

'Impenetrable' urban maze of east African coastal town: its implications on climate change

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1. Introduction

Climate change, a global catastrophe, has severe impacts both on urban centres and rural areas. Its effects, partly as a result of natural forces, are, but not limited to, alterations in the natural habitat which facilitate the spread of vector-borne diseases, interruptions to local and regional weather patterns that can impact upon agricultural outputs, natural disasters such as flooding, wildfires and cyclones. More so, loss of vegetation cover in cities reduces its abilities to reabsorb carbon dioxide leading to rise in urban temperatures which coincides with increased energy use for provision of human thermal comfort. This is in line with Cooper statement that creation of habitable spaces is synonymous with consumption of fossil fuels, partly as a result of the drive for optimal indoor conditions.

IPCC report on settlements along coastal cities predicts continued adverse effects of cyclones, landslides and limited availability of fresh water, in turn jeopardizing food security. The effects are more pronounced in developing countries characterized by limited resources which hamper their ability to respond to changing conditions.

These cities, which account for more than half of the global greenhouse gas emissions through their resource use in urban activities, can respond to by mitigating the effects or adapting to their consequences of climate change. Suggestions on how this can be achieved range from urban planning level, that is, more compact cities, sustainable transport systems to energy efficient comfortable buildings. Urban areas which have embraced or borrowed from practices and philosophies of vernacular architecture in terms of dwelling types and construction materials have managed to use the natural environment to maintain comfort levels with almost nought reliance on mechanical systems which are now widely spread and accepted.

Analysis by various field studies have shown that (indoor) thermal comfort experienced by occupants is a function of the prevailing mean outdoor temperatures; this means that we can relate comfortable indoor temperature to (micro)climate, region and seasons. Such research works in various free-running, hybrid and even air-conditioned buildings have resulted to universally approved dynamic comfort models. What this means is that urban microclimate which is informed by urban form and space has a direct influence on options by a space user to maintain acceptable comfort.

In addition, considerable research on interaction between indoor and outdoor environment, and relationship between buildings, climate and culture has been done. For instance, Rapoport examined how anthropological knowledge (of religious, spiritual and folk theories) has informed the architecture of urban or building design that embody different definition of what and how comfort can be achieved.

This paper presents case study of an East African coastal town, which being a conservation area has considerably contributed to mitigation of climate change effects by ensuring thermally comfortable indoor and outdoor conditions by virtue of its organic urban morphology. This statement is based on the outcome of the two following objectives: 1. To examine on how

evolution of urban form and space under influence of culture, traditions and religion have resulted to thermal zones which fall within acceptable levels, and 2. To carry an elaborate environmental study of the distinct architecture of the town with aim of investigating human thermal comfort levels.

2. Town historical development

East African coast consist of three main historical old towns namely Lamu, Zanzibar and Mombasa; where the latter will be further discussed.

Many visitors to the old town have emphasized on its apparent 'disorderly' character. For instance, part of the town was described by Stanley as 'a medley of tall white houses and low sheds, where wealth and squalor jostle side by side' while Charles stated that while the front view of the town was impressive, what lay behind was a mass of 'cajan hovels of the most wretched description'. From bird's eye view, as illustrated in fig. 1 below, the town looks like an impenetrable maze.

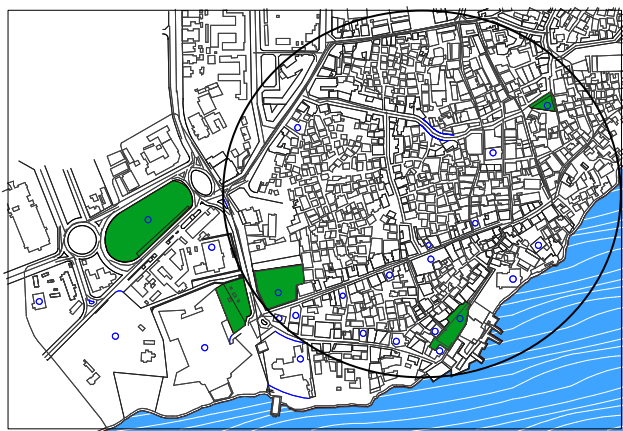


Fig. 1: Dense layout of Old town. Author.

Current Old Town urban image is a reflection of its development over time. It has gone through several phases of evolution from a small town to the north of its current location, to a commerce empire in the nineteenth century and to colonial town of the twentieth century. It has been exposed to a number of distinguishable external influences that have been adapted and incorporated in its own distinct cosmopolitan urban complex.

The Periplus of the Erythrean Sea is the earliest historical record that attests to the existence of settlements along East African coast as early as 60 A.D. The town which was probably occupied by native Africans upto as early as tenth century, later developed as a result of 'flourishing maritime trade, dependent of seasonal monsoon winds, with far distant lands of the Indian Ocean, consisting of Arabia, Persia, India and even China. The resultant intermarriages were the Swahili culture which is 'distinctly urban, mercantile, religious and cosmopolitan'.

These Swahili towns were sub-divided into wards (mitaa) that reflected inhabitants' place of origin and their ethnic affinities. Each ward was centred on a neighbourhood mosque. Allan noted that the 'Swahili followed a very standard Islamic plan, with a large central mosque and

main streets running off (meandering between irregularly placed buildings) from its vicinity'. The streets, organic and of labyrinth disposition, achieved privacy, one of the Islamic principles, in two ways; (1) Its division in small segments allowed for visual discontinuation, (2) Its complexity of bearing of the streets acted as natural mechanism that alienated strangers and prevented purposeless movements. However, the streets almost perpendicular to the coastline, besides circulation routes, also played significant role of channelling sea breezes into the obstructed built form behind, drain surface run-off and permitting pleasant glimpses to the ocean.

On the building level, as the trade prospered, the traders required bigger houses and 'pretentious residences' thus transforming the traditional mud and wattle huts. Barbosa suggests that the Portuguese influenced the use of stone and mortar, plenty of windows and flat roofs while Lewcock reports that the double-storied house with the upper floors with windows and doors overlooking courtyard was probably related to the Persians. In addition, wealthy Indian merchants acquired Omani houses, which were precipitate of desert-like and traditional mud and wattle houses, and modified them to meet their taste and requirements. The modifications included intricately carved wooden balconies, semi-circular wooden door and window lintels to increase ventilation and light. In terms of materiality, Sheriff says the houses were composed of a framework of mangrove poles tied together with coir ropes and walls constructed with lumps of coralline limestone; all these locally fetched.

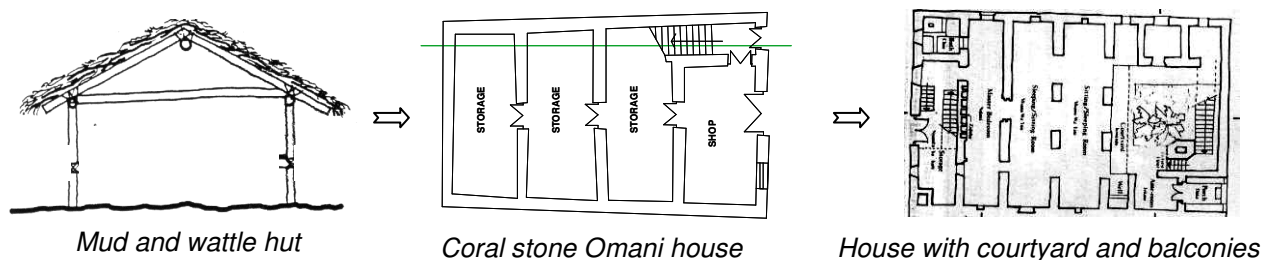


Fig. 2: Evolution of houses

Unarguably, the urban form and spaces developed as a result of pressures to develop, industrialization and quest for comfort. As the town transformed from mud and wattle huts to coral stone multi-level houses with balconies and courtyards, the urban space equally changed from 'negro huts scattered all over the place' to densely clustered coral jungle.

Hence, it is appropriate to state that the town did not develop under formal planning guidelines but rather responded to socio-cultural, functional and religious dictates.

3. Climate of East African coast

The coastal Old town are located about 4deg. south of the equator at an altitude of 16 meters above sea level experiencing warm-humid climate. The annual mean maximum temperature is 32.6 °C and an annual mean minimum of 21.8 °C. Work of Auliciems and Nicol give the neutrality temperature as a function of monthly mean outdoor temperature. As shown (fig. 1), neutrality temperature for a typical year varies within the range of 27.5°C and 29.4°C. Compared with the mean monthly maximum temperature readings, the outdoor recordings exceed comfort limits.

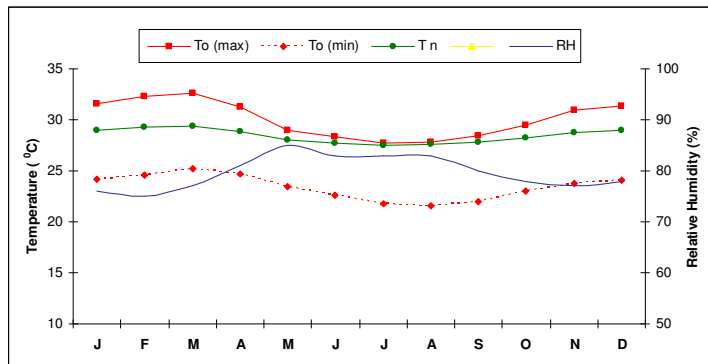


Fig. 1: Monthly neutral temperature variations in relation to mean maximum and mean minimum and relative humidity of a typical year of Mombasa. Source: Author

In this region, temperature discomfort is aggravated by the humid nature of the air. Relative humidity figures taken during the year show a characteristic high figure ranging between 70% and 85%. Plotting dry bulb temperature against relative humidity recordings for the year on a bioclimatic chart and psychrometric chart, two recommendations are deduced. Firstly, the region is off the comfort limits and comfort can only be maintained by supplementary air movement of between 0.1 to 0.4 meters per second throughout the year. This can be achieved either passively or actively with the latter carrying a price tag, namely in energy and technological knowhow.

Mahoney tables recommends that design of buildings in such climate need be narrow, have large windows and openings with shading devices, with group of buildings spread out and oriented towards the wind in order to achieve maximum ventilation. Further, the materials be lightweight with low retaining capacity, but of high insulation value. However, with the high densities in town and heavy-weight construction methods, the building designs had to be modified.

4. Urban environmental control concepts

Gathered from the climatic overview, there are primarily two ways in which buildings in warm-humid regions need to satisfy in order to maintain comfort; maximum utilization of wind for ventilation and the complete rejection of thermal gains. Within the study area, a number of techniques, some gathered from literature review, have been developed as climate adaptive strategies.

At planning level, the high density town of about 99 people per acre or 17 dwellings per acre, with buildings having north-south orientation, ensures the streets remain shaded through out the day. These densely irregularly packed buildings which defines the streets, together with entrance porches (*dakaa*, a building element only found in East Africa), ensures acceleration of the winds to the deeper impenetrable urban mass is regulated. According to Attamimy, the narrow and irregular streets induces air flows by stack and tunnel effects in accordance with Bernoulli's

theorem. Together with provision of shade, it creates a pleasant and comfortable street spaces that auger well for pedestrians.

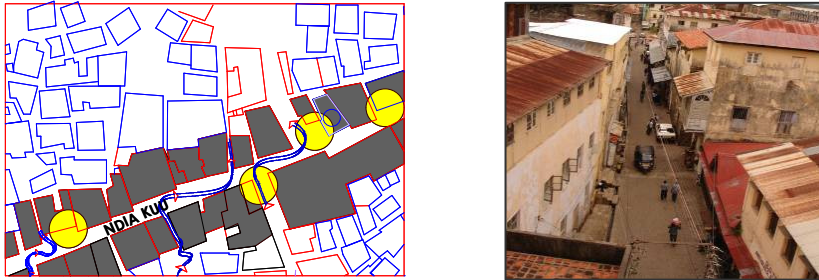


Fig. 3: Irregular plans of buildings defining a street creating small pockets of activities (highlighted in yellow). Source: Author.

The north-east direction of minor streets allows them to take advantage of north-east monsoons which occur between December and February. This is also the direction that the town receives sea to land breeze during the day of about 4 m/s and land to sea breeze at night of 1-2 m/s. These high speed winds, according to Koenisberger, increases building surface conductance. This, coupled with external envelope rough stucco finish, thus high surface area, helps to cool the building.

Regarding individual buildings, most of them have protruding wooden balconies with minor roofs that created deep shadows keeping the interiors cool while allowing sea-breeze to penetrate, making both exterior and interior spaces comfortable.

Another element, broad verandas or loggias, are duo-functional. Apart from being used by female members of the household to carry their chores in privacy, they also shaded the masonry walls while allowing breeze to penetrate into the interior.



Fig. 4: Environmental controls; wooden louvre windows, courtyards, loggias and protruding balconies. Author.

The Omani introverted building type influenced by Islamic conception of privacy culminated to a central courtyard, enclosed by rooms. The open to sky open courtyards provided natural light and ventilation to the rooms.

Interesting, is the windows with double louvre wooden shutters. This allowed the top shutters be opened for passive ventilation while shutting the lower louvers to shade the inhabitants from direct glare.

In reaction to Mahoney tables, the houses achieved light-weight recommendation through logical reduction of building mass. Intricate decorative niches, a development of Swahili elite, were curved out on the walls, sometimes covering whole walls. Therefore the walls were reduced to a thin web with increased surface area to maximize structure cooling. Ghaidan states ' the scale and regularity of the niches with their broken surfaces increased sound absorption and muffled domestic conversation, and they also tended to enlarge one's visual and aural perception of what were often rather confined spaces.'

5. Longitudinal study analysis

This section explores the relationship between urban morphology, microclimates and indoor thermal conditions. Urban contexts offer a rich and varied environment which influences the manner people use the urban spaces (movement, sequence and (quality and intensity of) activity). The urban spaces concerned in this presentation are spaces in and around three selected buildings in Old Town, Mombasa. Various research works have established that quality of urban spaces contribute to the well being of its users as well as extent of modifications to indoor microclimatic parameters (e.g. temperatures, air velocity and relative humidity). While urban form is an independent variable, independent of microclimate and microclimate is dependent on urban form and prevailing climate, adaptive measures by urban space users (indoor or outdoor) will depend entirely on the two; which has a direct correlation with energy use hence impact on climate change. Of the three buildings mentioned, two were traditional and one contemporary. The choice of these three buildings was motivated by similarity of urban morphology surrounding the buildings, namely narrow streets, orientation towards the ocean and at least one of their facades facing the same main street, Mbarak Hinawy street.

longitudinal study approach was used as six computer programmed digital data loggers were used to monitor ambient air temperature and relative humidity inside and outside the selected buildings over a period of four weeks between the months of September and October.

5.1 Typo-morphological analysis

The typo-morphological analysis exposes the various physical aspects of the town and the elements constituting the urban form which include the materials, urban spaces and proportions and dimensions of building forms. Figure 3 presents the relationship between openings to solid wall surface area (O: SW) ratios and building height to street width (H: SW) ratios. A significant difference in O: SW between house B and C is gathered from the graph, with the former having a smaller ratio denoting to fewer areas of opening to the solid envelope. Openings in house B are wooden with wooden louvers while house C windows are made of glass on aluminium frames with dead lights on the lower half of the window. On the other hand, house C has a smaller value of H: SW compared to the other houses. This means that house C is more exposed to the weather elements than the others.

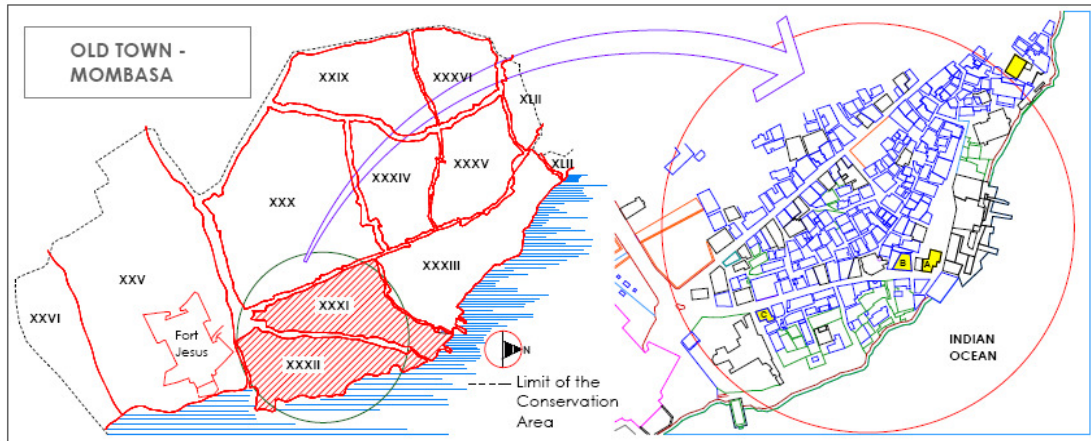


Fig. 2: Locations of the three houses, within Old Town, under investigation. Source: Author

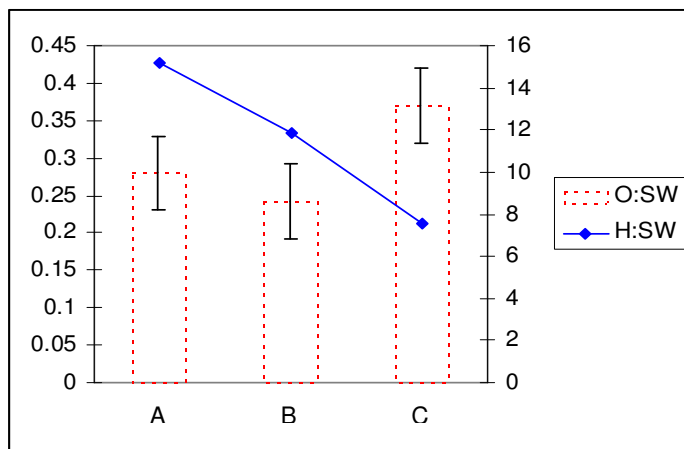


Fig. 3: Openings to solid wall surface area ratio and building height to street width ratio. Source: Author

5.2 Indoor v/s Outdoor Thermal Analysis

The three buildings are compared in terms of their daily, weekly performance in both day and night. An additional comparative parameter is the indoor comfortable temperature felt by occupants, a function of mean outdoor temperature based on Auliciems' single line model, $T_c = 0.31T_o + 17.6$, for both free-running and 'active' buildings. This temperature is unlike the recommended specific temperature what is described by international standards (ISO 7730 and ASHRAE 55-1981, ASHRAE 55-1992) which take no account of climatic variations, people culture, way of life and people adaptive behaviour e.g. kind of clothing and metabolism.

The following graph was generated for this analysis.

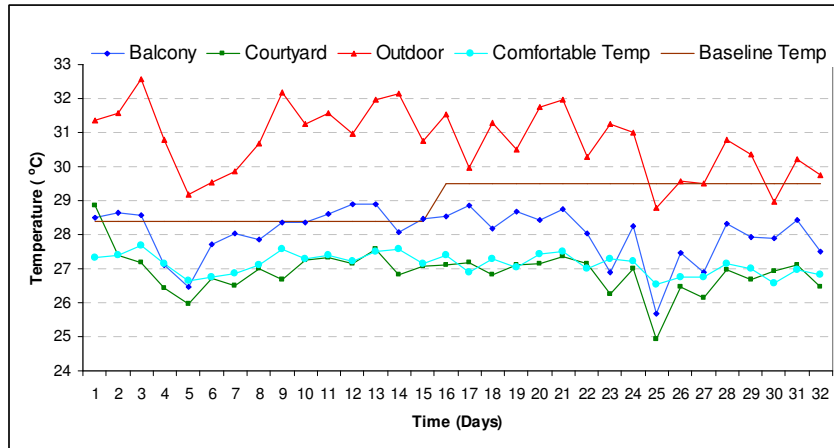


Fig. 4: Comparison between the houses with comfortable and baseline temperatures. Source: Author

In architectural place making, balconies and courtyard can be considered as extension of indoor spaces. Temperatures on these spaces were much lower by a margin of up to 4.8 deg C than ambient outdoor temperatures, with the courtyard thermal conditions being better than balconies'. In terms of comfortable thermal conditions, courtyard environment was all along within the comfortable temperatures with balconies' being slightly higher. This could be attributed to the exposure of balcony space to heat generated by reflective hard landscaped roads. Based on the width to height ratio of the courtyard compared to general ratios of the streets, it can be said that environmental conditions of the street user is almost equal to the one in courtyard or, if worse, closer to balcony conditions on the better times of the day.

The outdoor temperatures are also analysed against the baseline climate (temperature data from the Mombasa town meteorological station) for the months under investigation. The graph depicts a rise in outdoor temperature conditions, indicating that outdoor thermal conditions of Old Town are not exempt of the global temperature rise.

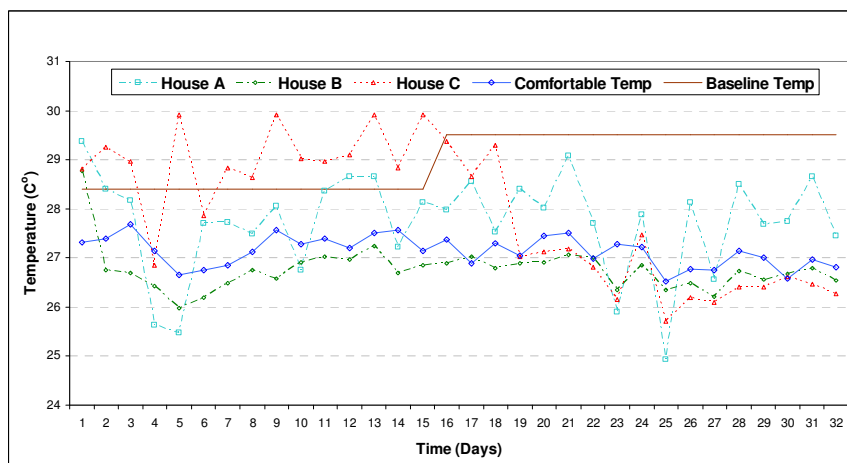


Fig. 4: Comparison between the houses with comfortable and baseline temperatures. Source: Author

Figure illustrates the thermal indoor conditions of the selected buildings in relation to baseline temperature and comfortable temperature. To note is that house B conditions were constantly slightly below, by an average of 0.4 degC, while house A slightly higher by 0.5 degC than the comfortable thermal conditions. On the other hand, house C under no influence of air-conditioning, was 2.1 degC higher.

Using Fanger's PMV comfort model, occupants of house A and B could have voted PMV=0 while occupants of house C on free-running conditions could have voted PMV=+0.5. In his studies of potential energy saving in buildings, Pitts found that allowing temperature variations of ± 3 degC, the building can save to a margin of 7% of its total annual heating energy consumption with a 4% energy saving in active cooling. In this case, it can be said house C consumes 4% of its energy to cool the building which in turn contributing more to global temperature rises.

Juxtaposing figure 3 and 4, the conditions around courtyard and balcony (to some extent the narrow alleys) can be termed as transitional; intermediary between indoor and outdoor. Such spaces are important in maintaining environmental continuity for thermal comfort, where changes in thermal intensity of different stimuli should be subliminal to avoid the sensation of discomfort. If someone moved from an indoor space of say 26.5°C to outdoor conditions of 31.0°C, such sudden thermal steps will be difficult to be accommodated with the body mechanisms, leading to discomfort and it will take at least 20 minutes for the body to reach steady-state level. On the other hand, these transitional spaces allow the body to adapt easily to the gradual thermal steps making such changes almost imperceptible.

5.3 Embodied Energy Analysis of Common Materials in East African Coast

Embodied energy levels of materials used in the buildings found within the study area are summarized in the table below:

Material	Range of Embodied Energy Values (GJ/ton)	Associated CO2 Emissions (Kg/ton)		
		A	B	C
Aluminium	200-250			
Plastics	50-100			
Steel	New			3200-3400
	Recycled			1600-1800
Glass	10-30			1100
Lime	3-5			37
Timber	Indigenous			710
	Imported			600-1100
Coral stone	0.02-1			45
Recycled aggregate	0.02-0.1			8
Soil	<0.5			3
Makuti	0.1-0.5			

Table 1: Indicative embodied energy of materials. Source Atkinson C., Howard N. (1991)

The table shows that materials with low embodied energy, which are widely used in traditional buildings, have equally carbon dioxide emissions (as they are sourced locally and require simple machinery to prepare), a major contributor to global warming. compared to the contemporary materials. The use of glass, aluminium and steel in house C makes it a major pollutant than the rest.

6. Conclusions

Longitudinal approach of measurement of microclimatic parameters have allowed for better analysis of indoor and outdoor thermal conditions over time.

The East African traditional coastal towns, which have evolved over time under influence of various cultures and religion, have spontaneously developed to respond positively to prevailing climatic conditions. From the study, we can deduce the following:

- The general orientation and interconnections of the streets enhances air movement to the deeper areas of the dense urban fabric.
- Its distinctive recognizable character is a resultant product of the interrelationship form (buildings and its elements like balconies, loggias and *dakaa*) and space (narrow streets) which have allowed for comfortable micro-climate passively as well as effective transient zones; resulting to almost a zero carbon society.

These traditional towns can provide useful lessons for building and urban designers, even if they cannot provide a straightforward template for modern living, by recognizing the significant environmental challenges present and how they will inform urban planning systems.

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