COVERED COURTYARD FOR THE ANDEAN CITIES

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ABSTRACT

The present study emerged from the need to contribute to the amelioration of the living conditions of the South American Andean population. The lack of human thermal comfort in economically poor places is obstructing development. Buildings need to be dependent on other conventional energy sources that become scarce and expensive. The passive solar systems are alternative solutions to improve living conditions of the inhabitants of the Andes.

This research examines passive solar systems that respond to a specific climate and to a particular cultural lifestyle, like those existing in the Peruvian Andes.

The study began by analyzing passive solar principles, climatic conditions and existing architectural patterns. It concluded by presenting a passive solar system utilizing covered courtyards and demonstrating their thermal efficiency. The integration of this passive solar system in the architectural design of this region can greatly improve the lives of the inhabitants in these cities.

1. INTRODUCTION

Most buildings in the Andes are cold. Many houses are located at altitudes as high as 4,500 m., and have an average indoor temperature of 8°C. Auxiliary heat is sometimes supplied by wood, or rarely by electricity at high cost.

Passive solar heating utilizing an inexpensive and abundant resource could greatly improve Andean living conditions. Peru is a land of almost continuous sunshine and except for some coastal areas of this country, passive solar heating is ideally suited. Solar energy is a resource which has thus far not been utilized for indoor heating in Peru.

This research proposed a solar energy design appropriate for the culture, climate, geography, and limited financial resources.

2. HYPOTHESIS

The covered courtyard is the passive solar system that will have the best thermal performance in the Andean cities. This statement is based on climatic conditions and existing housing patterns.

Throughout the year the sun remains very high in the sky in low latitudes. The most effective solar designs would use horizontal surfaces such as the floor or roof for collecting solar heat, which can then be distributed to the rest of the building. The direction east and west are also important for collecting solar heat using vertical surfaces. Building orientation is very important in such cold climates and especially in these narrow Andean valleys where building sites are restricted. The notorious intensity of Andean sun in the high Peruvian valleys results from the combination of high altitude and proximity to the equator and remains almost constant throughout all seasons of the year. Annual variations of temperature are small 1.5° to 3°C but diurnal (day to night) differences can be much higher, reaching 12°C.

3. EXISTING HOUSING TYPES

Two housing types have been utilized in these Andean cities: the traditional courtyard house and the contemporary compact house. The traditional courtyard house is organized around a patio which all its room faces. On the other hand, the contemporary compact house has a concentrated shape in which both the lot and the house area have decreased.

The two architectural patterns were analyzed in order to find the most advantageous for passive solar heating. It is important that the passive solar system to be used will not be awkward in the existing patterns, so as to be accepted by the users.

After having compared the envelope elements
of the housing types, we find that the courtyard house offers more connector elements to solar utilization than the compact house. The main difference between the houses are the courtyard walls which are connector elements that offer the best opportunity for solar gain in places like the Andean cities.

4. CLIMATIC CONDITIONS

Peru stretches from the equator to 18° south latitude. The Andes are a long, high range of mountains extending more than 2,000 km. the entire length of Peru and varying in width from less than 100 to 300 km., with many peaks higher than 6,000 m. More than half the population of Peru lives in the mountain valleys. Here the climate is almost uniform; monthly variations are very small. However, diurnal differences are greater. Insolation is always high.

This study focused on Puno, a typical Andean city in Peru. Puno is located in south-east Peru on the border with Bolivia (15°52' south latitude and 70°00'W). Its elevation is 3,875 meters above sea level.

The temperature in Puno remains nearly constant year-round (Fig. 1). The variation of the maximum daily temperature during the year is just 2.9°C while the variation of the minimum is only 6.5°C. The maximum temperature occurs in November (during the rainy season) while the minimum temperature occurs in July (dry season).

Puno's climate is underheated during the whole day throughout the year. The small monthly temperature variations and the high diurnal (day to night) temperature differences are the main characteristics of almost all the Andean cities. A cool "summer" occurs every day; "winter" occurs every night. The humidity remains in the comfort zone (32% to 74%) during the whole year (Fig. 2).

Puno receives a great amount of solar radiation year-round. The horizontal surface is almost as efficient as the latitude angle because the latter for Puno is relatively small (16°).

Puno is underheated all the year round so the optimum orientation is found where radiation is at maximum throughout the year. The horizontal surface receives the maximum annual solar intensity, remaining almost constant throughout the year (Fig. 3). Among the vertical surfaces the ones that receive the most radiation are the east and west orientations, the NE and NW surfaces receive almost the same yearly radiation.

![Graph showing Puno's ambient air temperature by hours.](image)

Fig. 1. Puno's Ambient Air Temperature by Hours.

![Psychrometric chart showing Puno's climate.](image)

Fig. 2. Puno's climate on a Psychrometric Chart.
After the climatic analysis for Puno has been done, the following strategies can be identified to produce thermal comfort:
- Maximize solar gain
- Minimize the heat loss (Isolation)
- Protect against winds (Isolation)
- Equalize the indoor diurnal variations (Thermal Mass)

5. COVERED COURTYARD

The covered courtyard or sunspace for low latitude locations has the same concept as the attached sunspace has in the United States. They are designed to be used primarily for passive solar heating. In the United States the sunspace is attached to the south side of the building because heating is needed during the winter season when the sun is facing to the south. In the Andean cities and in low latitude places the same principle is applied; the sunspace is attached to the center of the house because heating is needed year-round and the sun remains very high throughout the year. Therefore the horizontal (glass roof) surface is the best collector year-round.

The house is designed to "wrap around" the sunspace, or, the house is organized around this solar space. This configuration has the advantages of: reducing heat losses from the sunspace, transferring heat easily to a great area of the surrounding house, and allowing the inclusion of a large amount of thermal storage material.

In the United States, attached sunspaces often serve as working greenhouses. In Peru, the sunspace will have the same function as the patio or courtyard had in the old traditional Peruvian house. The courtyard will continue being the core of the house, a natural daylighted and now indoor space. The solar energy collected and absorbed by a covered courtyard is used to heat both the sunspace itself and the adjacent living areas (Fig. 4).

The sunspace can be used as a patio and as an outdoor-indoor space. It can serve more than one function including being an extension of the living space. It can become an aesthetic asset to a house. It will increase the amount of daylighting in the house and will act as a buffer zone to reduce heat loss from the adjacent living spaces.

The courtyard houses of the last century in Peru offered pleasant qualities of privacy, light, and air to their users. In colder climates, the courtyard may be covered to temper the air and mitigate the additional surface/volume ratio that the courtyard design implies.

Another consideration that will accentuate solar rhythms derives from having access to sunlight within the building. There is a perceptual irony in the incongruity of visual cues between the outside of the building and the inside of the court. For example, in a lot elongated east-west, when the west side of the building is dark in the morning, the east side of the building is sunlit but the west side of the court is shadowed. A similar phenomenon occurs on a seasonal basis with the north and south sides of the court and building.

The morning or afternoon lighted area is usually located in the second floor. This is very important because it will help to deliver heat immediately to the top floor in the morning, while that side of the house is still cold (Fig. 5). In the afternoon the lighted area over the east wall will help to deliver heat immediately (through windows) or to store heat (in storage walls) for later use, as shown in Fig. 5.

The procedure used to evaluate the performance of the covered courtyard as a sunspace for an Andean city, was based on the energy balance principle that all the heat gained in the sunspace (due to solar radiation) is
then lost (transferred) either to outside or into the house (adjacent rooms). During the daylighted hours (7 a.m.-5 p.m.) heat flows from the sunspace to the adjacent rooms (warm to cool) because the temperature in the sunspace is warmer than the temperature in the adjacent rooms. At night, the sunspace temperature drops below the adjacent room temperature, heat flows from the adjacent in the sunspace (7 p.m.-6 a.m.)

Fig. 6 shows the temperature variation for a 16 m² sunspace on June 21 in Puno. Materials used in this sunspace—8" brick wall with 1" gypsum on both sides; windows—double glazing with wooden window shutters; doors—1" solid wood. Other assumptions—windows and doors remain open from 7 a.m. to 4 p.m., temperature in the adjacent rooms is 18°C and the roof of the sunspace is a horizontal double glazing without night insulation. In order to transfer heat from the sunspace to the rest of the house doors, windows and vents need to be opened. Of course that this schedule may vary with the lifestyle of the users. However, for the purpose of comparison, this analysis assumed that windows will remain opened from 8 a.m. to 4 p.m.

Fig. 7 graphs the total heat (W/m²) per day flowing from an 8" brick wall sunspace into the house on June 21, for a 16 m² and 25 m² in each case tends to follow the same angle. There are also plotted for the same two sunspace sizes (16 m² and 25 m²) and the various roof apertures (25, 16, 10, and 5 m²).

6. THERMAL PERFORMANCE OF HOUSING TYPES

Three types of housing—traditional courtyard, compact house, and the covered courtyard—were evaluated in order to determine which has the best thermal performance on June 21 (winter solstice) in Puno, Peru. It
was considered in the three cases the same characteristics: floor area, lot orientation, lot dimension, facades, building materials.

The thermal performance was evaluated by calculating the total heat gain and subtracting from it the total heat loss. The results showed that the covered courtyard house has the best heat balance because its total heat gain per day represents 94% of the total heat loss per day. One way to retrieve the lost 6% of heat gain could be to use night insulation over the double-glazed roof of the sunspace (covered courtyard), this will significantly improve its thermal performance. The use of insulating materials such as polyurethane in walls and roof will decrease the envelope heat loss of the proposed covered courtyard house.

The main source of heat gain is from solar gains such as through windows (≈ 36% to 60% of the total heat gain per day). The covered courtyard house receives a great amount of heat gain from the sunspace which has its peak value at noon. A covered courtyard house receives in the day a greater amount of excess heat gain that will be stored in walls and floor inside the covered courtyard and delivered when heat is needed: evening and early morning. The time lag or time when the stored heat will be delivered from the sunspace to the rest of the house will depend on the kind of materials used for the walls and number of openings (windows and doors). In this analysis, it was used a 16 m² sunspace, 8" brick wall and 50 percent openings. The 8" brick wall has an 8-hour time lag. In other words, if the maximum amount of heat gain in the sunspace occurs at 12 noon, the maximum amount of heat transferred to the adjacent rooms will occur at 8 p.m.

The analysis demonstrated the great improvement in thermal performance that a covered courtyard can bring to houses in Puno or in areas with similar climates and similar latitudes. The covered courtyard house offers advantage of both the traditional courtyard house and the compact house. From the traditional courtyard house, it makes a nice in door-outdoor space with good daylight, but because it is covered, courtyard temperatures in winter are comfortable, making the sunspace suitable for family activities, and even growing plants. From the compact house, it takes the concentrated shape with little exposed area and, therefore a low rate of heat loss.

When a covered courtyard is included in a conventional compact house type, it does not change the daily or seasonal migration that affect the living patterns; moreover, it balances the daily migration of the east-west lot orientation, adding sunlight and heat to the part of the house that remains dark either in the morning or afternoon.
7. OTHER APPLICATIONS

Great improvement was shown in the thermal performance that a covered courtyard (sunspace) brings to a house. It is proposed to be used as a passive solar system in multifamily housing buildings. Houses in cold climates should be grouped around a sunspace that is heated through its glazed roof.

The principle will be same as one for single family housing. The difference will be the scale. The size of this sunspace has to be increased in order to deliver more heat to each house. The sunspace in a multifamily housing will be a space that will give light and heat to the surrounding houses. As the core, the sunspace will be the main organizer of the building and have many functions, providing a space where people can interact socially, as well as a comfortable space where children can play safely. In general, the covered courtyard will have the characteristics of a community space and will organize in a better way the urban design of cold places where there is always a lack of adequate spaces for community activities.

In the same way, it can be used in commercial and institutional buildings. The benefits of a covered courtyard are not limited to improvement in building energy use. The covered courtyard floor area will improve the circulation efficiency and will add valuable open space to the building. One important aspect of passive design is the energy saving in artificial lighting. Many building types, particularly schools, office buildings, hospitals, hotels, have open internal courtyards which can be glazed over to provide useful improvements to their thermal performance.

In the Andean cities, there is no problem with the summertime overheating, and the benefits of courtyard glazing in reducing heating loads can be quite significant.

8. CONCLUSIONS

This research intended to change the designers' attitude toward architecture in Peru. A building should be designed to strongly relate to the site and climate. The latter will determine the strategy to be used in the building, adapting the local building materials and methods of construction. The pattern of use and lifestyle of the occupants should also be taken into account. This attitude is obviously not entirely new in Peru, since much ancient Peruvian architecture (Pre-Incan and Inca) has reflected a strong relationship to daily and seasonal climatic and solar variations.

One largely untapped climatic resource is the Sun, it should be taken into account when designing a building, especially in underheated places but with a great solar potential, e.g. the Andean cities.

In this research I have demonstrated, the covered courtyard is the passive solar design which will maximize solar performance in Puno, Peru. Due to the high altitude, heating needs are great in winter, yet, due to the latitude and climate, solar energy is abundant. The design can be built using local materials; expensive imported building materials are avoided. The covered courtyard design will probably be suitable for Andean regions of Bolivia, Ecuador, and Colombia, since climate and available materials are similar.

In conjunction with the heating benefits of a covered courtyard solar house, the central space facilitates interaction among the family members. Activities tend to converge in the courtyard, prompting communications and awareness of each other. Thus, the covered courtyard design not only brings a warmth in to a home, it also reinforces the family unit.

9. ACKNOWLEDGEMENT

My deepest thanks are extended to Professor John S. Reynolds for his valuable advice and guidance in the preparation of this research at the University of Oregon.

10. REFERENCES