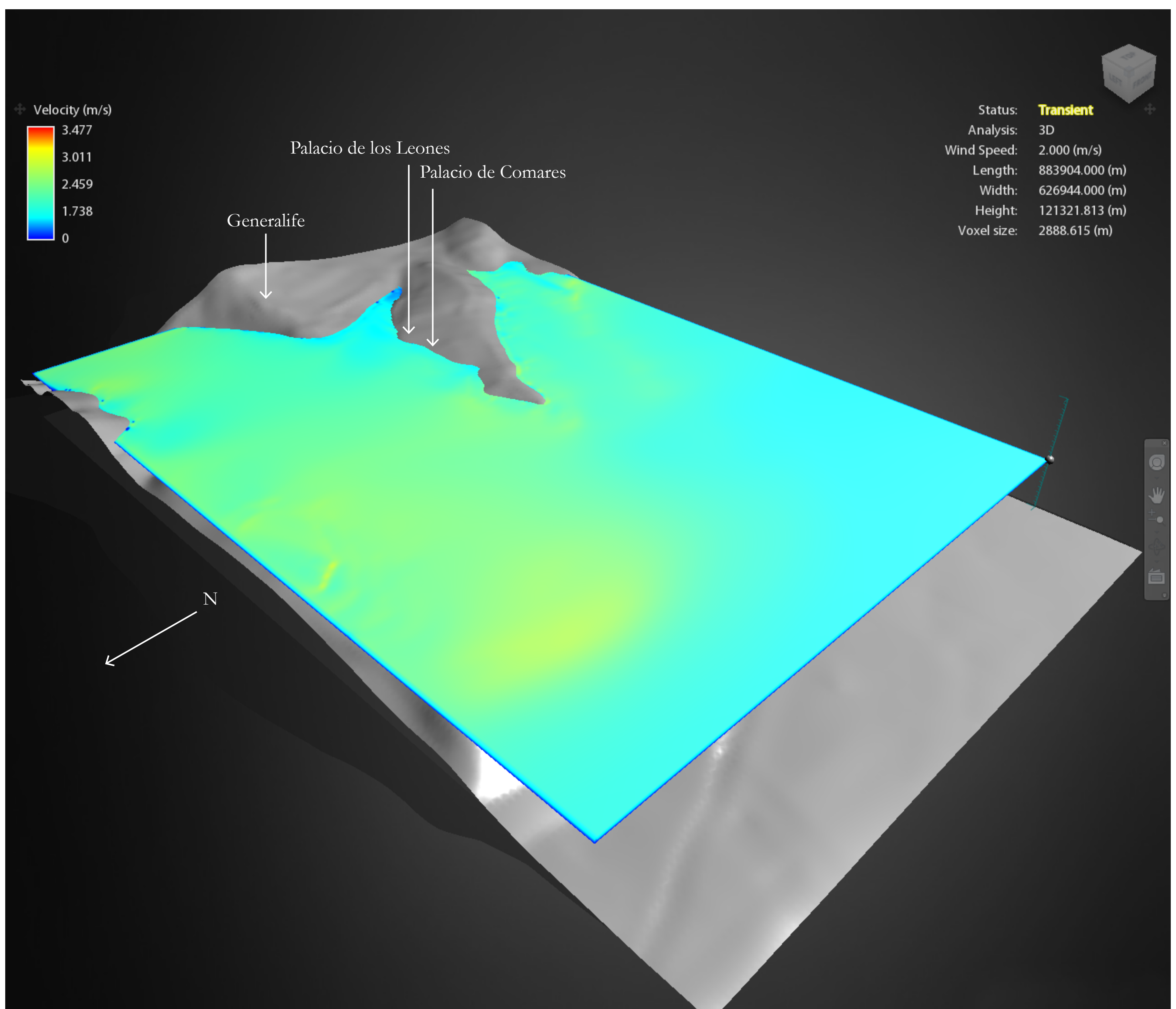
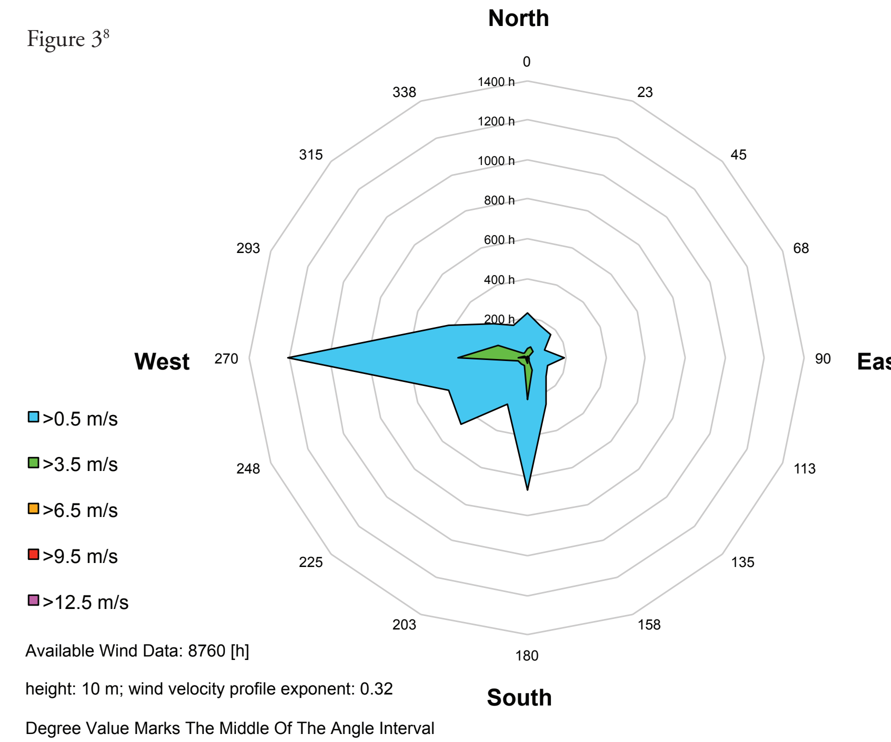


Figure 3[8]



of the vega to about 100 meters over the top of the Sabika (the wind tunnel should have been longer east to west but the simulation is altogether limited by its preference for models of isolated objects, rather than landscape surfaces). Setting a wind speed of 2 meters per second, wind proceeds at that speed over the vega, accelerates to 3 meters per second as it climbs the slopes of the foothills, and slows again once it crests the foothills. It speeds up significantly through

Figure 3[9], 3[10] Barometric ground pressure resulting from prevailing wind velocity over Digital Elevation Model of Granada at 5 meter LIDAR accuracy

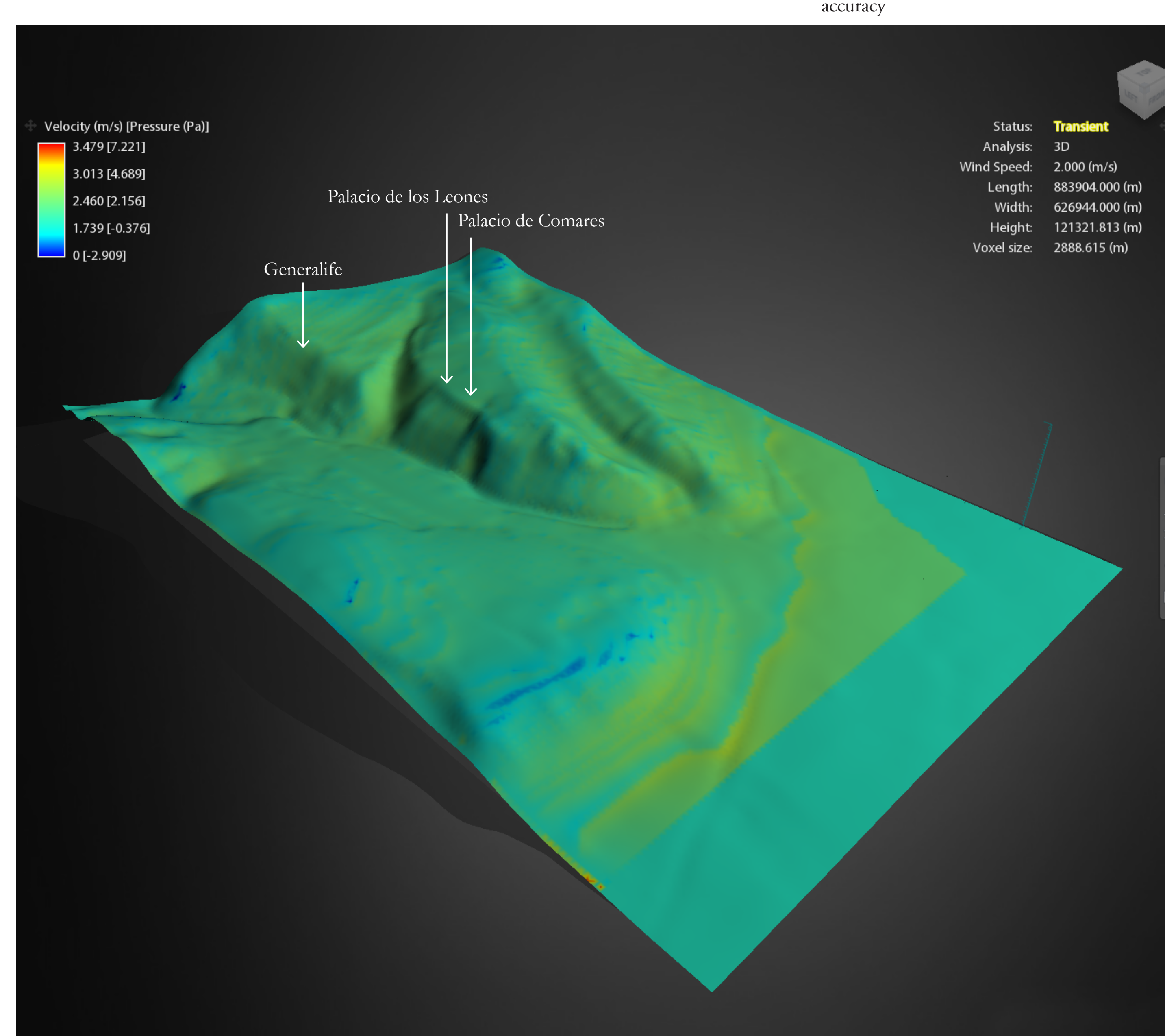
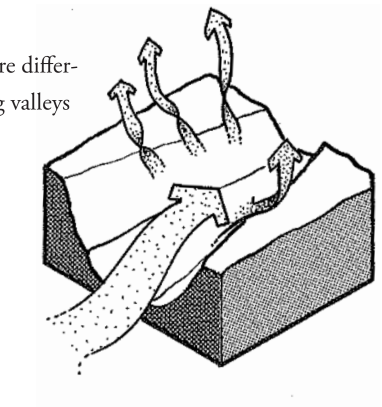


Figure 3[12] Magnified effect from pressure differential and convection in narrow sloping valleys (Lechner)



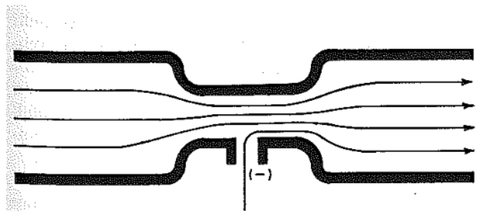


Figure 3[11] Venturi Tube illustrating the Bernoulli Effect (Lechner)

the Darro mountain pass due to the *Bernoulli Principle*, which implies an inverse relationship between speed and pressure in a fluid substance. In other words, when a constant volume of air is forced through a constricted area, it will simultaneously speed up and drop in pressure. Important to note is that the Generalife receives a lot of natural updraft from its western-facing slope, whereas the northern-facing slope of the Alhambra palaces does not (except, we can safely assume, during the much less common event of a northerly wind).

Figure 3[13], 3[14], Wind flow lines simulating interaction between prevailing wind and north side of Sabika hill

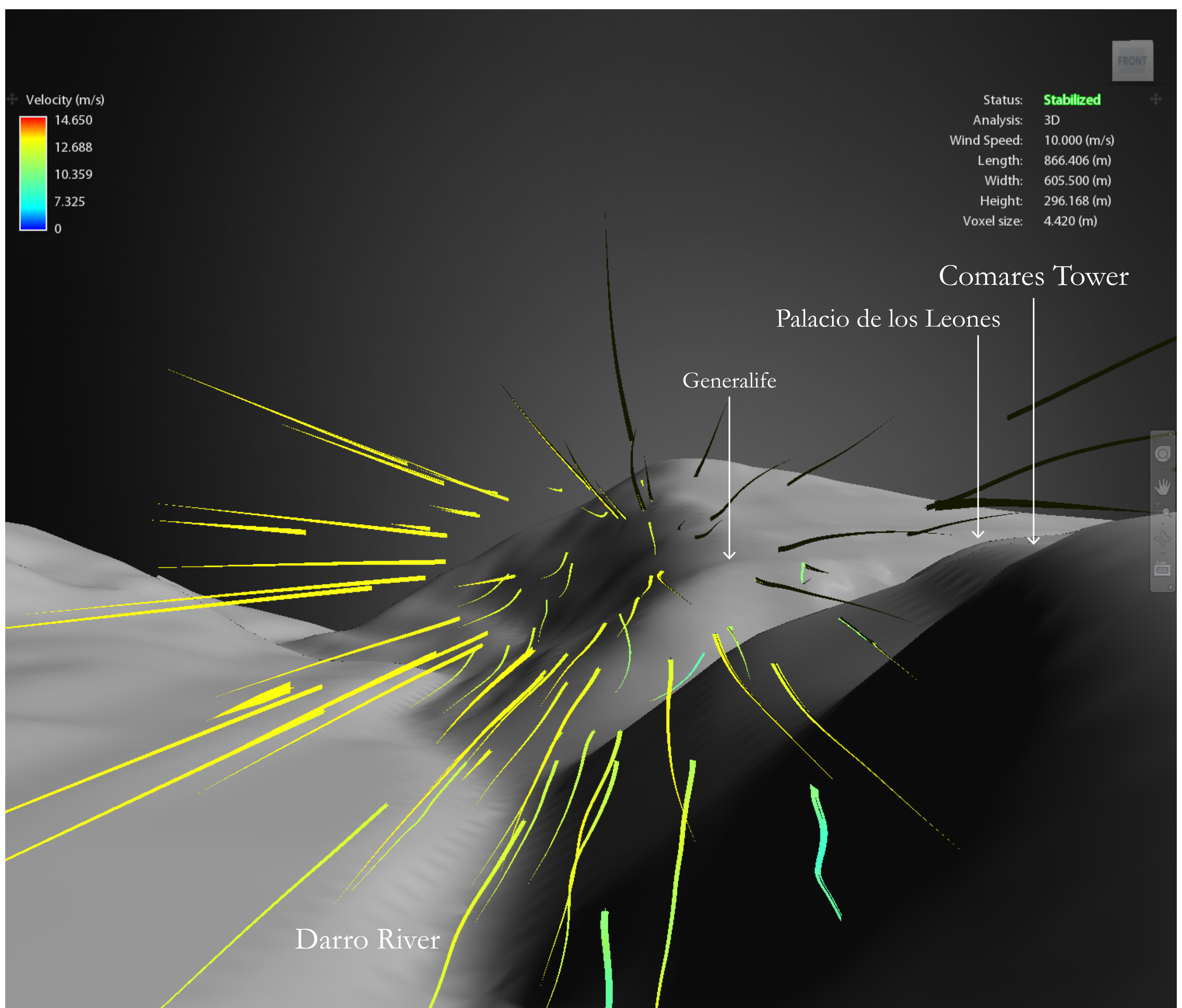
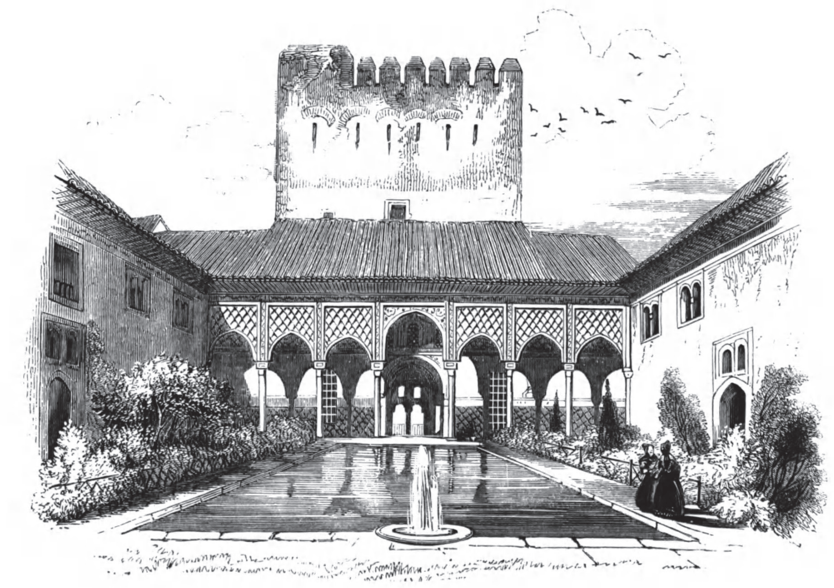


Figure 3[15] Patio de los Arrayanes (Goury, Jones and Gayangos)



Summer cooling in the Palacio de Comares

By 2 PM in summer months, the sun covers most of the *Patio de los Arrayanes*—75% of the total area on June 21st.[2] The sun's radiation evaporates water on the top of its placid water pool. Because the pool's large volume keeps the water cool, the difference in temperature between the water and surrounding gas and surfaces causes *evaporative cooling* of the air over the pool. The greater the difference in temperature, the greater this evaporative cooling effect—implying that the evaporative cooling is at its maximum in the hottest afternoon hours.[3] Moisture added to the air raises the relative humidity of the space 10-22 percent above air outside the palace.[4] Water vapor has a lower pressure than dry air, which creates a pressure differential with air outside the palace.[5] Since air flows invariably from areas of high pressure to areas of low pressure, the humidity over the pool draws in air from the sunbaked areas outside of the court. Water vapor cools the incoming air and consequently lowers the temperature inside the court to 4-8 degrees Celsius less than outside the palace.[6]

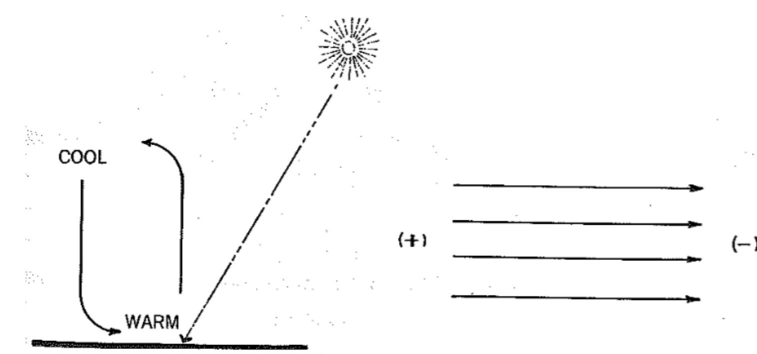


Figure 3[16] Diagrams illustrating the only ways in which air will move: convection and pressure differential

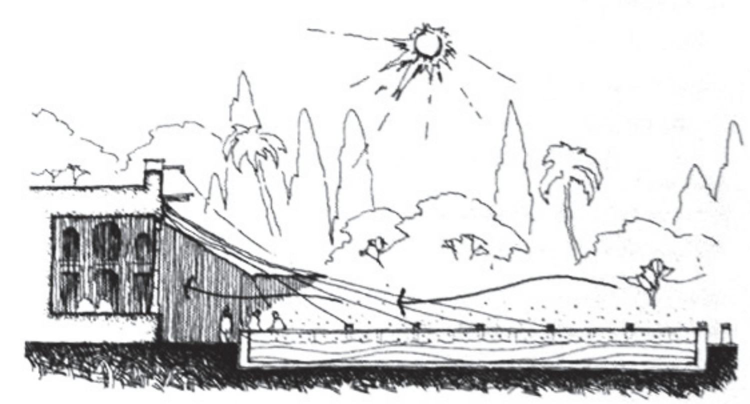


Figure 3[17] Section through porch and awnings extended over pool in Bagh-i Naw Shiraz, Iran, demonstrating Persian interior porch (Sullivan)

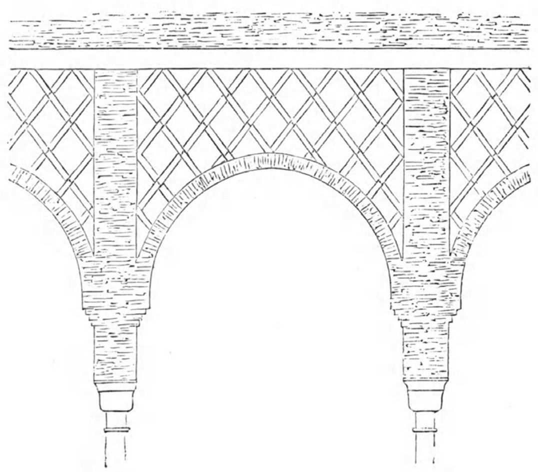


Figure 3[18] Patio de la Alberca arcade simultaneously catches breezes and blocks sunlight (Goury, Jones and Gayangos)

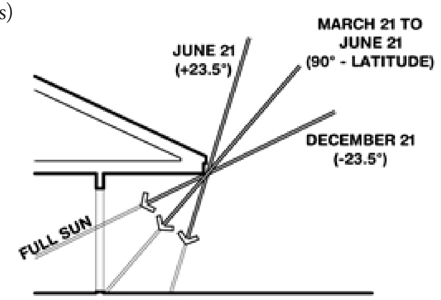


Figure 3[19] Guidelines for controlling solar exposure with overhanging roofs in Granada, Spain (Climate Consultant)

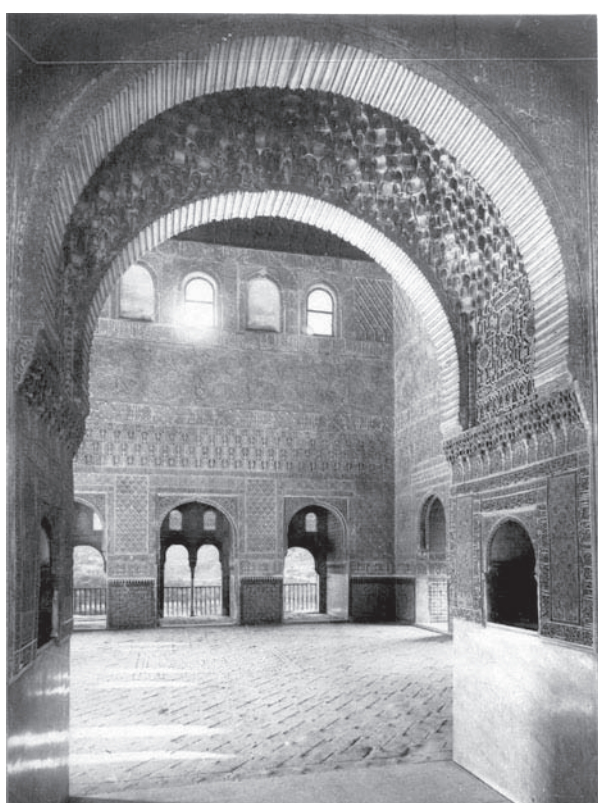


Figure 3[20] View into Hall of Ambassadors toward northeast (Garzon)

Galleries on either end of the *Patio de los Arrayanes* capture this cool, humid air from the pool similar to a Persian interior porch, which is designed to capture wind humidified over a pool.[7] By having roofs that are low enough, they also block direct sunlight from reaching the areas underneath.[8] Interconnected cool rooms behind the gallery then circulate incoming air. Architectural mass, still cool from the previous night, sustains the coolness.[9] Cool air displaces warmer air, which rises due to convection into the *Salón de los Embajadores'* high, domed ceiling—an early Umayyad invention—keeping lower areas cool. It then escapes through high ventilation windows.[10] Porous latticework shutters, a concept from the Tulunids in 13th Century Cairo, cover many of these windows to simultaneously diffuse sunlight and collect condensation from inside.[11]

The alcoves of the reception hall not only provide views of the landscape, but function as breezy cool seats. To understand the aerodynamics at work here, we must again invoke the *Bernoulli Principle*. One of the best ways to visualize the flow of fluid from high to low pressure is to think of what happens inside a spaceship when it is depressurized: all of the air is sucked out through a small opening. This is due to the *Venturi Effect*, coined in the late 18th Century to explain how a "drop in pressure corresponds with a suction action" in a closed air flow.[12] The theory implies that Granada's lower-pressure, high-speed westerly winds skirting the northern edge of the palace would suck out higher-pressure, warm air inside the Torre Comares. Sullivan posited that "breezes are forced through the narrow window opening facing the cliff,"[13] but if the westerly breezes passing by the north-facing slope of the Sabika at 3-4 meters per second experience a lower pressure than air inside the tower, he got the direction of the breeze wrong: it is more likely to be sucked out, not forced in. Unless one were to lean out of the structure, one could only be "in full force of the wind" by sitting in the tower's only west-facing mirador.[14] Subsequent studies involving more accurate modelling, or better yet, direct observation, are required to verify this phenomenon.

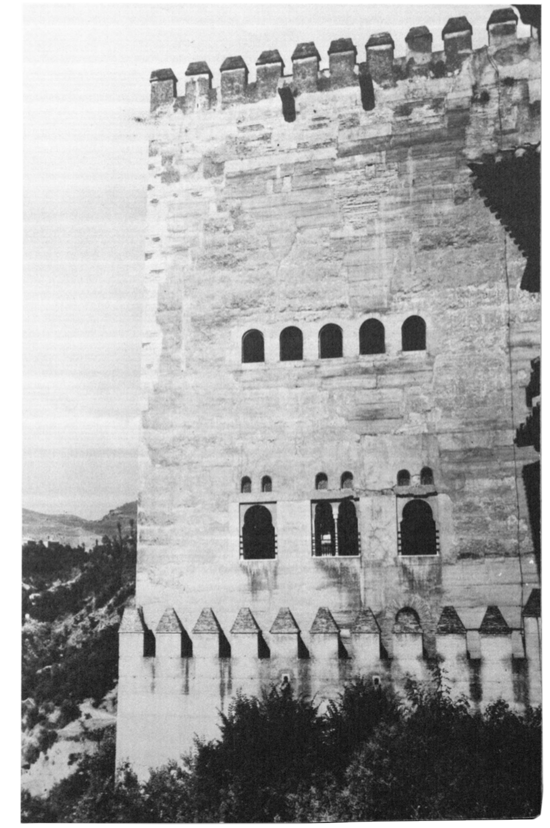


Figure 3[21] Hall of the Ambassadors, Alhambra (Grabar)

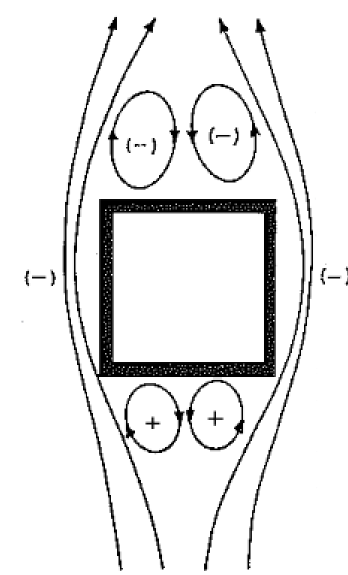


Figure 3[22] Turbulence and eddy events occur in the high and low pressure areas around a building. If westerlies can barely pierce the tower through its comparatively small, west-facing windows, high pressure air is bound to stagnate. Faster breezes are more likely to occur as air is sucked out into lower pressure, higher velocity areas north and east of the tower (after Lechner)

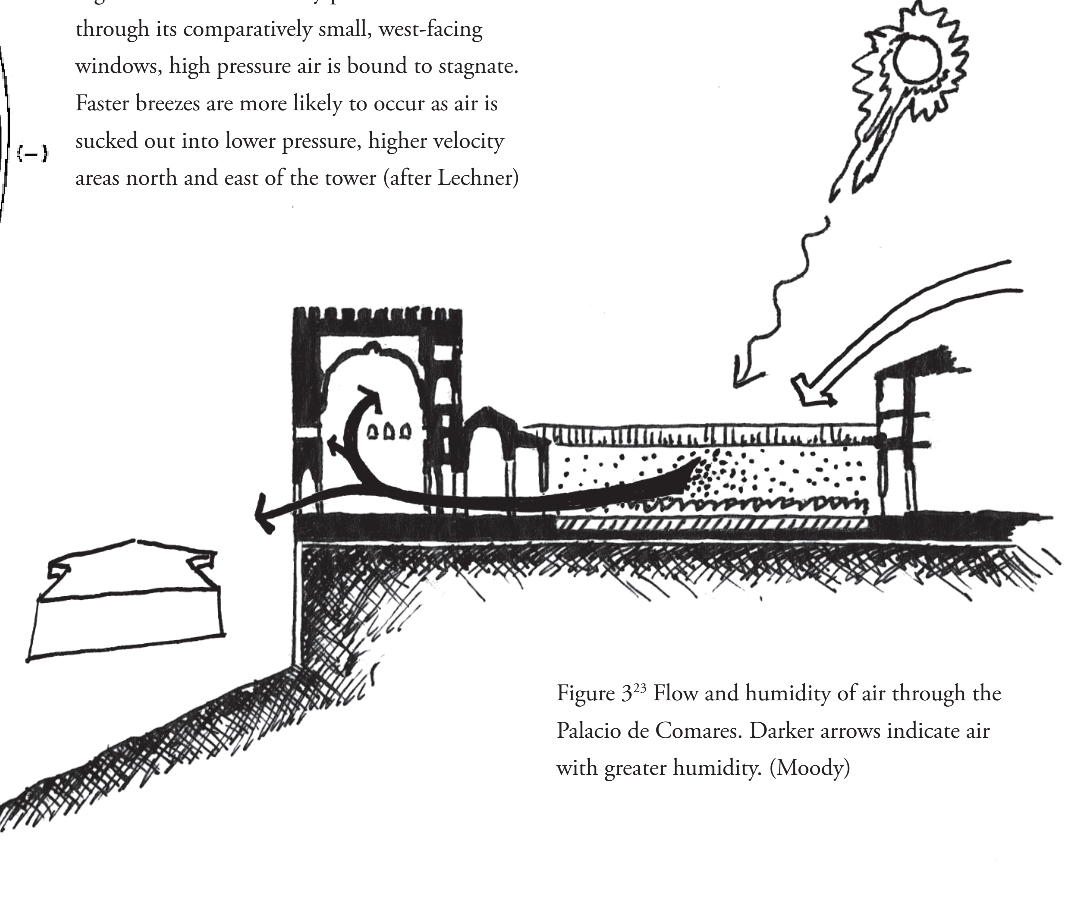


Figure 3[23] Flow and humidity of air through the Palacio de Comares. Darker arrows indicate air with greater humidity. (Moody)

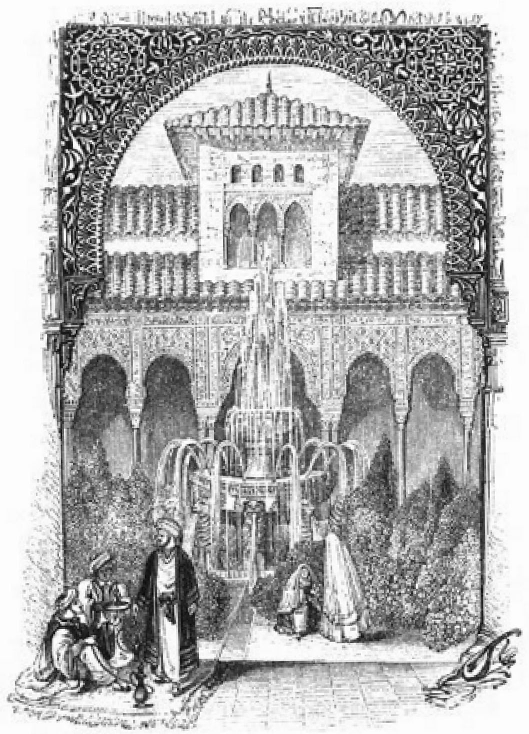


Figure 3[24] Entry to the Court of Lions (Goury, Jones and Gayangos)

Summer cooling in the Palacio de los Leones

At 2 PM on the summer solstice, the sun covers 77% of the total area of the *Patio de los Leones*.[15] Yet the temperature inside this court is 2-4 degrees Celsius lower than outside the Alhambra.[16] Aeration using fountains and garden plantings are both key to this process. By forcing water under high pressure through miniature openings, its fountains suspend water vapor in the air. Relative humidity in the *Patio de los Leones* rises 8-15% more than areas outside the palatine complex.[17] In the absence of a large water pool, this serves to create a pressure differential which draws in air from outside the courtyard and humidifies it.

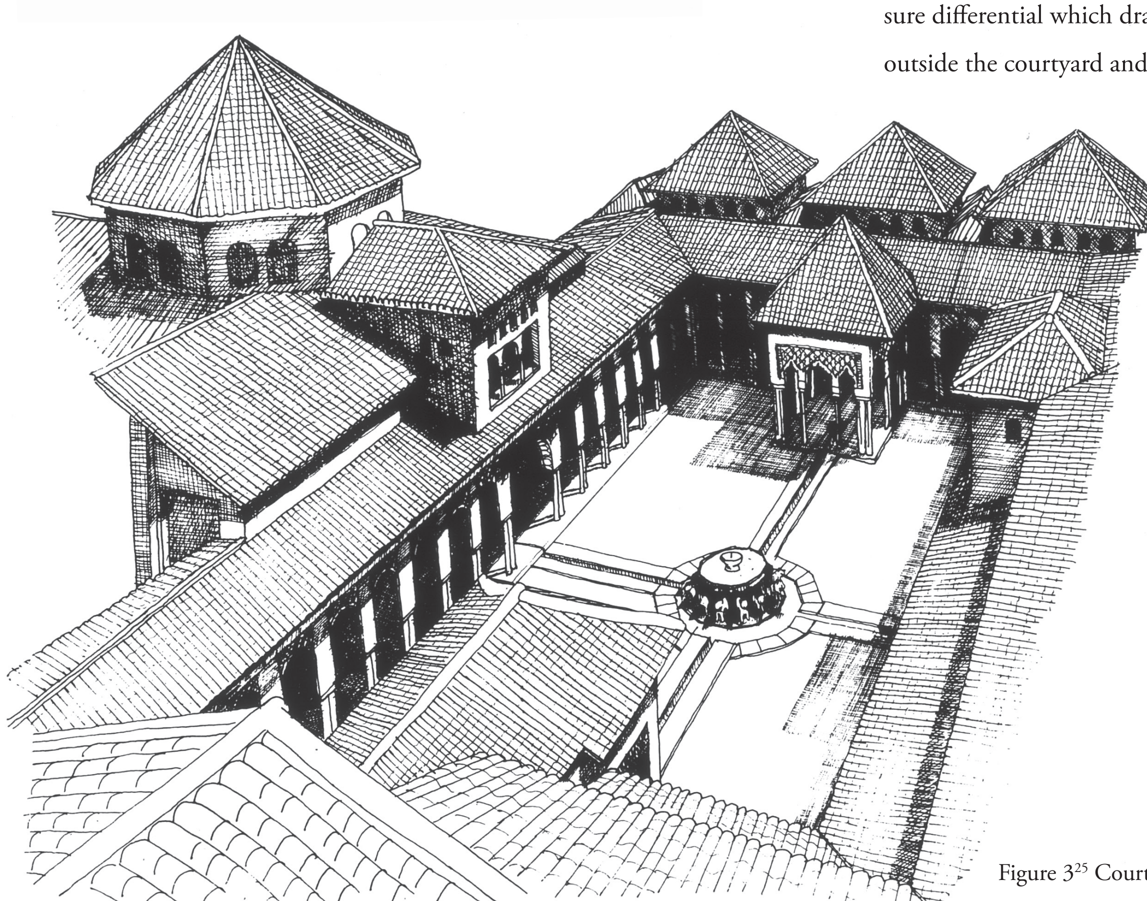
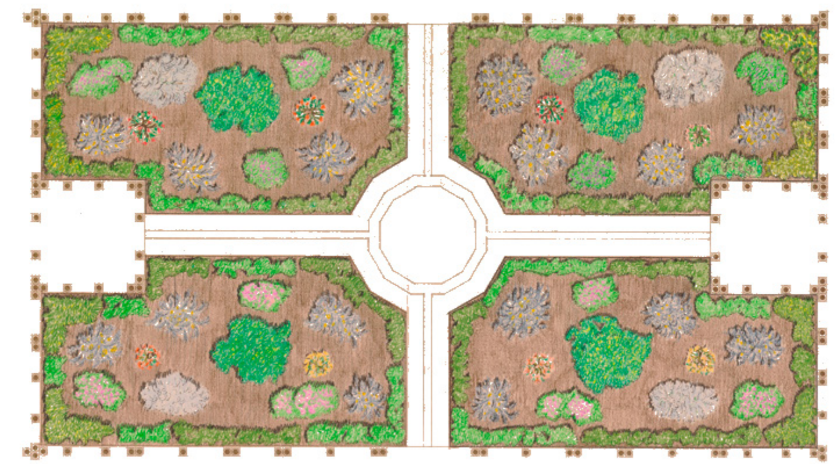


Figure 3[25] Court of the Lions

Figure 3[26] Plan showing the distribution of plantings in the Patio de Los Leones (after Reche)



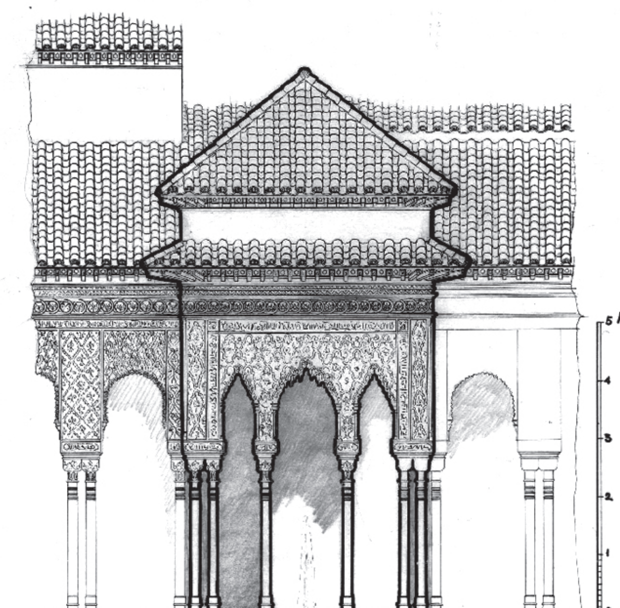


Figure 3[27] Schematic of the western kiosk in the Patio de los Leones, pre restoration (after Bueno)

Additionally, in the Nasrid era, each of the four quadrants would have been planted as a *bustán*, a merging between a vegetable and flower garden. Plants were watered via the court's rectilinear marble runnels using a technique inherited from Persian gardens called "blanket watering."[18] Walkways were raised above the planting beds to provide water spouts and dam the water.[19] Flooding the channels would sustain the fruit trees, and growing fruit trees transpire tons of water. The sun would then vaporize water dripping from the trees. This vapor would filter windborne pollutants in the air and supplement the fountains in attracting and cooling breezy air.[20] Trees with dense canopies like wallflower, jasmine, cypress, bitter orange, and lily would also provide shade to retard evaporation in the water channels.[21] [22]

Pavilions and galleries enclosing the courtyard on all sides capture the humid breezes and block radiant heat from the sun. Interconnected, cavernous cool rooms circulate and ventilate the air much like the interiors

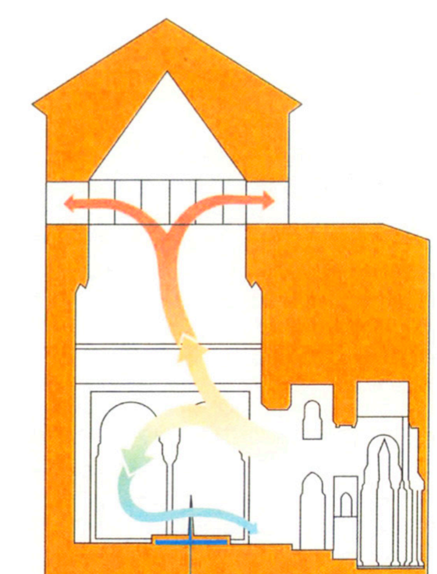


Figure 3[28] Airflow through spaces of the Alhambra (T.F. Editores)

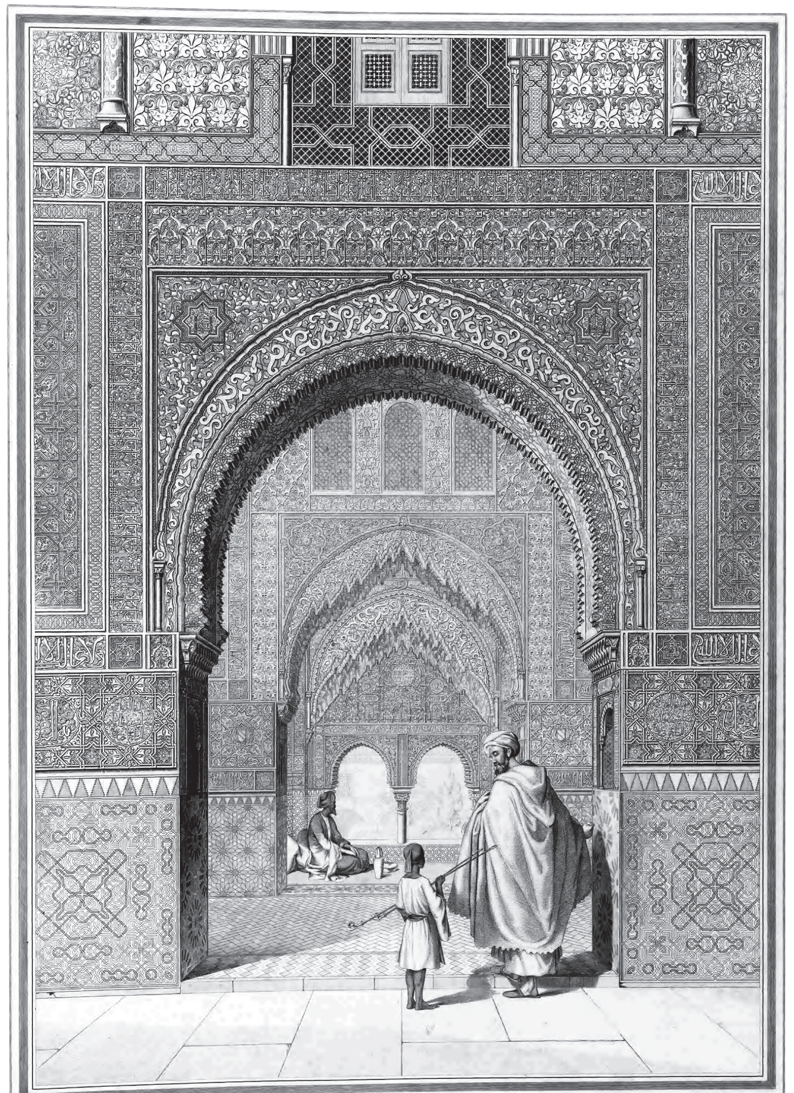


Figure 3[29] View in the Hall of the Two Sisters (Goury, Jones and Gayangos)

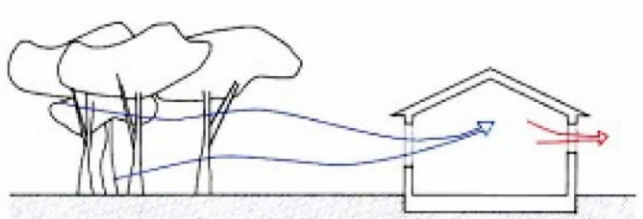


Figure 3[30] Evaporative cooling with vegetation (Alonso)

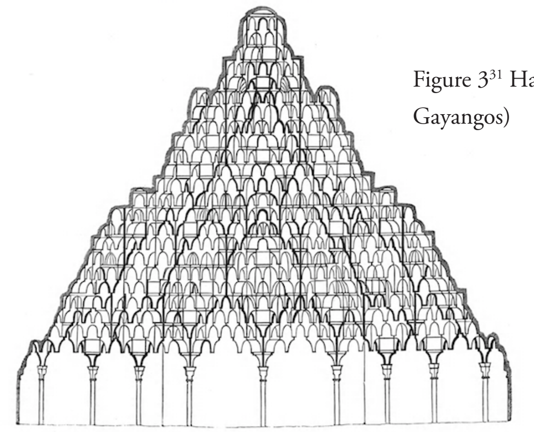


Figure 3[31] Hall of the Bark (Goury, Jones and Gayangos)

of the *Palacio de Comares*. However, many ceilings in this palace also contain *muqarnas*, or plaster-molded, mathematically-precise octagonal stalactites that originated in Persia or North Africa early in the 10th Century. The Nasrids installed more than 5,000 of these between the *Sala de los Reyes*, the *Sala de Dos Hermanas*, and the *Sala de los Abencerrajes*.[23] Aside from symbolizing the heavenly sky, they were much more effective than flat ceilings for collecting and recycling humidity.

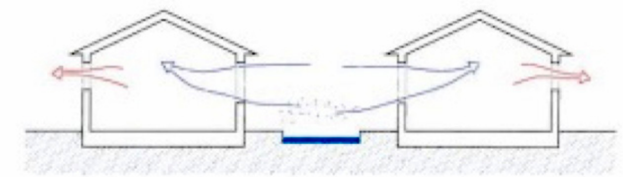


Figure 3[32] Evaporative cooling with water feature (Alonso)

Like the *Salón de los Embajadores*, openings both low and high provide cross-ventilation to the rooms of the Leones palace. The *Mirador de Lindaraja,* projecting from the northern edge of the palace, probably would have attracted humidified breezes from a lower terraced garden open to the landscape, but the details of this garden were erased under a 15th Century Christian garden which is enclosed by residences and bears little resemblance to the Islamic version.

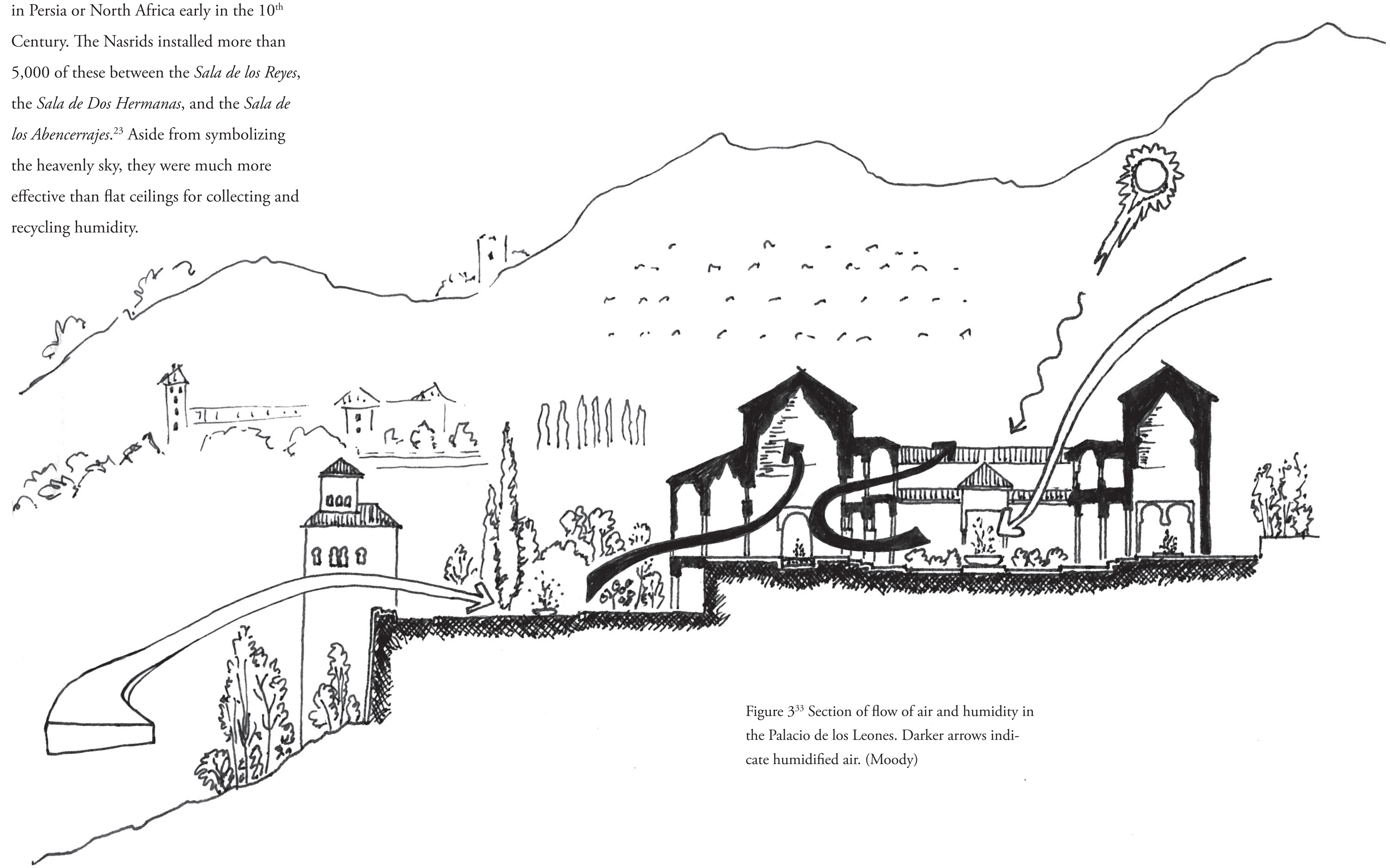


Figure 3[33] Section of flow of air and humidity in the Palacio de los Leones. Darker arrows indicate humidified air. (Moody)

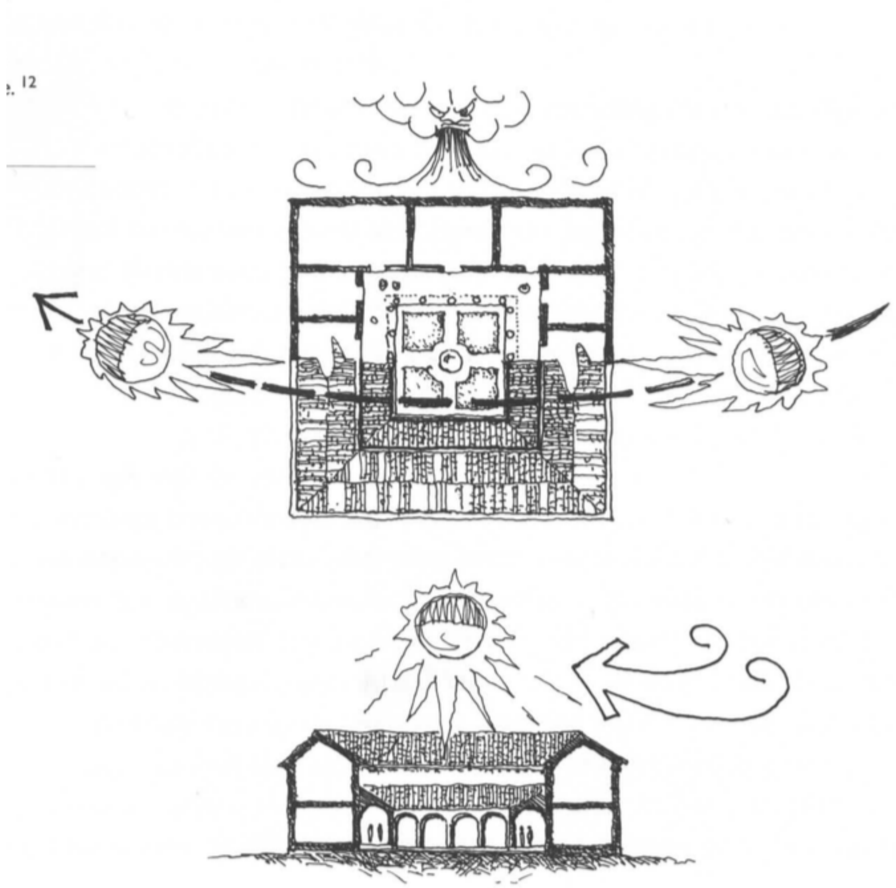


Figure 3[34] The courtyard (Sullivan)

Winter warming in the Palacio de Comares

The keys to sustaining warmth in the winter are enclosure and garden orientation. Walls around the garden block winter winds, while the positioning of the palace's main buildings to the north of the garden serves to capture the low winter sun, which hovers between 20-30 degrees in the middle of the day on the winter solstice. The height of the gallery's roof lets this mid-day sun penetrate the northern rooms and warm the interior floor.[24] The water pool also bounces additional radiant heat into the northern tower, whose architectural mass holds the heat of the sun well into the night. In the Nasrid era, thick doors would also block wind to keep in the heat.[25]

The Nasrids also supplemented structural elements with *braziers,* or portable containers for burning charcoal—often rose or grapevine trimmings that also smell sweet when burned moist.[26] Traced back to to Iraq in 824 BC, brazier technology could be politically risky without proper ventilation—the Roman Emperor Jovian was poisoned by the fumes from a brazier in his tent in 364, ending the line of Constantine—therefore high windows in the *Torre Comares* also served to ventilate fumes.[27]

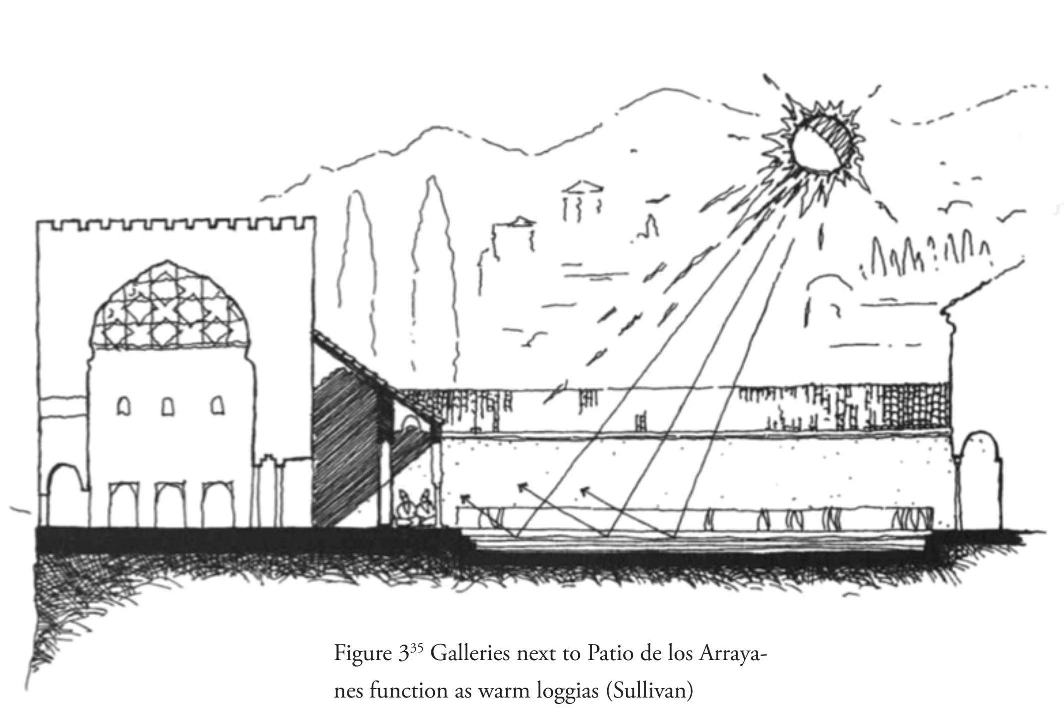


Figure 3[35] Galleries next to Patio de los Arrayanes function as warm loggias (Sullivan)

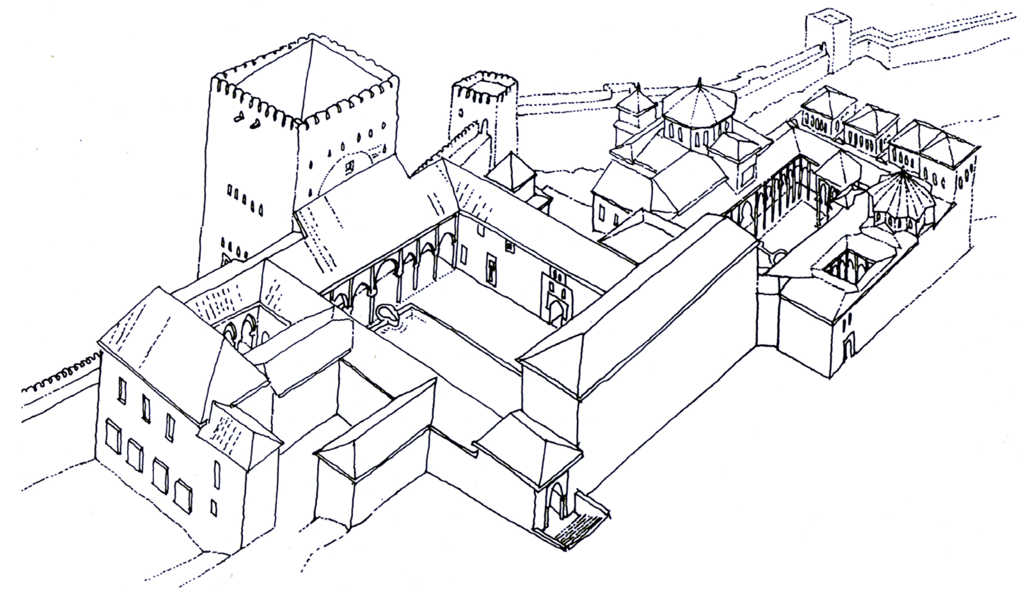
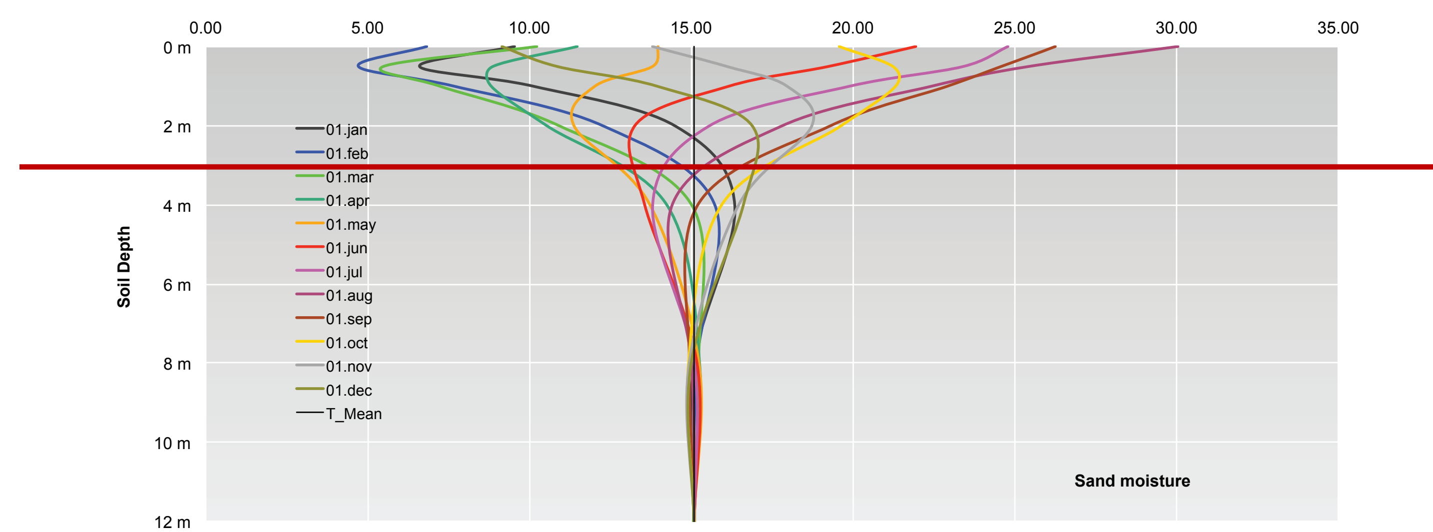


Figure 3 MIT Archnet, Granada palaces.

Figure 3[36] Granada soil temperature throughout the year. Notice relatively nominal swing between winter and summer for soil 3 meters deep (Alhambra cement was built from that soil) (Transsolar KlimaEngineering)



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