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Bioclimatic responsiveness of La Casa de Luis Barragán, Mexico City, Mexico

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ABSTRACT

The Casa – Estudio Luis Barragán, Mexico City, Mexico is a celebrated architectural work. The building and its site were enlisted in UNESCO World Heritage Site in 2004. The building is renowned for its innovative architectural features; however, little research can be found on its environmental performance of this building. The building is constructed mainly of high capacitive materials, large walled garden, and a number of courtyards, which provide thermal strategies appropriate to the cool high-altitude climate. As yet, little data have been collected on the thermal performance of this house. The paper makes an original contribution in this respect and argues that the often ignored bioclimatic aspects of the building underpin the pragmatic and poetic design aspects and these should be recognized as part of its cultural heritage and conservation.

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Cultural sustainability; heritage conservation; climate responsive design; thermal comfort; vernacular architecture

1. Introduction

The aim of this research is to investigate the climate-responsive nature of the work of Luis Barragán through his house in Mexico City. Little is known of the thermal performance of this house since most of the research on this building has been concerned with the architectural characteristics that led to its prestigious Pritzker Architecture Prize. The research is aimed at investigating the thermal qualities of the building and the potential provision of comfort for its occupants and its contribution to sustainability. The research follows a four-pillar model of sustainability, which examines the design of buildings from four sources of wisdom; that is, environmental, social, economic and culture (Yencken and Wilkinson 2001).

2. Background

The chronology of La Casa de Luis Barragán starts in 1939 with the acquisition of a vast piece of land located on Daniel Garza's neighbourhood in Mexico City (see Figure 1). Luis Barragán lived in this house for four decades. In 1980, he received the Pritzker Architecture Prize and a few years later (in 1988), he passed away. After his death, the properties in Francisco Ramirez 12th and 14th were acquired by FAT-LB (Fundación de Arquitectura Tapatía Luis Barragán) and the government of Jalisco State, in which Luis Barragán was born. In 2004, both the house and the studio (Figure 2) were included in UNESCO's World Heritage List as it remains as the only private residence in Latin America with such distinction. It has now under gone adaptive re-use and is a museum (Figueroa 1989; UNESCO 2014; Zanco and Vitra Design Museum 2001). Surprisingly, little work has been carried out on the environmental performance of this house; hence, the first part of the paper examines the bioclimatic strategies that are appropriate to Mexico City. Studies have been carried out largely from the architectural design perspective (Van den Bergh 2006). Those related to passive low-energy architecture have also been largely descriptive, noting the strategies used to complement the architectural quality (Figueroa and Castorena 2013).

3. Bioclimatic studies of vernacular and modernist houses

There has been considerable research on the bioclimatic performance of vernacular houses and houses designed using Modernist principles (Hyde 2000). However, there appears to be a niche area of research, which looks at the bioclimatic performance of Regionalist Modern buildings. The buildings, as the name implies, adopted the principles of Modernism but also adopted attributes that responded to local climate and culture (Frampton 1980). The approach was supported by proponents such as Olgyay and Olgyay (1963) and Fry and Drew (1956).

The importance of these buildings is noted by Allaback (2003). In her study of the modern home, she discusses the success and failures of the development of Modern Architecture in housing. Allaback (2003, 29) states,

> ... in comparison with any other building type, house design and construction is simple and inexpensive. It is in the realm of house design, therefore, that architects were able to stretch the limits of the modern style, even to the point of discomfort.

It was only in the later period of post modernism that Modern buildings adopted a more Regionalist direction and turned to prove something 'more comfortable' (Allaback 2003, 29).

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Figure 1. Street façade of La Casa de Barragán from General Francisco Ramírez. The building is orientated east and west in a compact row house configuration.

In recent years, environmental responsiveness of buildings has become of importance and studies have been carried out to examine not only the cultural antecedents but also their performance (Hyde 2008; Puteri and Ip 2006). The building described in the study is from the early period of Modernism and reflects Regionalist thinking, so it is significant that this building is studied from the bioclimatic perspective.

4. Methodology

The study uses a Post Occupancy Evaluation technique called 'closing the loop' to understand thermal behaviour of building fabric together with satisfaction expressed by the occupants of the building (Hyde 2006; Roaf et al. 2004). Information from the design and operation phase is used. The study explores three interlocking techniques of Indicative, Investigative and Diagnostic recording (Hyde 2006).

4.1. Data collection

Data collection involved three stages. The first stage involved Indicative recording using observation and photographic techniques to understand the microclimate, form and fabric of the building and the passive and low-energy building attributes. Second, Investigative recording employs objective measures; temperature and humidity data are recorded using Hobo Sensors (http://www.onsetcomp.com/). Third, Diagnostic recording uses both Indicative and Investigate techniques over time through a longitudinal study and subjective information is gathered using a satisfaction questionnaire administered to occupants (Hyde 2006; Vischer 2002). Due to limited resources, only a pilot study was carried out which used the Indicative and Investigative techniques. The study took place in the summer over a 2-month period examining the library, living room and guest bedroom. These were selected as they were reportedly habited by Luis Barragán frequently.

4.2. Data analysis

4.2.1. Assessment of desirable climate responsive building attributes

The initial work on the data analysis involved comparing the building attributes to desirable attributes for the climate as advocated by Mahoney Tables (Koenigsberger et al. 1973). The Building Bioclimatic Chart (Figure 3) and the Bioclimatic Chart (Figure 4) recommend design strategies suitable for the local climate.

4.2.2. Assessment of thermal comfort

Analysis of the data from the monitoring process aimed to examine the comfort in the two study areas. The thermal comfort inside the building is the result of a number of factors: first, the environmental factors which include air temperature, air movement, humidity and radiation; and second, the personal factors, such as metabolic rate, clothing, state of health and acclimatization (Givoni 1992). The important factors included in this study are the environmental factors since these are influenced by the climate and building fabric. In addition, acclimatization is also considered since it is environmentally related.

The study uses modern indicators of thermal comfort to assess the range of comfortable conditions found in the building. The comfort zone can be calculated from an analysis of climate and it is based on seasonal adjustments due to acclimatization. These adjustments can be quite significant. Extensive studies have shown that people feel comfortable within a band (± 3.5 K) of neutral temperature which is best described as a function of outdoor mean monthly temperature (Szokolay 2004). Researchers have determined through formulae for calculating this neutral temperature (Auliciems 1981; de Dear and Brager 1998a; Fanger 1967, 1992; Griffiths 1990; Humphreys 1978; Nicol and Raof 1996). In this study, neutral temperature was calculated by algorithm developed by de Dear and Brager (1998b).

$$T_{\mathrm{n}} = 17.8 + 0.31 * T_{\mathrm{av}},$$

where, T_{n} = Neutral temperature; T_{av} = Monthly outdoor average temperature.

The above expression was used to derive the comfort zone for occupants for June. The average temperature in June is 27°C and the corresponding neutral temperature (T_{n}) is 26.2°C, with upper comfort level of 28.7°C and lower level of 23.7°C (de Dear and Brager 1998b).

However, to establish the conditions within study areas, important environmental parameters such as air temperature, air movement, humidity, and surface temperatures need to be calculated/ monitored. Hence, measurements of above-mentioned factors (except air movement) were made for each of the spaces. Temperature and humidity data were collected using HOBO data loggers, and spot measurements of the floors, walls and roof were carried out. This led to a determination of an internal operative temperature combining radiation and air temperature effects. Using the CBE comfort tool (http://smap.cbe.berkeley.edu/comforttool/), it is possible to evaluate the comfort conditions taking these factors into account based on the Adaptive Model as calculated using a

Figure 2. Floor plans of La Casa de Luis Barragán (Redrawn after http://www.casaluisbarragan.org/planos.html). Location of temperature and humidity sensors are shown in the plans. © [Catalina Corcuera]. Reproduced by permission of Catalina Corcuera, Director, Casa Luis Barragán.

comfort tool (Hoyt et al. 2013). When assessing comfort, the main issue is not only the relationship of indoor comfort to this index and to the operative temperature but also the changes in temperature as it is this dynamic that also accounts for discomfort (Santamouris and Asimakopoulos 1996).

5. Findings

5.1. Climate analysis

Mexico City is located at an elevation of 2250 m, not very far from the equator in the Northern hemisphere (latitude 19°N).

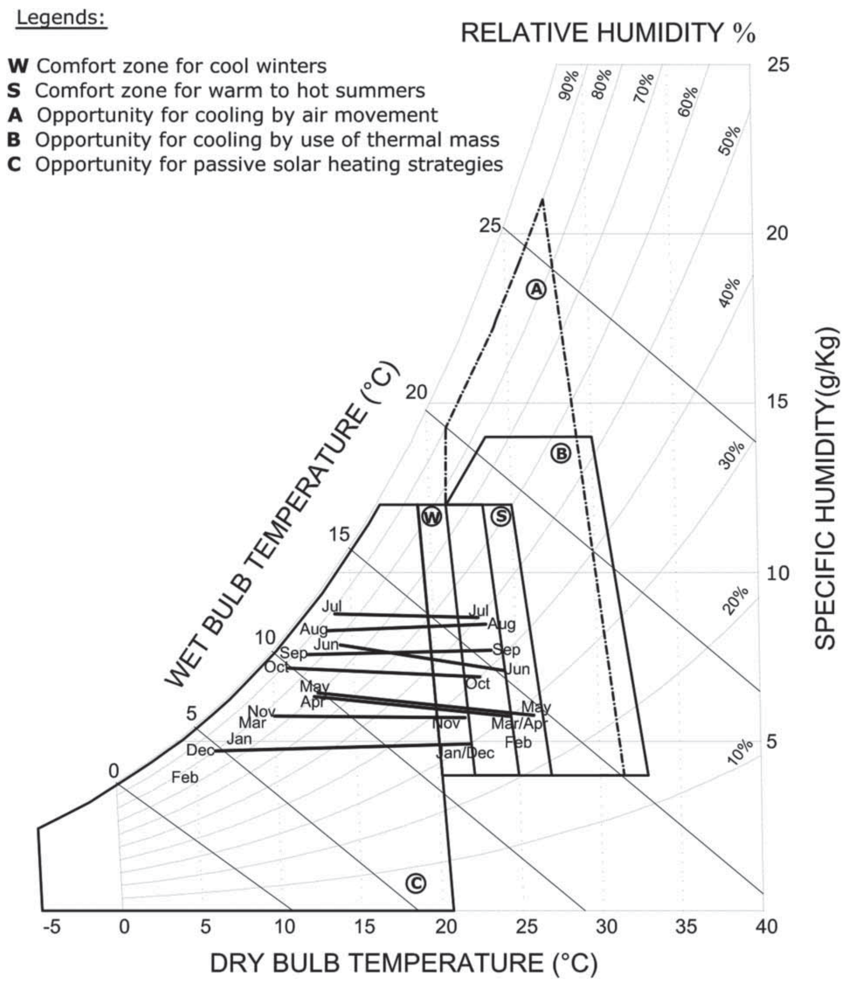

Figure 3. Building bioclimatic chart for Mexico City. Control potential zones are derived using Szokolay (1986).

The annual average temperature is 16°C. The lowest temperature can reach −2°C during the coldest mornings of winter in January and February. The maximum temperature in the late spring and summer (May to June) can reach up to 32°C.

The climate in Mexico city can be divided into two main seasons: rainy season occurs during summer and it is mostly between June and the start of October. Dry season takes place from November to May with very little or no precipitation through the entire period. Dry season can also be divided into a cold period from November to February and warm period from March to May. These effects are created by a dry polar air steam, which travels from the north in the cold period, and by a tropical air stream in the warm period. The average annual rainfall for the Valley of Mexico is 820 mm, which is distributed during the summer months. This climate is classified as a Cool Climate (Koenigsberger et al. 1973; Szokolay 1982).

The Building Bioclimatic chart (Szokolay 1991) and Bioclimatic Chart (Olgyay and Olgyay 1963) (Figures 3 and 4) illustrate that the temperatures are below the comfort zone for most of the year. They both recommend using passive solar heating strategies in winter if there is enough solar radiation available. These charts do not indicate a major issue for summer months; however, the use of thermal mass and or ventilation can be effective for summer cooling.

Further analysis and closer scrutiny of the Building Bioclimatic chart (Figure 3) and Bioclimatic chart (Figure 4) infer strategies for providing comfort by utilizing thermal mass without the need for ventilation. Hence, in the study, it was not necessary to carry out ventilation measurements. Further guidelines for passive design are found in the Mahoney Tables (Koenigsberger et al. 1973).

5.2. Mahoney analysis

Mahoney Tables recommend strategies for form and fabric based on microclimate (Koenigsberger et al. 1973).

Microclimate: The bioclimatic strategies of the building align with the recommendations from Mahoney Tables as shown in Table 1; however, all the habitable rooms are not orientated towards the North side. The building has its long axis, North and South. The implication is that the building loses the opportunity for passive heating in winter. However, as shown in Figure 1, the building is a compact/row-house configuration, which has buildings adjacent to the North (polar facing) and South. The microclimate to the East and West moderates the solar access to the facade. The garden on the West contains mature trees and vegetation (see Figure 5).

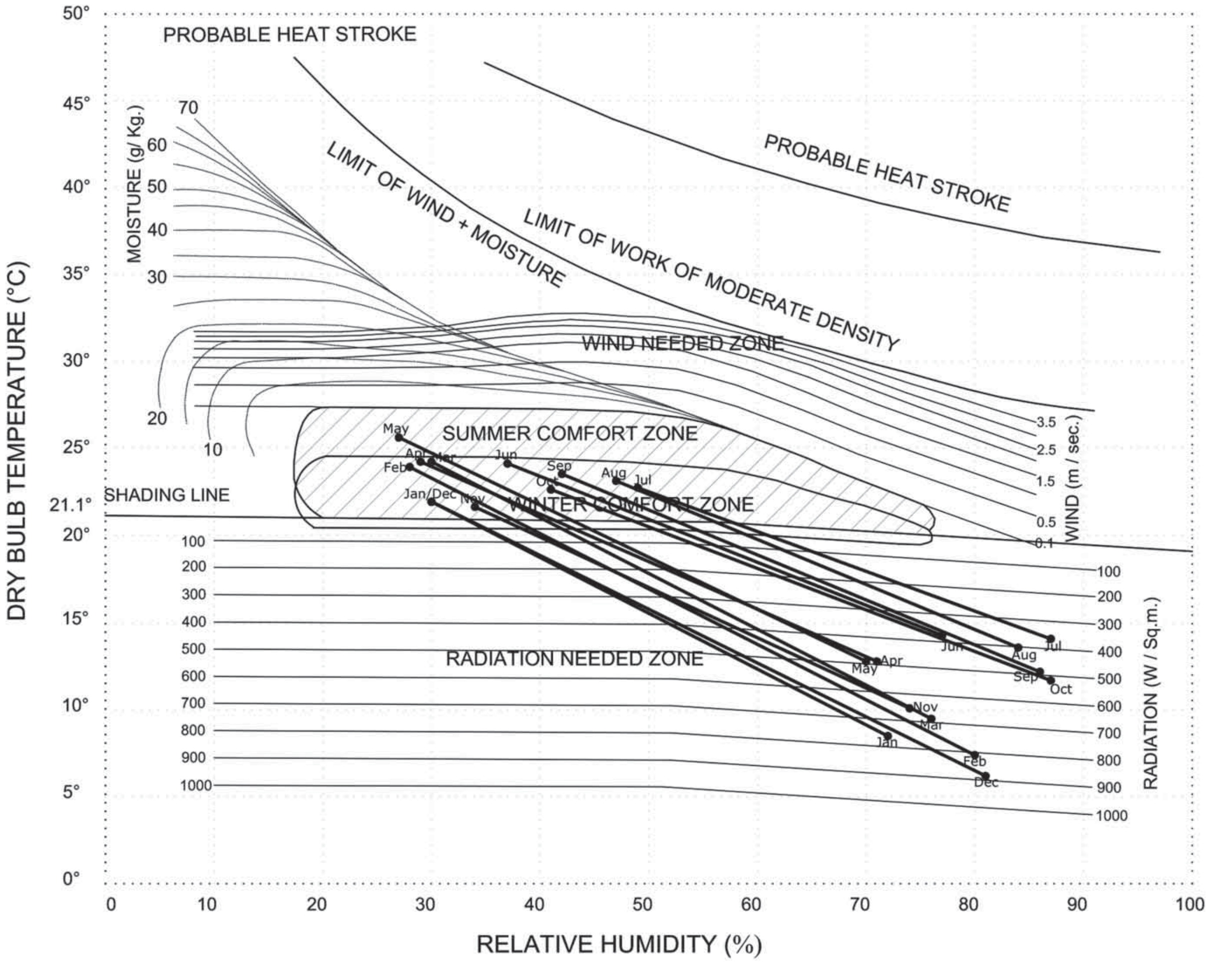

Figure 4. Bioclimatic chart for Mexico City. Based on the bioclimatic chart developed by Olgyay and Olgyay (1963).

Table 1. Recommended building attributes for Mexico City (based on Mahoney Tables (Koenigsberger et al. 1973).

Micro climate	Form	Fabric
• Layout-orientated north and south with the long axis east west	• Air movement – double-banked rooms temporary provisions for air movement	• Walls – heavy external and internal walls
• Spacing-compact form and layout for housing	• Openings – large openings 40–60% and openings in internal walls	• Roofs –heavy over an 8 hours' time lag or light weight and well insulated
	• External features – good drainage	• Protection of openings –exclusion of direct sunlight.

The major weakness of the building is the large inoperable west facing windows in the siting room and library, which are without overhangs. In this case, the microclimate is used as a moderator to prevent overheating as seen in the site plan; large mature forest trees were planted to block the western sun. This would prevent direct radiation striking to the façade.

Form: The form of the building is shown in Figures 6 and 7. The volumetric relationship shows a central staircase which provides ventilation vertically though the building and to an opening in the roof forming the terrace. However, for this climate, ventilation is not a major factor for providing comfort to the interior as noted in the Mahoney analysis. It is sufficient to provide ventilation for air-quality purposes. The north façade (Equator facing) consists of a 300mm wall constructed of double-brick veneer and is adjacent to the studio. The south façade consists of a single block wall (200 mm thick) with brushed plaster rendering to both internal and external wall surfaces (*U* Value of 1.6 W/m^2 K) and is adjacent to the storage room, restroom and machine room on ground level and mezzanine above. The eastern façade facing the street consists of a large double-brick veneer wall with only four openings, which account for only 9% of the façade area. The largest window provides daylight to the library. However, it does not provide visual connection with the exterior and it cannot be opened for natural ventilation. The remaining windows belong to the guest area and to the private offices in the studio. The opposite situation occurs with the western façade facing the garden in which seven large windows are placed along every room with that orientation.

The form of the building is consistent with the Mahoney recommendations. As shown in Figures 6 and 7, the building comprises a number of self-contained volumetric spaces. The living room and library are an example. It comprises double-banked rooms (i.e. two rooms placed side by side) with seasonal (temporary) provisions for air movement. Large openings are

Figure 5. Western facade (Left) has microclimate modification feature, that is, extensive afforestation of mature trees (Right). © [Catalina Corcuera]. Reproduced by permission of Catalina Corcuera, Director, Casa Luis Barragán.

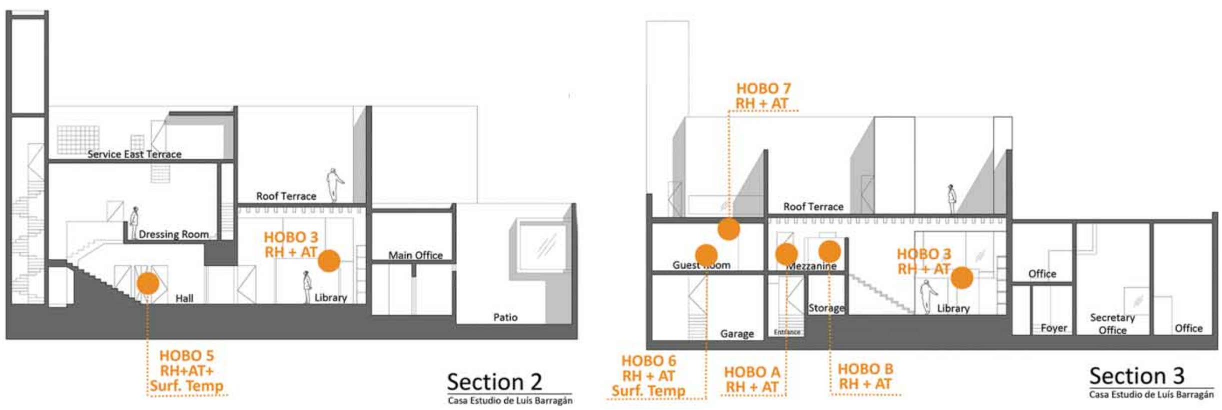

Figure 6. North–South section with temperature and humidity sensor locations. © [Catalina Corcuera]. Reproduced by permission of Catalina Corcuera, Director, Casa Luis Barragán.

found in the internal walls of living area and studio as shown in Figure 8. The ventilation opportunities provide single side ventilation to the westerly garden space. When we visited the house in summer, these windows in the bedroom were open to provide ventilation. The living and library space were ventilated through stack effect; that is, wind-driven ventilation though the stairway of the building.

Fabric: Table 2 shows that the external and internal walls are heavy. Roofs are also heavy over an 8 hours' time lag. Protection of openings is provided with exclusion of direct sunlight. Hence, the building is consistent with Mahoney's requirements. The design of building adhered to the climate responsiveness strategies and with the exception of orientation, it meets all of the Mahoney criteria and given the urban location, conformity to the planning grid is a severe constraint prohibiting conformity to good orientation principles.

6. Monitoring of library and living room

The Library and Living Rooms comprise an open space which interconnects the east and west façades. The placement of data loggers is shown in Figure 2. Hobo 3 was placed on a separating partition wall in the living room (Figure 6), which collected temperature and humidity data at 5-minute intervals.

Barragán's library and living space is the second largest space of the house; it was conceived as an area for leisure, reading and relaxing; nonetheless, it was also used to receive and interact with his guests. Both the living room and the library are located within the same physical space. It consists of an almost rectangular area with a floor-to-ceiling height of 5.3 m. The entire space stretches from the eastern wall through the garden facade; thus, it keeps an east–west orientation in which the eastern and middle portion contains the library area, and the western portion allocates the living room. The physical element, which divides the room, consists of a 2.5 m height wall; this solution creates an effective visual barrier while it allows illumination, sound and thermal connection between both areas.

Figure 9 demonstrates a stable temperature range in this space in the first week of June. The temperature peaked between 2100 and midnight and minimum temperature was recorded around 0900 and midday. As seen in Figure 8, the external environmental conditions (i.e. temperature and humidity) fluctuated significantly. The diurnal temperature range was more than 10°C for the whole week. However, the internal temperature variance was little and hovered around 24°C for all the week, which was found to be within the thermal comfort band. Thermal comfort band was determined by using daily average outdoor

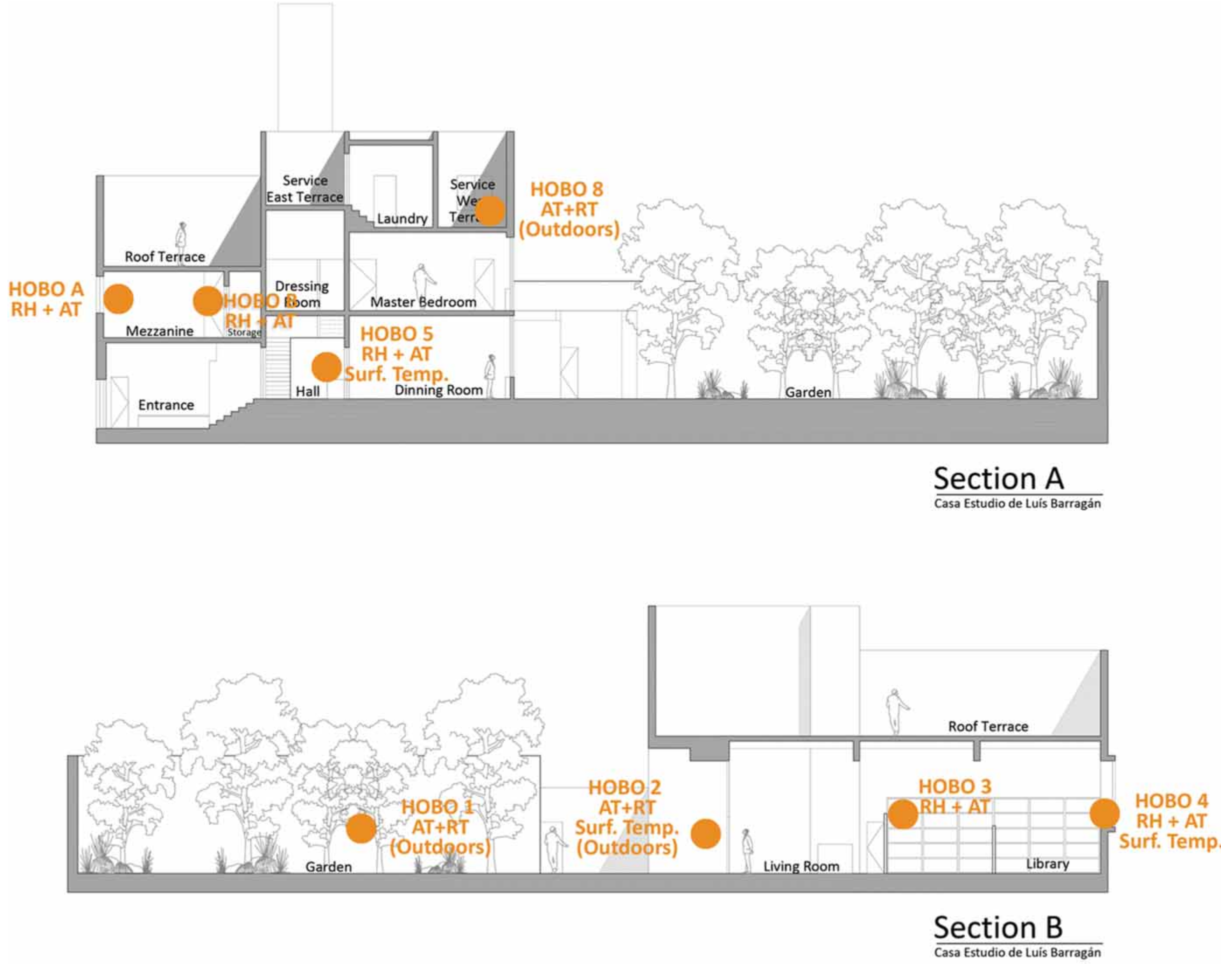

Figure 7. East–West section with temperature and humidity sensor locations. © [Catalina Corcuera]. Reproduced by permission of Catalina Corcuera, Director, Casa Luis Barragán.

Figure 8. View to the Library (Left) and View to the Living Area (Right). © [Catalina Corcuera]. Reproduced by permission of Catalina Corcuera, Director, Casa Luis Barragán.

temperature (de Dear and Brager 1998b). However, this method does not consider the effect of humidity; therefore, a separate humidity comfort zone was used. Outdoor humidity remained within the humidity comfort zone (i.e. humidity ratio between 4 and 12 g/kg) for majority of the time.

The overall stable indoor temperature and humidity are attributed to the effect of thermal mass and lack of air movement in the building. The logic behind this inference is that without significant air changes between the internal and external environment, the internal environment is unlikely to reflect that of the external environment. It is often generalized that the passive buildings cannot control humidity; however, in this, case a significant impact is seen which is interesting, and provides an exception to that rule.

Table 2. The construction elements, which enclose the living and library space.

Orientation	Building element	Adjacent area
North	300 mm wall – double brick veneer	Studio building (lobby)
South	200 mm wall – single block with brushed plaster rendering in both faces	Storage room, restroom and machine room on ground level and mezzanine above
East	300 mm wall – double brick veneer and rough plaster rendering in both faces. Single layered semi-transparent fenestration (not operable)	Francisco Ramirez Street
West	100 mm partition wall – drywall faces anchored to an aluminium structure with no insulation layer. Operable fenestration	Living room
Roof	Light weight timber joists and floor boards	Bedrooms
Floor	Concrete slab on ground, no insulation.	N/A

7. Guest bedroom

The Guest Room is located in the southeast corner of the mezzanine level of the house (Figure 2). This room was selected, as it was the most exposed to environmental conditions. The eastern wall or street façade wall consists of a double-brick veneer and plaster rendering in both interior and exterior sides. It also has an operable window equipped with a shading screen in the interior on the east and south elevations, which can provide cross ventilation (see Figures 10 and 11). From the furniture layout shown in Figure 2, this would give ventilation across the bed to enhance comfort at night. Furthermore, the construction is similar to that found in the living room and library. This construction system provides a form of capacitive insulation, which reduces ingress of thermal energy from the eastern wall and also from the roof. Two sensors were installed in this room as shown in Figure 2. Table 3 shows the surface temperature of the external wall, which are at or below the air temperature indicating that the envelope is not introducing a large amount of radiant energy into the room.

Figure 12 clearly demonstrates dampening of internal temperature, whereas external temperature fluctuation is in the range of 10–14 K (14–28°C). Moreover, there was a 6–7 hours' time lag observed between external and internal peak temperatures. The use of a double-brick veneer in the exterior

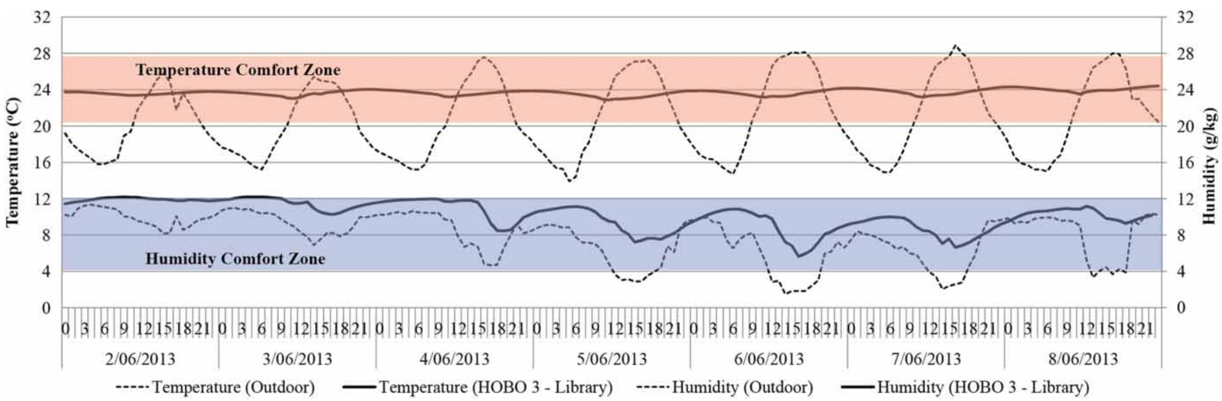

Figure 9. Internal temperature and humidity (expressed in g/kg) were within the respective comfort zones at the Library during the hottest period. (Note the large variation of outdoor temperature and humidity and almost stable internal temperature and humidity in the room. This is attributed to lack of effective cross ventilation.)

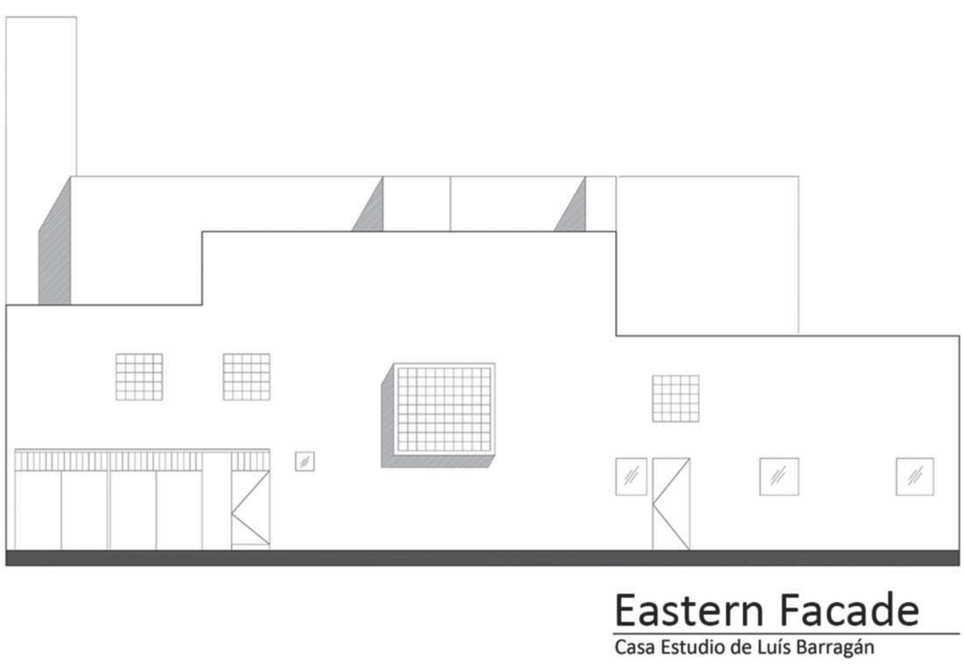

Figure 10. Eastern Façade of the Casa. © [Catalina Corcuera]. Reproduced by permission of Catalina Corcuera, Director, Casa Luis Barragán.

Figure 11. Windows configuration in the Guest Bedroom. © [Catalina Corcuera]. Reproduced by permission of Catalina Corcuera, Director, Casa Luis Barragán.

Table 3. Summary of surface temperature patterns guest room.

Maximum		Minimum	
Schedule	Variation	Schedule	Variation
16:00 and 21:00 Temperatures 25.58–26.50°C	5 hours Variation 0.92°C	9:00 and 11:00 Temperatures 23.20–24.29°C	2 hours Variation 1.08°C
Broad difference between highest samples but very similar temperature range		Similar behaviour to air temperature recordings and minimum variation as well	

walls provides a higher thermal mass in the building fabric. This form of construction retains heat during daytime and releases to the environment at night time when the internal temperature drops. The cavity also plays a role in proving thermal separation between inside and out. A key question is whether thermal comfort will be maintained at night if the external temperature is above 30°C. The Bioclimatic Charts (Figures 3 and 4) demonstrate that summer average temperature (26–27°C) in Mexico City remains within the comfort zone. The aim of passive buildings is at best to achieve internal temperatures equivalent to external ambient conditions and to avoid conditions where the internal temperatures are above ambient. However, to achieve thermal comfort conditions, it is important to take into consideration the radiant temperature of the surface of the room in addition to the air temperature and humidity.

The internal temperatures can be attributed to the thermal mass in the bedroom; the temperature was 'dampened' while the external temperature fluctuates in a range of 10 K and higher, and it remains in the thermal comfort zone. It is important to note that potential conditions for fabric heat storage exist in this building. For thermal mass to operate effectively in cooling mode, night ventilation is needed (Hyde 2000). The disposition of rooms shown in Figure 2 indicates the availability of cross ventilation and thus satisfies these conditions.

This behaviour allows the room to remain without a temperature differences greater than 3°C. Although some people could conceive 27.5°C as hot and uncomfortable, information from a weather station nearby (*National Meteorologic Service, Tacubaya ESIME weather station*) showed that outside temperatures remained at 27°C to 28°C between 20:00 and midnight during the period of the study, and thus the hottest room temperatures consist of a short time period in which indoor and outdoor temperatures balance and is followed by a 13-hour cooling period from 20:00 to 09:00 in the morning.

Since the main use of this space is dormitory, the occupancy period will most likely take place between 20:00 and 09:00 as well. The analysis of the Adaptive Comfort model for this location and time shows that comfort conditions can be met within a temperature range of 21°C to 26.5°C for all the week (Figure 13). In this case, Barragan's Guest Bedroom provides temperatures between 23.1°C and 27.1°C and humidity remains within the comfort zone (i.e. humidity ratio between 4 and 12 g/kg), particularly appropriate during sleeping hours (See Figure 12).

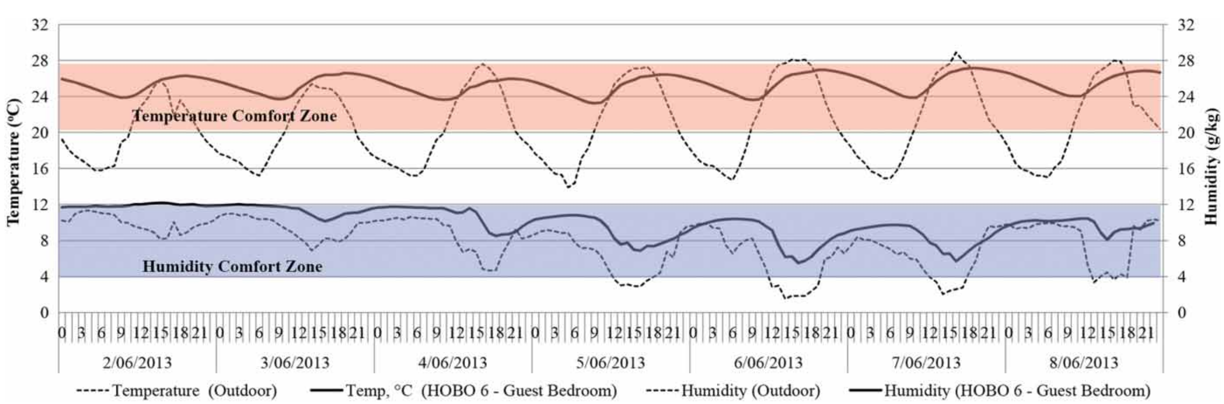

Figure 12. Weekly temperature and humidity variation at outdoor and in the Guest Bedroom (Eastern) (HOBO 6).

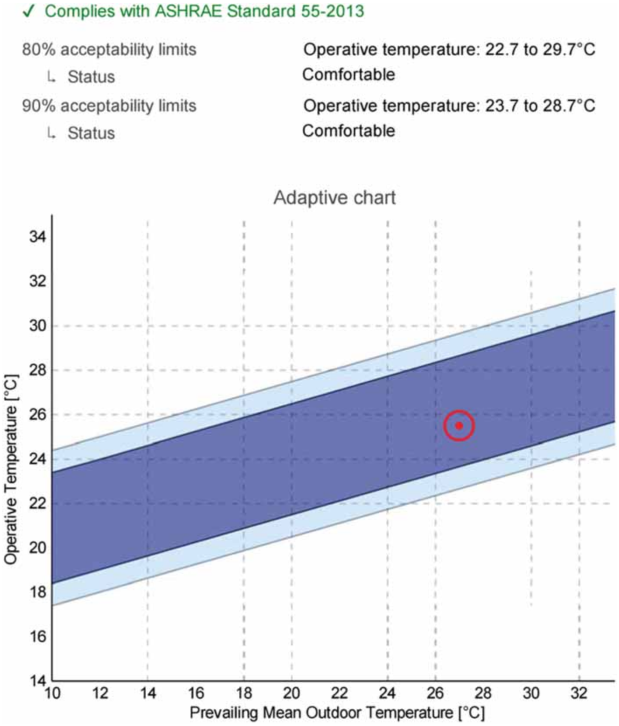

Figure 13. Adaptive Comfort Band derived using CBE Thermal Comfort Tool (Hoyt et al. 2013) with an outdoor air temperature of 27°C, indoor temperature of 24°C and mean radiant temperature of 26°C.

8. Conclusions

In conclusion, the study demonstrated that this is a strong passive building. The building demonstrated excellent thermal behaviour during the monitoring period. The stable temperature profile in this building is largely due to the sensibly small openings and very high levels of thermal mass. The orientation of the building and its relationship with the microclimate and window openings are less than optimal; however, this is compensated by other strategies such as the use of thermal mass and shading. In the summer period, examined in this study, the capacity of the envelope to facilitate air movement appears limited, as the area for openings is less than optimum as compared to those recommended by the Mahoney Tables. This may have potential effects on the comfort of occupants.

However, the study using monitoring in the summer period does not support these observations. Internal temperature in the study areas of the house sits within the comfort conditions for summer (i.e. temperature between 20 and 27°C). Humidity remains within 4–12 g/kg and temperature less than 25°C falls within an acceptable range. Interestingly, it appears that the effects of thermal mass compensate for the other suboptimum passive features.

Little work has been done on the environmental quality of this building; this is the first such study and will assist with ongoing methods for conservation and add to the significance of the building as a World Heritage Listed building. The observations in the Indicative Study support the view that this is a potentially strong passive/low-energy building for its time in history. However, it is hard to use modern standards for evaluating historic buildings. In this case, a high mass building strategy is used which is consistent with historical examples of its time and forming a strong pragmatic design foundation. This is a fascinating building where a mixture of traditional and modern architectural ideas is found, where the poetics of architecture are complemented with a pragmatic approaches to thermal design to provide comfort to occupants. The adaptive reuse of the building as a Museum brings a new challenge for maintaining the cultural heritage of the past with the current social needs. This study is a start to ensure that the environmental conditions within the building are maintained as originally designed, so the future generations can experience the environment the building creates as it was originally intended.

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Disclosure statement

No potential conflict of interest was reported by the authors.

References

Allaback, S. 2003. *Essays on Modern Architecture for the National Historic Landmark Program. National Park Services*. Accessed August 7.http://www.nps.gov/nhl/learn/specialstudies/ModernArchitecture.pdf

Auliciems, A. 1981. "Towards a Psycho-physiological Model of Thermal Perception." International Journal of Biometeorology 25 (2): 109–122.

de Dear, R. J., and G. S. Brager. 1998a. "Developing an Adaptive Model of Thermal Comfort and Preference." ASHRAE Transactions 104 (1): 145–167.

de Dear, R. J., and G. S. Brager. 1998b. "Towards an Adaptive Model of Thermal Comfort and Preference." ASHRAE Transactions 104 (1): 145–167.

Fanger, P. O. 1967. "Calculation of Thermal Comfort: Introduction of a Basic Comfort Equation." *ASHRAE Transactions,* 73 (2): III4.1–III4.20.

Fanger, P. O. 1992. "Efficient Ventilation for Human Comfort." Paper presented at international symposium on room air convection and ventilation effectiveness. Tokyo: University of Tokyo.

Figueroa, A. 1989. *El arte de ver con inocencia: pláticas con Luis Barragán*. Azcapotzalco: Universidad Autónoma Metropolitana.

Figueroa, A., and G. Castorena. 2013. "Inspiration from the Vernacular in the Architecture of Luis Barragán." In *Lessons from Vernacular Architecture*, edited by W. Weber and S. Yannas, 154–163. Azcapotzalco: Universidad Autónoma Metropolitana.

Frampton, K. 1980. "Critical Regionalism – Modern Architecture and Cultural Identity." In *Modern Architecture: A Critical History*, edited by K. Frampton, 314–327. New York: Oxford University Press.

Fry, Maxwell, and Jane Drew. 1956. *Tropical Architecture in the Humid Zone*. London: Batsford.

Givoni, B. 1992. "Comfort, Climate Analysis and Building Design Guidelines." *Energy and Buildings* 18: 11–23.

Griffiths, I. 1990. "Thermal Comfort in Buildings with Passive Solar Features: Field Studies." Report to the Commission of the European Community, ENS3590. UK.

Hoyt, T., S. Schiavon, A. Piccioli, D. Moon, and K. Steinfeld. 2013. *CBE Thermal Comfort Tool*. Center for the Built Environment, University of California Berkeley. http://cbe.berkeley.edu/comforttool/

Humphreys, M. 1978. "Outdoor Temperatures and Comfort Indoors." *Batiment International, Building Research and Practice* 6 (2): 92–105.

Hyde, R. 2000. *Climate Responsive Design: A Study of Buildings in Moderate and Hot Humid Climates*. London: E & FN Spon.

Hyde, R. A. 2006. *'Closing the Loop': Exploring the Link between the Design Brief and Post Occupancy Evaluation to Improve Sustainable Design.* Adelaide: ANZAScA Conference, University of Adelaide.

Hyde, R. 2008. *Bioclimatic Housing: Innovative Designs for Warm Climates*. London: Taylor & Francis.

Koenigsberger, I., T. G. Ingersoll, A. Mayhew, and S. V. Szokolay. 1973. *Manual of Tropical Housing and Building Design: Part 1, Climate Design*. London: Longman.

Nicol, F., and S. Raof. 1996. "Pioneering New Indoor Temperatures and Standards: The Pakistan Project." *Energy in Buildings* 23: 169–174.

Olgyay, V., and A. Olgyay. 1963. *Design with Climate: Bioclimatic Approach to Architectural Regionalism*. Princeton: Princeton University Press.

Puteri, S. J., and K. Ip. 2006. "Linking Bioclimatic Theory and Environmental Performance in its Climatic and Cultural Context – An Analysis into the Tropical Highrises of Ken Yeang." PLEA 2006 – The 23rd Conference on Passive and Low Energy Architecture, Geneva, Switzerland, 6–8 September 2006.

Roaf, Susan, Andrew Horsley, Rajat Gupta, and Royal Institute of British Architects. 2004. *Closing the Loop: Benchmarks for Sustainable Buildings*. London: RIBA.

Santamouris, M., and D. Asimakopoulos. 1996. *Passive Cooling of Buildings*. London: Earthscan.

Szokolay, S. V. 1982. *Climatic Data and its Use in Design*. Canberra: RAIA Education Division.

Szokolay, S. V. 1986. "Climate Analysis Based on the Psychrometric Chart." *International Journal of Ambient Energy* 7 (4): 171–182. doi:10.1080/01430750.1986.9675499.

Szokolay, S. V. 1991. *Climate, Comfort and Energy. Design of Houses for Queensland Climates*. Brisbane: The University of Queensland.

Szokolay, S. V. 2004. *Introduction to Architectural Science: the Basis of Sustainable Design*. Oxford: Elsevier, Architectural Press.

The United Nations Educational, Scientific and Cultural Organization (UNESCO). 2014. "Luis Barragán House and Studio, Description." Accessed 30 May 2013. http://whc.unesco.org/en/list/1136

Van den Bergh, W. 2006. *Luis Barrágan, the Eye Embodied*. Maastricht: Pale Pink Publishers.

Vischer, J. 2002. "Post Occupancy Evaluation: A Multifaced Tool for Building Improvement." In *Learning from Our Buildings: A State-of-the-Practice Summary of Post-Occupancy Evaluation*, edited by Federal Facilities Council, Board on Infrastructure and the Constructed Environment and National Research Council, 23–34. Washington: National Academies Press.

Yencken, D., and D. Wilkinson. 2001. *Resetting the Compass: Australia's Journey Towards Sustainability*. Collingwood: CSIRO.

Zanco, F., and Vitra Design Museum. 2001. *Luis Barragán: The Quiet Revolution*. Skira.