Field Study of Passive Techniques and Adaptive Behaviour in the Traditional Courtyard Houses of Kabul

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Abstract. This paper examined the passive techniques used in the traditional courtyard houses of Kabul using on-site measurements of their thermal environment during winter and summer. It was found that the high thermal mass structure was efficient in creating a stable indoor environment during both seasons. The adaptive behaviour of migrating horizontally to the northern and southern rooms during winter and summer was found to be effective. Moreover, the added insulation from the attached neighbour building and the thermal mass effect on the second layer rooms were found to play a major role in creating cool and stable indoor spaces in summer. The basements were among the coolest spaces during the summer months regardless of their opening conditions. However, a permanently closed basement was as cool as the minimum outdoor air temperature during the daytime. During the winter days, indoor thermal comfort varied based on solar orientation and the south facing rooms received direct solar radiation therefore provided longer comfort periods. The central courtyard was found to be a sheltered space during the winter and summer, which created a comfortable semi-outdoor space for specific periods during these months.

1. Introduction

During the past decade, the growing urban population backed by the slow regulating bodies has resulted in a chaotic situation in the major cities of Afghanistan. In Kabul, 70% of the city is informal with poor infrastructure and in the formal parts of the city, the newly built houses do not fit the local culture and climate. The housing sector has gone through different typologies which have been majorly influenced by the trending architectural style (Figure 1d). For instance, the traditional courtyard houses follow the Islamic cities’ fabric and the detached buildings were introduced during the British colonization which was further urbanized in the 1950s to a more European lifestyle. The old housing styles somehow responded to the climate by respecting solar orientation, using thermal mass and allocating space for greenery. However, during the past decade few architect graduates could not respond to the high housing demand and given the sudden economic growth of that time, the houses were built to maximize the floor space use, with irrelevant decorations and full reliance on air conditioning. The envelope was not insulated, solar gain and shading were not controlled, and no space was allocated for vegetation. These houses also noted as “Narcotecture” [1] are few and the direct risk they pose is not considerable. But indirectly in a few years, this became the trending style and people once living in the comfortable buildings were looking up to this type of buildings. This notion will not only destroy the identity of the city but will also increase energy consumption. On the other hand, there are no active regulations for energy saving and energy efficiency in the building
sector. In a city with wide weather fluctuations during the year (Figure 1c), this has resulted in higher
energy consumption for heating and cooling. Currently, the houses consume more energy during the
winter to heat the indoor spaces by burning coal or wood. The smoke from biomass affects indoor air
quality and exacerbates the outdoor pollution during the winter. Some of the hazardous compounds
such as benzene, acetaldehyde, hydrogen chloride and dioxins in the air were found to be from burning
coal and wood [2]. In Kabul 26% of the houses are regular (detached) houses, 1% are apartments and
70% are irregular houses [3]. It is projected that by 2060, 50% of the Afghans will live in the cities [3]
therefore to prevent an increase in energy consumption, it is important to introduce passive heating
and cooling techniques. Among the housing types in the city, the traditional courtyard houses better
represent the local culture and used passive and low energy techniques for space heating and cooling.
Previous literature [4–9] studied their socio-cultural aspects and briefly presented the passive
techniques. However, their thermal environment has not been studied intensively. In addition, studies
in similar climates and typology of houses have focused on the thermal performance of this housing
type during the summer months by separately investigating the passive techniques [10–15]. This paper
investigated the indoor and outdoor thermal environment of these houses by physical measurement
using a holistic approach, during the winter and summer, to find the passive and low-energy heating
and cooling techniques. In addition, the adaptive behavior of inside-courtyard horizontal and vertical
migration was also studied. The results of this research are intended to provide a repository of
bioclimatic strategies for the contemporary houses that fit the climate of Kabul.

2. Methodology

2.1. Case study houses

The case study houses are located in the old city of Kabul in a neighbourhood called Murad Khani
(34°N, 69°E) (Figure 1). The six houses were selected to represent different sizes and forms of
courtyard houses from an initial study of the existing single-family courtyard houses in Asheqan-
Arefan [16] neighbourhood and the destroyed collective housing of Serai-Lahori [17]. The aim was to
study the thermal performance of courtyards with different proportions and to find the optimal size
and strategies that optimize the performance of this type of houses. H1 has the largest courtyard
(11x12x6m) with extended semi-outdoor space on the first floor and four medium height trees. H2 has
the enclosed deep courtyard (5x6x6m) while H3 has a medium size courtyard (10x6x6m). The

![Figure 1: (a) Kabul city location; (b) Murad Khani site; (c) Climate in Kabul; (d) Houses in Kabul.](image-url)
courttyard in H4 is similar in size to CY1, and CY5 is also a medium size courtyard with staggered form and a large tree at the centre. The smallest courtyard CY6 (4x4x3m) is located in the first-floor level and separated physically from CY3 by a wall (Figure 2d).

All the courtyard ground surfaces are brick-paved except for CY1, CY4, and CY5 that have grass cover as well. The structure is made up of stone foundations, thick mud-brick walls in the ground and first floor and mudbrick infill with wooden frame in the upper floors. The façade facing the courtyard is entirely or partially made of a modular wooden frame that is connected to the horizontal wooden framings of the floors and the roof. Only a few openings are made at the outer façade facing the narrow alley. The flat roof frame is covered with woven shrubs, wooden boards and a thick layer of mud. The courtyard is surrounded by single- and double-layer multipurpose rooms.

Figure 2. (a) Murad Khani neighbourhood; (b) Case study houses; Floor plans (c) Ground floor H1, H2, H3 and H6; (d) First floor; (e) H4; (f) H5; (g) CY1; (h) CY2; (i) CY3; (j) CY4; (k) CY5; (l) CY6.
2.2. Field investigation outline

The field investigation was conducted during the winter (6-22 February) and summer (28 July-19 August) of 2018. A brief investigation of air temperature and relative humidity was carried in the courtyards and one attached indoor space followed by an intensive measurement in H1, H2, and H3. In each house, air temperature, relative humidity was measured in all the surrounding spaces including the basements at height of 1.1m.

Moreover, globe temperature and airspeed were also measured in the northern and southern rooms as well as in the courtyards to assess thermal comfort. Vertical distribution of air temperature was measured in the main rooms and the courtyards at different heights (Figure 2). The outdoor conditions were recorded using a custom-made aspirated radiation shield for air temperature [18], an ultrasonic anemometer and radiation sensor located at the height of 4m above the roof in H2. All measurements were logged automatically at 1min interval and the sensors were further validated by comparing with more accurate sensors such as the Assmann Psychrometer.

3. Results and Discussion

3.1. Summer

3.1.1. Indoor thermal environment. Figure 3 shows the indoor thermal environment of H1 during the summer. As shown, the outdoor air temperature ranged between 22-36°C while humidity was between 10-30% on a fair weather day. Solar radiation reached 900W/m² and no rain was recorded during the measurement period. Wind flowed from the north with an average speed of 2.2 m/s during the day and from the northwest at 1.17 m/s during the night.

Meanwhile, the indoor air temperatures in the surrounding rooms were between 26-32°C on average. During the daytime, the peak indoor air temperature shifted based on the room orientation. For instance, the eastern rooms were warmer in the morning and the western rooms were warmer than the outdoor during the afternoons. The northern rooms were cooler by 3°C on average although they faced south. The reason is that the low altitude solar radiation entered the eastern and western rooms during the morning and afternoon and the horizontal overhangs protected the northern rooms during the noon. This happened because the windows were closed, and the cool night air did not enter the indoor spaces. Indoor relative humidity ranged between 10-20% under open window condition which was well below the acceptable range.

Figure 3b shows the indoor air temperature and relative humidity in H1 in the first layer and second layer spaces. The effect of thermal mass and orientation can be noted in the surrounding spaces. For instance, H1:E1 is made of high thermal mass walls and a domed ceiling, therefore during the daytime this space was the coolest space facing the courtyard. The southern room (H1:S1) did not receive direct solar radiation, therefore, the air temperature ranged between 27-30°C during the daytime. On the other hand, the northern room (H1:N1) was the warmest space in this level but still maintained lower than outdoor values. In the first floor, the courtyard extends in east-west direction, hence the eastern and western rooms were insolated for longer periods. Therefore, the peak daytime air temperature in H1:E2 and H1:W2 was higher and equal to outdoor. Similarly, in H2 the northern room was warmer than the southern room (Figure 3c). In H3, similar condition in the northern and southern room is noted except in the first floor where the southern room was as warm as the opposite wing (Figure 3f). This is probably because the room was not attached to another building, and the high thermal mass wall facing the alley received direct solar radiation during the day and emitted it back during the night. Nevertheless, during the night, on average most of the indoor spaces were warmer than outdoor due to the closed conditions.

Moreover, during the day the second layer rooms (H1:N1, H1:S1) experienced stable and cool environments. This is the effect of added insulation from the neighbour building and the high thermal mass structure (Figure 3b). In contrast, during the night under closed conditions, these spaces were warmer than outdoor.
Figure 3. Indoor and outdoor thermal environments during the summer. (a,b) H1; (c,d) H2; (e,f) H3.

Figure 4. Temporal variations of air temperature and relative humidity in H1. (a) Night ventilation and closed conditions; (b) basements.
3.1.2. *Effect of night ventilation and closed conditions.* During the field measurement, the effects of night ventilation and closed conditions were also checked. The results show that when the windows were opened at night, the air temperature in H1N1 and H1S1 fell 4°C and when the windows were closed during the proceeding day the peak daytime air temperature also fell 2°C (Figure 4a). The night-time air temperature was not as cool as the outdoor because the building layout does not promote cross ventilation. Under the closed conditions a very stable thermal environment was recorded in the southern rooms while the northern rooms had fluctuating air temperature. Nevertheless, the air temperature in the first-floor rooms was higher than the ground floor.

Moving downwards, both basements were cooler than the ambient during the day and the night. However, the closed basement H1B2 was as cool as the minimum outdoor air temperature even during the daytime. A temperature difference of 14°C was noted during the daytime in this space (Figure 4b). Relative humidity was between 30-50% in H1B2 and 20-40% in H1B1. In both cases, the relative humidity was within the acceptable range. These spaces were recorded to be the coolest indoor spaces during the day and the night.

3.1.3. *Indoor Thermal comfort.* Indoor thermal comfort was assessed in the northern and southern rooms of H1 and H3 during the winter and summer. Operative Temperature was calculated based on the measured parameters at the centre of each space. The adaptive comfort range was plotted based on the newly introduced adaptive comfort equation by Toe and Kubota [19]. The resulting limit ranges between 28-32°C. Figure 5 presents the results of operative temperature in the northern and southern rooms of H1 and H3. As shown, the operative temperature in the southern rooms lies within the comfort range while the northern room (H1N1) was uncomfortable during the peak hours. On the other hand, the operative temperature in H3 show that the rooms in both wings had similar conditions and were uncomfortable during the peak hours.

In addition, the Standard Effective Temperature (SET*) integrates the effects of air temperature, humidity, radiation, air speed, clothing insulation and metabolic rate on human thermal comfort. In calculating SET*, the metabolic rate was assumed to be 1.0 met, which represents a sedentary person and clothing insulation was calculated to be 1.6 in winter and 0.69 in summer [20]. Figure 5b presents the results of SET* calculations in H1, as shown the values were below 30°C in the southern room while the northern rooms were uncomfortable during the peak hours.

![Figure 5](image.png)

**Figure 5.** Indoor thermal comfort in summer. (a) Operative temperature in H1 and H3; (b) SET* in H3.

3.2. *Winter*

3.2.1. *Indoor thermal environment.* Figure 6 shows the temporal variations of air temperature and relative humidity in the indoor spaces during the winter. Figure 6 a, b shows the indoor conditions in H1 under cloudy conditions. As shown, in all the ground floor spaces the air temperature was higher than the outdoor during the day and the night. This is attributed to the thermal mass structure and closed windows. On the other hand, in the basement spaces, the average air temperature was also
higher than the outdoor. The closed basement performed well during the day and the night while the permanently open basement had lower night-time values. In H$_2$, a similar difference between outdoor and indoor is noted. Figure 6e, d shows the indoor conditions in H$_3$ in fair weather days. As shown, the northern room on the first floor that received direct solar radiation was warmer than the rest of the spaces. One level below, the room (H$_3$N$_1$) was as warm as the courtyard during the daytime but because of the narrow courtyard proportions ($w/h=1.0$) this space did not receive solar radiation; therefore, it was cooler than the upper level.

Figure 6. Indoor and outdoor thermal environments during the winter. (a, b) H$_1$; (c, d) H$_2$; (e, f) H$_3$. 
3.2.2. Indoor thermal comfort. Figure 7 shows thermal comfort assessment in the northern and southern rooms in H3 during the winter. As shown, the northern rooms were comfortable during the peak hours when the heater was not used, and no occupants were in the room. H3N2 received more radiation and therefore the SET* values reached 25°C while the lower room received less radiation with SET* values reaching 21°C during peak hours. On the other hand, the southern room that did not receive direct solar radiation was cooler. Moreover, during the heated days, all the spaces show overheating conditions and comfortable conditions during the night. A significant heat loss is noted which is due to the low airtightness of the wooden façade.

![Operative Temperature and SET*](image)

**Figure 7.** Indoor thermal comfort in H3 during winter. (a) Operative temperature; (b) SET*.

3.3. Thermal environment of the courtyards

Figure 8 shows the comparison of courtyards in terms of air temperature and relative humidity during winter and summer. As shown, during the winter day the large courtyard CY1 was as warm as the outdoor while CY3 was cooler. The smaller courtyards (CY2, CY6) were warmer on average because of the night-time higher air temperatures. CY4 which is a wide courtyard was relatively cooler during the day and followed the outdoor during the night. Although this courtyard shares the same size with CY1, the grass area is higher and therefore cooler daytime conditions are expected.

During summer, CY1 and CY3 were warmer than outdoor during the peak hours. Similarly, CY2 was also warmer than outdoor during peak hours but due to the closed proportions of this space, the night-time conditions were warmer and therefore this space was warmer than outdoor on average. CY4 had similar conditions as the outdoor while CY5 had the lowest peak air temperature. On average CY6 was the warmest space among all the spaces with the maximum air temperature being slightly higher and minimum values 4°C warmer than outdoor.

Thermal comfort was assessed in the centre of two courtyards (CY1, CY3) during winter and summer. In both seasons the results show that the courtyards were protected from the outdoor wind. A shadow analysis shows that one-third of the wider courtyard (w/h=2.0) was insolated for 5 hours during a sunny winter day. On the other hand, the radiation reached only the northern wall of the courtyard in CY3 (w/h = 1.0) and CY2 (w/h = 0.77). The SET* was used to assess outdoor thermal comfort in these semi-outdoor spaces and the results show that CY1 provided comfort for long hours and the values were within the comfort range during the afternoons. On the other hand, the conditions in CY3 was slightly cool but acceptable during noon. In summer, both courtyards were habitable during the peak hours with SET* values reaching 38°C. As shown in the shading analysis, both courtyards received solar radiation for ten hours, but the amount of surface area affected was different based on the w/h ratio. In contrast, both spaces were comfortable during the morning and night. This confirms the efficiency of using this space during the summer night as an outdoor sleeping area.
4. Conclusions
This paper investigated the thermal environment of the courtyard houses in the old city of Kabul by on-site measurement. The main findings are summarized as follows:

- The thermal mass structure created an isolated indoor environment. The peak indoor air temperature shifted based on room orientation. For instance, the western rooms were warmer during the morning and eastern rooms experienced warmer conditions during the afternoons.
- The efficiency of migration to the northern rooms during the winter and to the southern rooms during the summer was confirmed by assessing the indoor thermal comfort in these spaces.
- The second layer rooms had the most stable environment with low air temperature due to the added insulation from the attached neighbour and the thick thermal mass structure.
- A permanently closed basement was found to be the coolest space during summer while the permanently open basement space also provided lower air temperature during the day and the night while maintaining sufficient daylight.
- The indoor thermal comfort during winter was found to be related to the orientation of the room during the day and the thermal mass structure during the night.

Figure 8. Thermal environment of the courtyards. (a) winter; (b) summer.
The courtyard space sheltered from the cold and warm winds during both seasons and created a comfortable semi-outdoor space during the winter noon, by capturing solar radiation and, during the summer night by capturing the cool night air.

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