The ‘Teatinas’ of Lima: Energy Analysis and Possibilities of Contemporary Use

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ABSTRACT
“Teatinas”, roof openings for zenithal ventilation and daylighting, were systematically used in buildings in the city of Lima and in most of the Peruvian coast from the mid-18th century to the end of the 19th century. The purpose of the study was to evaluate the thermal and lighting performance of the rooms where the “teatinas” were used and to assess an eventual use of similar resources in contemporary architecture. After defining the climate of the city, the buildings where they were installed and the “teatinas” themselves, the thermal and lighting conditions resulting from their use were calculated based on comparative measurements and simulations: air temperature and relative humidity, ventilation, lighting levels and glare. The results showed that the presence of a “teatina” in a room provides comfortable hygrothermal conditions, good air intake and circulation inside a room. As compared to conventional windows, the “teatina” allows for a more even distribution of daylight inside the space and more possibilities of avoiding glare. Finally, it is concluded that “teatinas”, consistent with the climate and daylighting conditions of the city of Lima, did fulfill the comfort requirements of homeowners of that period of time and are a valid reference and concrete alternative in the current search for comfortable spaces in energy-efficient buildings.

INTRODUCTION
The addition of teatinas on the roofs of Lima buildings became widespread after the 1746 earthquake. Despite the temperate climate of the Peruvian coast, its recurrent use was due to the need of providing natural ventilation and light to spaces which, due to the density and homogeneity of the urban grid, had little or no access to outside breezes and daylight.


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Teatinas were systematically incorporated in buildings until the end of the 19th century. Afterwards, Neoclassical architecture, and later modern architecture, excluded them completely. The strategy of catching wind and capturing natural light through the roof has not been maintained or resumed in the Peruvian coast. This study examines the objective thermal and lighting conditions achieved by the presence of a teatina in a room, and its ability to provide thermal and lighting comfort in the spaces where it is present. This study has been more fully developed and submitted in a doctoral dissertation [1].

METHODOLOGY

Given the inexistence of similar research studies in Peru, it was necessary to address previously certain aspects in order to be able to choose appropriate indicators for the energy assessment to be developed within this study.

In addition to determining the definition, the variables and the evaluation of thermal and lighting comfort, it was necessary to identify the energy assessment tools and the most common environmental control strategies in architecture. The geographic, climatic and lighting characteristics of the city of Lima were identified and a prior study was made to relate the teatina to its historical context. Ten buildings containing a total of ninety-seven teatinas were surveyed and measured in order to identify typical construction characteristics and components –as related to the particular features of the urban grid– of the buildings and rooms where they were found.

Afterwards, a ‘model room’ containing a ‘model teatina’ was defined. Jointly, both have typical characteristics insofar as orientation, layout, dimensions, form and finishes. These models were used in the simulations and some assessments were performed in settings with similar characteristics, since they had to be made on-site. The ‘model’ room is a quadrangular space, 5 meters long by 5 meters wide, with a height of 4.20 meters. For the lighting assessment, a ‘contemporary’ height of 3.00 meters was considered as an additional variant. The dimensions of the ‘model’ teatina were defined based on the sampling average, as well as the typical orientation of the opening (SSW).

Figure 1. Dimensions and characteristics of the model “teatina”.
The purpose of the energy assessment was to identify the thermal and lighting behavior of the ‘room/teatina’ combination as compared to its objective capacities of providing comfort to its occupants. Specifically, the following aspects were evaluated:

<table>
<thead>
<tr>
<th>Aspects to be Evaluated</th>
<th>Method</th>
<th>Resource or Instrument</th>
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<tbody>
<tr>
<td>1. Thermal Assessment</td>
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<tr>
<td>Solar Radiation</td>
<td>Computer Simulation</td>
<td>Nomogram/AutoCAD</td>
</tr>
<tr>
<td>Ventilation</td>
<td>On Site</td>
<td>Thermo-Hydrometer/Anemometer/Smoke</td>
</tr>
<tr>
<td>2. Lighting Assessment</td>
<td></td>
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</tr>
<tr>
<td>Lighting Level</td>
<td>Models</td>
<td>Lux Meter/Model</td>
</tr>
<tr>
<td>Glare</td>
<td>Calculation</td>
<td>Glare Index</td>
</tr>
</tbody>
</table>

RESULTS

Thermal Assessment

In order to calculate the effect of solar radiation on the teatina, both that which passes directly through the opening and that which falls on its opaque structure were taken into account. In the first case, the equidistant solar projection was used to identify the months and hours when direct solar radiation entered through the opening, and a nomogram was superimposed on the former in order to obtain the incidental energy. Using AutoCAD, a graphic image of the entrance of direct solar radiation into the room was obtained.

Figure 2: AutoCAD simulated rendering on the month when most direct solar radiation enters through the “teatina”: December

The result was that the cumulative daily average of solar energy entering the room in the months of January and February ranges from 2.5 to 3.5 kWh, being higher at around 4:00 pm (approximately 0.9 kWh), when the eave presents the least obstruction and the sunrays are most perpendicular with respect to the opening.

Figure 3: Nomogram superimposed on solar projection. Based on times of day, the amount of direct and diffuse solar energy through the “teatina” opening facing SSW is inferred.
To predict the energy passing through the opaque surfaces of the teatina, thermal transmittance was calculated taking into account the ‘sun-air’ temperature (tsa). Given that the air temperature entering the teatina is equal to the external temperature, the following formula (Evans, 1980) was applied:

\[ Q = U \cdot A \cdot \alpha \cdot R \cdot r, \] \[2\]

According to this calculation, the approximate amount of energy (Q) passing through the opaque surfaces of the teatina is close to 0.17 kWh. This value proved to be rather low, since the transmittance of the element, consisting of a packed mud layer about 10 cm thick, which also shares the characteristics of the rest of the covering, is equally low.

From the values obtained, it can be stated that both the direct and diffuse solar radiation entering through the teatina opening and the heat passing through the opaque material are not enough to significantly raise the interior temperature of the room. The relatively low energy values and the ventilation provided by the component itself ensure continuous outflow of excess heat.

To evaluate the ventilation in a room having a teatina, the energy conditions of the air and the air movement within the space were assessed.

On-site testing in the Casa de la Riva during 72 consecutive hours comprised temperature and relative humidity measurements in a single room under two different conditions: with the teatina open and with the teatina closed. The results are depicted in a psychrometric chart showing summer comfort zone limits and comfort zone corrected with ventilation, as per Coch and Serra (1994) [3].

![Psychrometric chart showing temperature and relative humidity data, considering vertical opening of the open (left) and closed “teatina” (right). Outdoor stations (in blue) and indoor stations (at human occupant level, in red) are represented. Testing was carried out during particularly hot and sunny summer days.](image)

Although on both days the external temperature was close to 29 °C at the warmest moments, it was observed that, with the teatina closed, indoor temperature reached almost 28 °C, while with the teatina open, indoor temperature stayed at around 26 °C. These results are due to the presence of an indoor thermal mass that was cooled by the ventilation itself in the preceding hours, and to the ability of constantly expelling the air being heated inside. As to the air movement pattern within a room equipped with a teatina, site measurements were made in the Casa de la Riva and the Casona de San Marcos to determine speeds and direction, using in this case an anemometer and a smoke machine.
Wind directions are rather particular since, regardless of the location and the size of the exit opening, the incoming air direction is markedly vertical. Once it reaches the floor, it spreads horizontally in all directions, mainly away from the inflow direction. Incoming air mixes with existing air and finally leaves through the opening on the opposite side (Figure 5). Wind speed inside the room, at the lower section of the teatina, is between 30% and 60% of outdoor wind speed. Outdoor air descends rapidly once inside the room, though it is warmer than existing indoor air, because of the pressure differences created by the wind itself, since both, outdoor and indoor air, quickly mix due to the existence of continuous convective movements within the space.

The resulting temperatures inside a room equipped with a teatina, in addition to wind presence and speed, ensure thermal comfort for occupants under typical hot summertime conditions in the city of Lima.

**Lighting Assessment**

**Illuminance** measurements were performed using scale models, considering a work plane at 80 cm from the floor, overcast sky and ‘model’ room and teatina characteristics. Table 2 shows average DF results (%, Daylight Factor) from various situations, followed by iso-DF curves (Figure 6).
Photos 4 and 5. View of the Room A.01 model and detail of the roof and “teatina”.

### Table 2. Characteristics of Openings and the Room to Measure Lighting Levels

<table>
<thead>
<tr>
<th>Room Model</th>
<th>Description</th>
<th>DF (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.01</td>
<td>Teatina / roof covering with joists / ‘traditional’ roof height (4.20 m)</td>
<td>1.13%</td>
</tr>
<tr>
<td>B.01</td>
<td>Teatina / smooth covering / ‘traditional’ roof height</td>
<td>1.61%</td>
</tr>
<tr>
<td>B.02</td>
<td>Teatina / smooth covering / ‘conventional’ roof height (3.00 m)</td>
<td>1.94%</td>
</tr>
<tr>
<td>C.01</td>
<td>High window / smooth covering / ‘traditional’ roof height</td>
<td>1.98%</td>
</tr>
<tr>
<td>C.02</td>
<td>High window / smooth covering / ‘conventional’ roof height</td>
<td>2.37%</td>
</tr>
</tbody>
</table>

Figure 6. Light distribution at the work plane in the various rooms.

Considering that minimum values suggested for home environments range from 0.5% to 0.6% (Baker & Steemers, 2002) [4], it can be stated that the results obtained under any of these scenarios far exceed those requirements. To the extent that the lighting level values obtained from Europe overcast sky and in the north of the United States of America represent approximately one third of those reached in our tropical latitudes, it can be stated that the illuminance obtained from all of the results are suitable even for tasks requiring greater precision (classrooms, reading areas, etc.).

Light distribution patterns show that in a room with a teatina, lighting is distributed more evenly as compared to a room with a conventional high window with the same dimensions. In addition, the greater height of the space is confirmed to provide more homogeneous illuminances, with higher values in the area facing the opening.
To determine the glare, the Unified Glare Ratio (UGR) was applied, using the following formula (CIE, 1995, p. 117):

\[ UGR = 8 \log \left[ \left( \frac{0.25}{L_b} \right) \cdot \Sigma \left( L^2 \omega / p^2 \right) \right] \]  \[5\]

Possible glare was determined by considering the ‘model’ room with teatina, a sight line at a height of 1.20 meters, five different points inside the room and four typical scenarios of sky brightness and lighting level (Figure 7). Projections were made considering both the ‘traditional’ and the ‘conventional’ (contemporary) height of the room. The results of the various scenarios are shown in Figures 11, 12, 13 and 14.

![Figure 7. Model Rooms and Measurement Points for Assessing Glare](image)

**Figure 7. Model Rooms and Measurement Points for Assessing Glare**

![Figures 8 and 9. Results in a room with a ‘traditional’ height (4.20 m, B.01) and a conventional height (3.00 m, B.02), with “teatina”.](image)

**Figures 8 and 9. Results in a room with a ‘traditional’ height (4.20 m, B.01) and a conventional height (3.00 m, B.02), with “teatina”.**

![Figures 10 and 11: Results in a room with a ‘traditional’ height (4.20 m, C.01) and a conventional height (3.00 m, C.02), with high window.](image)

**Figures 10 and 11: Results in a room with a ‘traditional’ height (4.20 m, C.01) and a conventional height (3.00 m, C.02), with high window.**
Despite the relativity of the results given that both the height and the sight line direction are usually variable, it is confirmed that the overhead lighting – in this case provided by the teatina – performs better in preventing the visual discomfort associated with the glare phenomenon, as compared to conventional lateral natural light.

CONCLUSIONS

Teatinas, consistent with the climatic and light characteristics of the city of Lima, did meet the comfort requirements of the city inhabitants of the time, who incorporated them systematically in buildings for more than one hundred years since the mid-18th century. In addition to good wind uptake and distribution inside the rooms, their lighting performance is better than that of a conventional window, because teatinas distribute light more evenly within a space and are more likely to prevent glare.

The thermal and lighting conditions achieved in rooms having teatinas, show that these elements continue to represent a valid design alternative to be considered. Based on the identification and comprehension of the phenomena associated with the energy performance of teatinas, alternatives and specific details may be proposed in order to improve their efficiency and adapt them to various contemporary applications.

REFERENCES