Architectural and environmental housing typology analysis in Huamachuco, Peru

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ABSTRACT: This work focuses on the city of Huamachuco, a town 3200 meters above sea level in Northern Peru. The main aim of this study is to share and disseminate technological knowledge on architecture, building technology and lifestyle of Huamachuco inhabitants. The paper objective is to (1) highlight the concept of architectural quality in Huamachuco, (2) compare the living environment of existing traditional dwellings in comparison with newly constructed concrete dwellings, and to (3) identify the reasons for neglecting ecological construction technologies and materials in the new built environment. The research methodology went through different phases that range from qualitative data collection and quantitative measuring, to data analysis and findings reporting. Firstly, a typological study was conducted visiting 110 houses. The typological study enabled us to describe and understand the housing typologies and classify those under four major typologies according to their construction techniques: 1) adobe, 2) rammed earth, 3) concrete and 4) mixed technique. Secondly, detailed field studies were conducted for representative houses representing the four categories. Finally, 10 houses have been thoroughly audited for using measuring equipment to collect data related to temperature, relative humidity, carbon dioxide concentration, lighting intensity, and envelope thermography.
Keywords: housing quality, livability, thermal comfort, air quality, climate, adobe, rammed earth

INTRODUCTION

On the verge of the third millennium, many countries are suffering from a housing crisis that can be assessed from a quantitative and qualitative approach. The factors behind the housing crisis include population growth, globalization, decentralization, governance and strong migratory trend from rural areas. These changes create new reality and put a serious pressure on housing needs in cities. As a consequence informal housing, self-made construction or architecture without architects emerges as an answer to this need. Across the developing countries more than 95% of housing is built by inhabitants and without architects (Gnaiger 2014). Despite the dynamic role of self-built housing, in creating jobs and consuming building materials, they remain problematic. If quantitatively self-built housing efforts are considerable for providing shelter, qualitatively they are criticized. In most of those buildings, there is a gap between the developed construction and the inhabitant's needs. For example, housing units are characterized by small spaces for economic and planning reasons. In many cases economical and planning constraints lead to low quality housing, with poor urban infrastructures. Consequently, the inadequate housing and lack of comfort affect the liveability of those housing. The living quality remains unsatisfactory or poor in most patterns of habitat.

In this context, architects have a meaningful role. The role of the architect is to constantly seek the best possible models and solutions to ensure a minimum architectural quality in order to meet and foresee the changing needs of users. With the UN development goals and improved economic conditions in many emerging countries there is a hope to share welfare of humanity and provide a better quality of life in the built environment. Therefore, this study is reporting the findings of a Master thesis that focus on the evaluation of housing quality of Huamachuco City in Peru. The study is a first step research to provide a better understanding of the housing typologies, construction techniques and environmental quality of self-built housing. The scope of this paper is limited to assess and compare different construction techniques and housing typologies in Huamachuco without providing solutions. However, this is a fundamental step to help developing architectural and construction solutions in the future. The paper audience is mainly architects, building engineers together with policy makers concerned with informal housing and urban planning. The context analysis, methodology and study outcomes are elaborated in the following sections.

METHODOLOGY AND CONTEXT

This research methodology is based on five major steps that were conducted by the author from January to April 2015. First, a field mapping was conducted to identify the housing typologies regarding their state, local, construction technique, building materials, housing setting in the street, and window to wall ratio (WWR). Secondly, IEQ monitoring was carried out in 10 representative houses selected based on step 1. With the use of data loggers, CO^2 meters, thermal cameras and lux meters the indoor was assessed. Thirdly, comfort analysis was conducted following adaptive comfort model EU EN15251 (Attia 2015) (Singh 2016). Fourth, a set of structured interviews were conducted with all families of the 110 houses to define their social, economic status and life style and post occupancy evaluation of their habitat. Finally, a set of observations were made through interviews with Huamachuco municipality urban planning department to validate some findings or clarify issues related to the built environment in the city and related to physical, aesthetic, sensory, safe, and sociological issues.

The city of Huamachuco is the capital of the province of Sanchez Carrion and is located 184 km from Trujillo on South Pacific Ocean Coast. Huamachuco is located at 3290m altitude; latitude is 07°50' South and longitude 78°03' West. The climate is temperate with cold nights and sunny days. Rain is considerable from January to April and October to the end of the year and often during the months of May to September. The city was discovered by the Augustinian priests sent by the King of Spain in 1551. Huamachuco is known for its knitting art, cuisine and above all its attractions like the famous archaeological site Marcahuamachuco which is one of the largest Northern Peru. The city benefits from its proximity to natural sites and thermal baths as Yanasara or El Eden. The main activities of the city are agriculture and mining. According to the 2007 census, the city has an estimated population of 28,300 inhabitants, 57% urban population (INEI 2008). According to studies conducted by the University of Lima, 77% of homes are mud constructions (adobe and rammed earth). 69% of city residents are satisfied with living in Huamachuco and 20% are very satisfied (PUCP, 2015). Based on Figure 1, it is expected that the city will increase its surface area by 5% annually attracting citizens from the whole Province. Between 1000 and 2000 households are expected to be constructed annual for the coming 10 years.

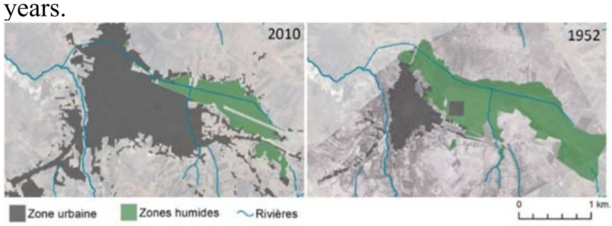

Figure 1: Urban expansion of Huamachuco between 1952 and 2010 (Gonzales 2013).

HOUSINGS TYPOLOGY ANALYSIS

To conduct our typology analysis and classification we relied on 3 indicators. The first was the city vs. rural urban context, the outdoor vs. private space housing interface and the building construction technology. The following paragraphs elaborate on the methodology and provide basic analysis results.

Based on our field analysis we identified a dichotomy regarding building density in Huamachuco. The downtown is densely occupied with concentrated buildings while the city fringes and peripheries are low density and low-rise housing development with isolated houses located in a rural setting. During our analysis we were seeking information on density and building concentrations which are essential to qualify an anthropic space. Therefore, we distinguished rural and urban habitat typologies. Especially that the architectural facades language varies between urban and rural areas. For example a rural facade has a semi-public space between the inside and the outside of the building something we do not find in the city centre as shown in Figure 2.

Next we relied on the presence or absence of outdoor spaces for our classification. The presence of semi-private outdoor spaces had a large impact on livability in terms of the amount of light that will enter the house and the renewal rate of the air. Also the presence of semi-private outdoor spaces plays a leading role as a spatial extension of the house, offering an outdoor space dedicated to relaxation or breeding of animals. We were able to distinguish three types of organization in relation to an outdoor area:

- Spatial organization of the house around one or more external centers (patios) (A).
- Spatial organization based on a linear progression or corridors including an outdoor space (B).
-Spatial Organization without outdoor space (C).

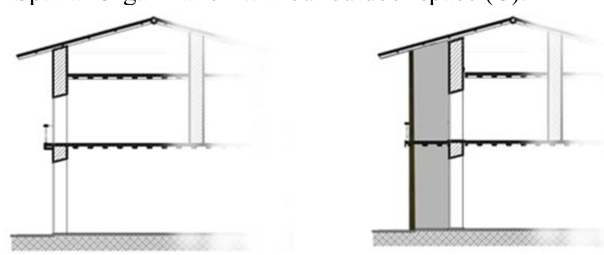

Figure 2: Schematic sections presenting the city centre facades (left) and rural facades (right).

Based on this classification we found that Group A was the most dominant type (60% of the sample of 110 houses visited). A patio will provide privacy and maximum access of light and air and is better accepted because it meets the local lifestyle.

Finally, we identified two main groups of constructions in Huamachuco that can be classified under traditional and modern construction. The first group represents traditional techniques based on vernacular architecture. Vernacular architecture of Huamachuco is built exclusively from earth-based materials. Rammed earth constructions are known among locales as '*tapial*' while erected walls are made following the ancient technique of adobe bricks. Earthen architecture is highly neglected by the people of Huamachuco in favor of new materials (concrete structure and backed brick walls). The lack of light (regarding intensity and distribution) indoors is a concern in most earthen construction technique based housings. We realized a correlation between percentage of opening (window to wall ratio (WWR)) and construction technique. Buildings with a WWR ranging from 30 to 50 were post and columns concrete constructions. Any WWR below 30 will be most probably associated with earth construction. The small openings impact the lifestyle of inhabitants and force them to use the outdoor as a semi-private space as mentioned earlier. To compensate the lack of light intensity indoors, inhabitants will perform their daily working or house related activities, such as sewing, tricot, or washing laundry, in front of their houses.

The second group represents modern construction techniques mainly made from concrete skeleton structures. Concrete and baked clay brick is labeled by locals as '*noble materials'* who appreciate all the benefits they provide to homes such as: stability, durability, long life, clear spans, non-load bearing walls with larger windows and the various free forms structures.

Based on our mapping analysis we can classify the construction techniques in the city under the following four categories as shown in Figure 3 and Figure 4a:

- Rammed Earth (A).
- Adobe Brick (B).
- Casted concrete skeleton structures with baked brick walls (C).
- Hybrid technique combining concrete and different types of bricks for a single building. For example an adobe in the lower floor and baked bricks on the upper floor (D).

Figure 3: Images representing the four dominant housing construction techniques in Huamachuco.

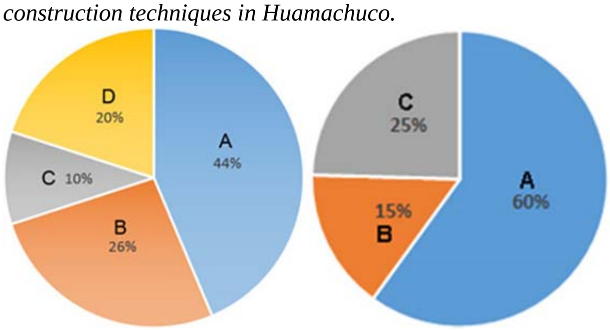

Figure 4a:distribution of a sample of 110 houses according to the construction technique (left), 4b, distribution of a sample of 110 houses in relation to an outdoor area (right).

COMFORT ANALYSIS

The following section presents the comfort analysis results based on the environmental audits conducted in 10 representative houses. The following sections report the outcomes for three different housing types.

Rammed Earth Houses

The selected house is a rammed earth construction located within a 15 minutes' from the Plaza de Armas. There are no acclimatization systems in the house. The only modifications made to the house are the addition of a bathroom in the backyard and the reconstruction of a separation wall with the neighboring house.

Temperatures: Figure 5 illustrated the results of the monitoring of the dinning/kitchen space over four days. As shown in the figure the temperature profile does not follow the variation of the external environment. We note three small peaks each time around 7am, noon and from 20h. Since the space is used for kitchen and dining, we realized that that these peaks coincide with meal times when the whole family is gathered for eating. On the other side, the internal temperatures remained stable. Temperatures varied generally in the range of 15 to 18° C. Indoor temperatures peaks are not caused by the external environment, and they are due to the concentrated presence of occupants in the space. We calculated an outside temperature difference from 9 to 28°C (19°C difference) and an inner variation much smaller, between 15 and 18 ° (3°C difference). Between the peaks, the temperature inside seems to remain constant (between 15 and 16 °C). We concluded that the rammed earth envelope plays an insulating role in maintaining a constant temperature despite the increases and decreases of the outdoor temperatures. Thermal comfort is not achieved and is considered marginal. The only moments of comfort are due to the peaks generated by the meeting of the whole family in the kitchen, around noon to 19h.

Relative Humidity: According to Figure 6 relative humidity inside seems to remain constant, usually high between 75 and 85%. Although there is a relationship between humidity rate drops and peaks to the outdoor environment, the rate never drops below 70%. The comparison between the indoor and outdoor humidity confirms that the envelope ensures its protection of the internal environment against hygrothermal fluctuations outside.

Carbon Dioxide Concentration: The room where the CO2 meter has been placed was the bedroom but as it contains a large plasma screen, it is the full day occupied for watching TV. According to Figure 7, CO^2 rate increases sharply at 18h and stays high exceeding 1500 ppm. Then it dropped at 6am and depending on the day, it adopts different attitudes; remains stable at around 400 ppm at the first day of recording or varies in a range between 500 and 1200 ppm in the second recording day. Unfortunately, because of frequent power outages in

Huamachuco we witnessed a data loss between 23h and 6am on the third day. We expect that the CO^2 rate reached its maximum during this interval, corresponding to sleeping period where 3 occupants sleep in the room. Overall, the CO^2 level exceeds the limit of 1000 ppm allowed by WHO (2000). The absence of windows for natural ventilation cause a hazard potential to occupants including the toddler who spends most of his time in the bedroom.

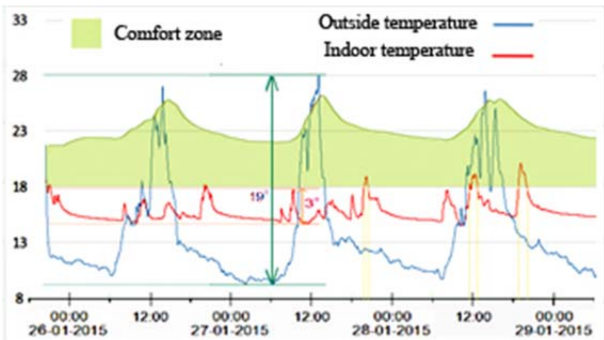

Figure 5: Temperature profile in the rammed earth house.

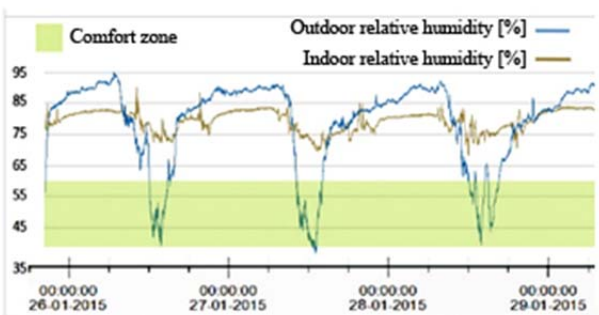

Figure 6: Relative humidity profile in rammed earth house.

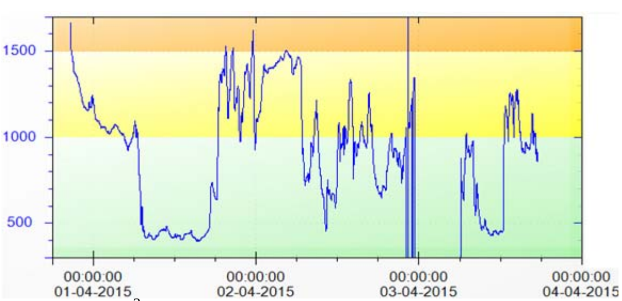

Figure 7: CO^2 profile in the rammed earth house in ppm.

Adobe Houses

The selected house is located on the outskirts of town, in the district of Cuchilla. The house consists of two parts: 1) a small room with a covered roof which serves as a storage and garage got motorcycle and a (2) house built of adobe bricks. It was built on the ruins of an old adobe house. The measurements were taken in the bedroom.

Temperatures: According to Figure 8, the indoor temperature follows the variation of the outside temperature. This close matching of the indoor and outdoor temperature profiles informs us about the alarming state of the envelope. This is due to the unsealed roof/wall edges that might prevent the envelope to respond adequately to its air tightness function. As a consequence the air infiltrates easily in the interior. We found this problem in most visited adobe houses.

Relative Humidity: As shown in Figure 9 relative humidity varies according to a substantially similar profile to the outdoor relative humidity. The agreement is almost perfect for the highest values with differences only up to 5%. When the outdoor humidity drops, the internal humidity follows the line but with a difference of 10 to 25%. Similar to the temperature profile above there is a close proximity of the two humidity profile. These results indicate the poor envelope construction and the difficulty to maintain outdoor independent indoor temperatures. The comfort zone is reached for the majority of days when between 11h to 18h.

Carbon Dioxide Concentration: As shown in Figure 10 the CO^2 rates are almost stable. Although four people sleep in the same room, CO^2 remains stable at around 400 ppm with a slight increase to reach 500 ppm from 20h and lasts until 6am (occupants sleep time). This low rate of CO^2 confirms that we are facing a home where the air is overly renewed continuously. Finally, we used the thermal camera to assess the location and space of those cracks. The results are presented in Figure 11.

Concrete Houses

The selected apartment is in a building located 5 minutes from the city hospital and the stadium. The apartment is occupied mostly by various people working in the week in Huamachuco and returning to Trujillo during the weekend.

Temperatures: We observe that the temperature profiles within the apartment describes are smooth and shifted compared to outdoor temperature (see Figure 12). This phenomenon is due to the high thermal mass of the envelope building material and air tightness of the envelope. The envelope material absorbs and stores heat or cold. The walls emit the excess heat stored during the day so that the room remains hot for several hours after the start of the falling temperatures outside. The phenomenon is reversible in summer. We could conclude that the envelope plays a regulatory role of the internal environment by providing a stable framework in which the temperature varies between 13 and 18°C (5 ° difference) while outside, this can vary more significantly. However, the tthermal comfort was rarely achieved with an average indoor temperature of 15°C.

Relative Humidity: The indoor relative humidity hardly changes throughout the recording time as shown in Figure 13. The result is 80%. The envelope plays a role to maintain a constant relative humidity regardless of fluctuations in the external environment due to the relatively better air tightness.

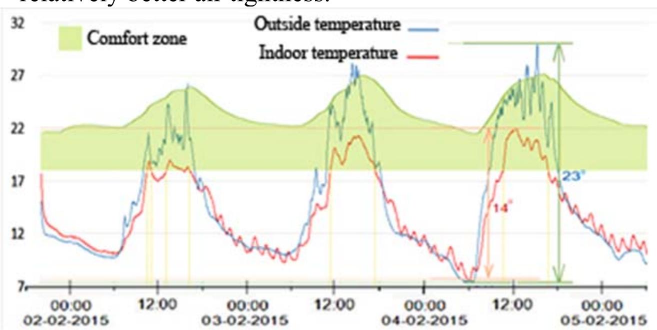

Figure 8: Temperature profile in the adobe house.

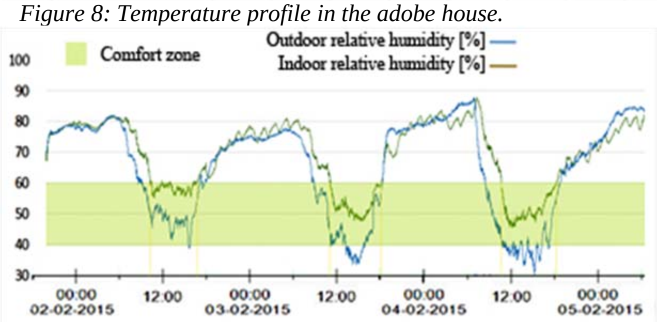

Figure 9: Relative humidity profile in adobe house.

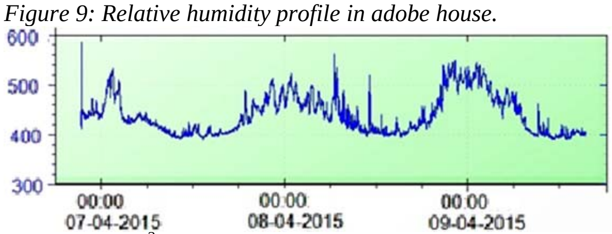

Figure 10: CO^2 profile in the adobe house in ppm.

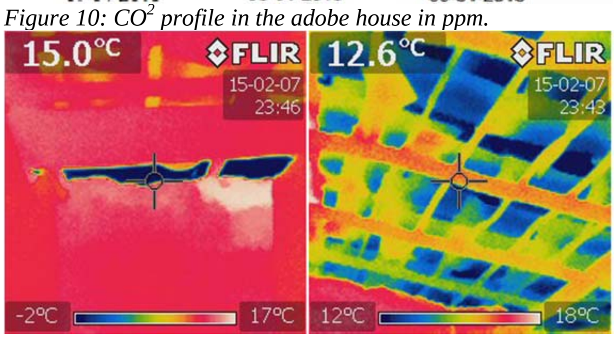

Figure 11: Gaps and cracks between the top of the wall and roof showing the poor construction of the roof.

Carbon Dioxide Concentration: The CO^2 levels soar when it exceeds 23h. It suddenly drops from 8am to stabilize around 400 ppm for the remainder of the day. The data logger is placed in a room where the occupants are sleeping. The peak of the profile presented in Figure 14 corresponds to the sleeping time. The highest rate nearly reached 1500 ppm. The vertical fall of the rate of CO2 takes place every day at 8:00 am precisely, when occupants wake up and open the window to air the room. The indoor air quality can be qualified as poor.

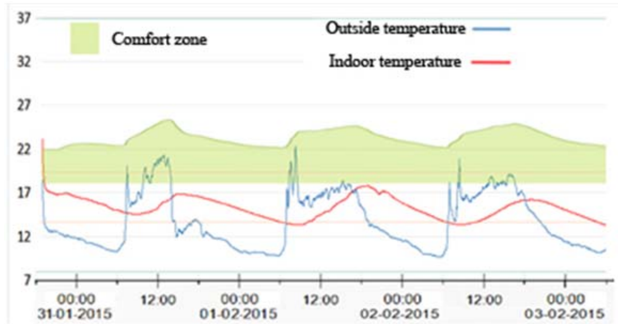

Figure 12: Temperature profile in the concrete apartment.

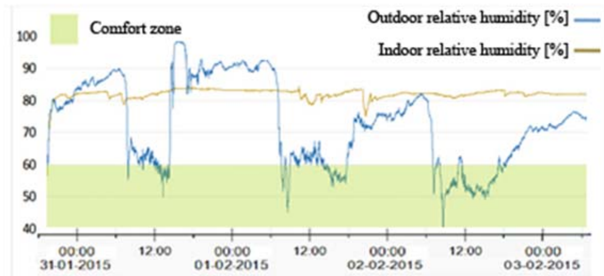

Figure 13: Relative humidity profile in the concrete apartment.

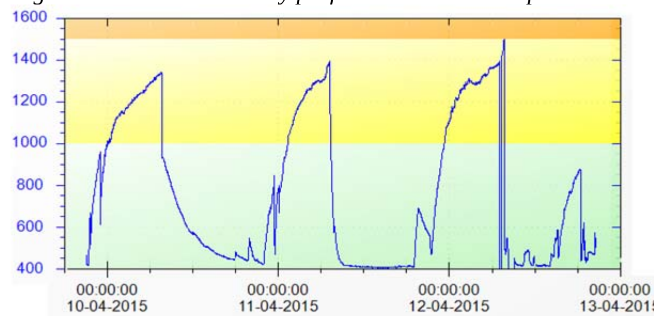

Figure 14: CO^2 profile in the concrete apartment in ppm.

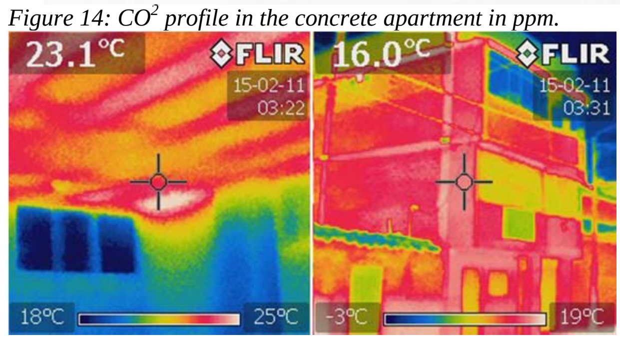

Figure 15: Ceiling showing concrete beams store and emit heat after nightfall (left). The concrete structure (columns and beams) stores the most heat (right).

DISCUSSION AND CONCLUSION

The following paragraph summarized the findings related to thermal comfort in the three main construction techniques followed by a discussion on the post occupancy evaluation and interview results.

Firstly, the monitored performance of the rammed earth houses has all shown the same phenomenon: significant reduction in the amplitude of fluctuations in the indoor environment. This is partly due to the thermal mass of the material permitted by the thickness of walls is 70 cm. But we also note that rammed earth houses offer within framework characterized by low temperatures and which rarely reaches the thermal comfort zone (95 to 100% of the time duration of the measurements is outside the comfort zone)

Secondly, we are witnessing a paradoxical result for adobe houses that goes against intuition taking into account the thickness of the wall that reaches 40 cm. This thickness is supposed to give the thermal mass which involves shifting the temperature profile and reduce the amplitude. However, results show that adobe houses function as if they do not have a thermal mass. Nevertheless, taking into account that there are more thermal exchange between the inside and the outside, the adobe houses reach the comfort zone for longer times than the rammed earth houses (75 to 82% of the time the total duration of the measurements is outside the comfort zone). There is a correlation between the relative humidity and the type of construction; the adobe houses never reach the critical threshold of 1000 ppm and keep CO^2 concentration at a stable rate. This confirms that the construction quality is very poor in most adobe houses. Thirdly, modern concrete homes with post and beam structures showed an active functioning of thermal mass. The time period where the thermal comfort zone is reached remains comparable to rammed earth houses with about 92% of the duration of the action is outside the comfort zone.

On the other side the population of Huamachuco rejects earthen construction for several reasons. First because of the few openings associated with this type of construction. Secondly, for the limitation of indoor spaces regarding free spans and wall thickness (up to 70 cm for rammed earth walls). The earth construction is associated with poverty and rigidity not allowing future extensions like adding floors thereafter as in the case of concrete houses. This situation results in abandoning earth construction in favour of concrete which is associated with negative environmental impacts. Technological choices and the earth construction methods in Huamachuco are rudimentary while concrete construction is one step further regarding marketing and construction technology quality.

From the current situation we predict that earthen architecture heritage and traditional architecture of Huamachuco will get dominated by concrete constructions and buildings. Earth construction and sustainable building materials use are not valorised from a quality, technology and policy point of view in Peru. Like many other villages and cities in India, Egypt or Vietnam the local knowledge of earth construction technology will disappear and all associated life style and architectural housing typology will change. We are glad to report and document the situation of the built environment in Huamachuco and highlight the correlation between architectural typology, construction technology, indoor and outdoor use in the city's urban pattern and the daily citizen's life style. This interconnection and refined coexistence with land, earth, landscape and animals forms the culture of Huamachuco today. We hope that in the future the city can combine the local culture of the past and technical progress of today using sustainable building materials and technologies while maintain highest quality of life in the build environment.

Finally, we can conclude based on our findings that our field study documented construction poor quality and the associated habitability problems that arise in reality. All investigated houses do not fulfil the minimum thermal and visual comfort requirements. Therefore a full building performance simulation is required to assess the comfort on an annual basis. The following step could be the investigation of appropriate affordable and comfort effective solutions on a strategic level. A series of guidelines and convocational training can guide the inhabitants of Huamachuco to achieve better quality of their habitat and even investigate the need to installing active heating or cooling systems in the future.

ACKNOWLEDGEMENTS

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