Establishing Energy Efficient Building Codes in Developing Nations:

An analysis of window characteristics suited to hot-dry climates through a study of the residential byelaws of Lahore, Pakistan.

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ABSTRACT

Evidence that windows are responsible for most heat gain through solar radiation into a building underlines the importance of climatically sensitive window design. Many of the recent building practices in the developing world are dismissive of the more environmentally appropriate traditional building forms, adopting instead, an urban form that is neither environmentally sensitive nor sustainable. Such practices demonstrate a lack of understanding between the thermal performance of windows in relation to the urban geometry, yet are in most instances legitimized by inadequate regional building codes. A case in point is that of Lahore Pakistan, where despite a predominantly hot-dry climate there is no mention of suitable apertures within the building code, this situation is exacerbated in residential areas by the byelaw requiring a mere 1.7m distance between the building unit and boundary wall on two sides of the building. Taking Lahore as a prototypical developing world city, this paper addresses the specific spatial arrangements created through the existing building codes and focuses on controlling solar gains through an analysis of the window characteristics that are most suited to the climatic and urban environment. The discrepancy in building codes is investigated through software simulations that evaluate real housing clusters with particular focus on the obstructed facade (by boundary wall or adjacent building) for which suitable window characteristics that balance seasonal natural light and thermal gains are determined. A further set of simulations addresses the effect of modifications in the byelaws regarding the distance of obstruction and the consequent adjustments necessary to window characteristics. The results of these simulations provide the knowledge-base for a critique of the environmental sensitivity and suitability of the existing byelaws, and propose modifications that would optimize both climatically appropriate window design and land use within the urban environment of Lahore.

INTRODUCTION

The twentieth century technologies and universally available materials have greatly facilitated the trend towards homogeneity of the urban built form across the globe. This trend is popular in all aspects of urban built form but is particularly obvious in the form of public and commercial buildings in most city centers the world over.

Traditional building design was perfected over a long period of time, with the construction practices, architectural vocabulary and urban form of a region being sensitive to the climatic conditions and cultural requirements of that region. The result was an urban-scape unique to the place and the people, with the building envelope maintaining comfortable indoor conditions.

However the influence of new materials and technologies has resulted in a drastic shift in the built form which in most instances is far removed from tradition and also the goal of maintaining comfortable indoor conditions. While these changes to the urban form have been somewhat conscientiously undertaken in First World Countries in that desirable indoor conditions remain within achievable limits, the situation within developing countries, particularly those with hot climatic regions, leaves a lot to be desired. The *modern urban form* in such parts of the world and the accompanying lifestyle is largely reliant on mechanical methods of air conditioning to maintain comfort which is an unsustainable and expensive option. This situation is exacerbated by the unquestioned adoption of design standards that have been developed in colder parts of the world and are geared to satisfying comfort and energy use in developed nations. The extent of this practice can be gauged by the situation in much of South Asia where the comfort standards laid out in ASHRAE guidelines have been incorporated within the national building standards and are legislatively enforced. The irrationality of such practice is reinforced in recognizing that even within regions of the world that are similar in their climatic environment, variations in the comfort parameters will exist due to the differences within the culture and lifestyle choices of the people of the various regions.

The formulation of a robust workable code is rooted in an understanding of the environmental efficiency and behavior of different building types within the particular climatic and cultural environment of that region. Such understanding is typically based upon empirical data, however it appears that not all building types have been given due attention; the urban residential form has been largely ignored in this regard, with the major focus of such research being the traditional building (Oktay, 2002) while the study of modern buildings has remained almost exclusively within the realm of office buildings. It is therefore an imbalanced understanding of thermal comfort and occupant behavior that has been created and on which we continue to base our requirements of comfort.

A robust building code implemented within a well-designed regional energy policy would go a long way toward improving this situation by ensuring the design and construction of all buildings (irrespective of purpose) results in the internal environment being as close to comfort parameters as possible. Comfortable conditions could then be achieved through passive control or low energy measures and if artificial air conditioning were still required, the reduced temperature differential between the desired and existing would result in a significant reduction in energy costs.

In the absence of an accurate database of regionally appropriate comfort parameters the environmental efficiency of the buildings cannot be gauged nor a solid measure of the success of building standards formulated. At the very least, existing inappropriate guidelines can be modified in order to adapt them to the local climatic conditions. Focusing on the hot-dry South Asian scenario, the primary *design flaws* in the existing standards that render it inapplicable are:

The glazing ratio: The design guidelines for window size and placement were developed in climates that design for daylight: providing adequate natural light in to the building. These recommendations were based on the window area to wall area of the room and vary for different climatic zones; the consensus however is that the optimal glazing ratios lies between 25% and 40% providing adequate light while not incurring undesirable thermal gains and avoiding disability or discomfort glare (Muneer et al, 2000, Baker et al, 2000). In a hot climate, however, there is ample sunlight and providing natural light into the building is not of concern. Rather, the glazed surface area needs to be managed in order to control the solar gains in the building.

Rate of air change: Traditionally based on standards developed for maintaining desirable internal conditions in a conditioned environment, the rate of air change is not applicable to naturally ventilated buildings in hot climates where the speed of air takes precedence over rate of air exchange purely for the cooling effect of air movement.

The following addendum to the standard requirement of air changes is seen as:

Wind speed: The cooling effect of wind speeds between 0.5m/s and 3m/s has been documented however speeds above 1.5m/s are not advised because of the nuisance factor created through the disturbance of paper etc. (Baker, 2000). The cooling effect of re-circulated air through the use of mechanical fans is utilised in most hot climatic regions the world over. This reliance on fan generated wind speed to counteract the effect of increased temperature has been documented to ‘occurs [sic] at temperatures of around 26^{o}C’ (Nicol et al, 2014 p.128). The consequent reduced temperature is known as the *Effective Temperature.* The cooling effect produced is significant with a wind speed of 1m/s causing a 3^{o}C reduction in effective temperature at 30^{o}C (Baker, 2000), and 4^{o}C at 40^{o}C (Nicol, 1994).

It is surmised that recirculation of indoor air in hot climates would prove a beneficial low energy measure and should be accommodated within building standards and guidelines particularly in such regions where such practice is established.

Thermal Comfort in a hot-dry environmnet

The rigidity of comfort parameters determined through climate chamber experiments does not reflect the seasonal variations within conventional comfort ranges wherein occupants adapt to the environment and accept significant deviations in their surroundings. This behavior has been utilized in the development of the adaptive model for achieving comfort and recently this approach has been validated by several international standards such as ASHRAE 55-2004 and EN15251 through the recognition that indoor comfort temperatures are dependent on changing outdoor conditions (Nicol et al, 2014).

One such representation of the relationship between indoor comfort temperature and outdoor temperature is the 1978 formula developed by Humphreys:

$$T_c = 12.1 + 0.53T_o \qquad (1)$$

Where T_c is indoor comfort temperature and T_o is outdoor temperature.

This formula has been found to be 95% accurate in predicting comfort temperatures during summer months for occupants in environmentally controlled buildings in the South Asian country of Pakistan (Nicol et al, 1995). It is assumed that the range of validity of this formula will have an upper limit of 47^{o}C, (the average high temperature of Multan, one of the 5 cities in the study and with the highest average temperatures of the sampled cities).

It is to be noted that this equation does not take into consideration the cooling effect of wind speed. The use of ceiling fans is standard adaptive behaviour in such climatic conditions and the Oxford Brookes report specifically mentions the cooling effect of ‘about 2^{o}C for average air movement’ in Multan with ‘an approx 4^{o}C shift between still air and 1m/s’ (Nicol, 1994, p23). A modification of Humphreys’ formula is thus undertaken to incorporate a conservative 2^{o}C reduction in temperature due to the effect of re-circulated air movement, giving the relationship for *Effective Comfort Temperature* ($T_{ce.}$):

$$T_{ce} = 10.1 + 0.53T_o \qquad (2)$$

LAHORE, A CASE IN POINT

The case study undertaken is the city of Lahore in Pakistan, a typical developing world city which is prone to the issues of conformity to developed world trends in urban form and lifestyle. Located at 31.34^{o}N and 71.20^{o}E, Lahore experiences severe hot-dry summer with a mean average temperature of over 35^{o}C for five months of the year and remaining over 30^{o}C for a further two months (Weatherspark, 2013). With peak summer temperatures of over 45^{o}C, the control of solar gain was the central design consideration in indigenous architecture. The modern urban form however has abandoned the dictates of tradition, with thinner walls (standard construction of 9” load-bearing brick masonry), lower thinner flat roofs, and significantly larger glazed apertures – where previously apertures were small and were protected from the sun’s glare by either external open-able shutters or fixed marble/wood jalli.

The situation in Lahore epitomises the unsustainable condition of the urban-scape of many parts of the developing world with the existing energy regulations based on inadequate research and the local building codes largely ignoring the issue of thermal performance of residential structures. Lahore falls within the same climatic region as Multan, and as such the predictive values of Equations 1 and 2 in the preceding section are applicable. In Lahore where the mean maximum summer temperature is 40.4^{o}C, indoor comfortable conditions would be at 33.7°C, or at 35.7°C where the environment is supplemented with fan-generated re-circulated air.

The Building Code

Much of the residential development within the city falls under the jurisdiction of two major and several minor building control agencies all of which conform to national recommendations. Through this, residential structures within Lahore are regulated within the same byelaws and guidelines irrespective of their location. Universally the building codes specify mandatory clear areas on the periphery of plots –the depth of which is dependent on the dimensions of the plot, residential units are restricted to two storeys in height with a maximum height of 8m and with the upper storey limited to 75% of the floor area of the ground.

The cultural trend, supported by the high land prices is to construct over the entire area permitted by the building codes. This trend combined with the uniformity of plot sizes, a rectilinear *industry standard* road network, and building code dictated volumetric conformity produces a high density low-rise urban form which has remarkable similarity with respect to open spaces between buildings and solar shading by adjacent buildings.

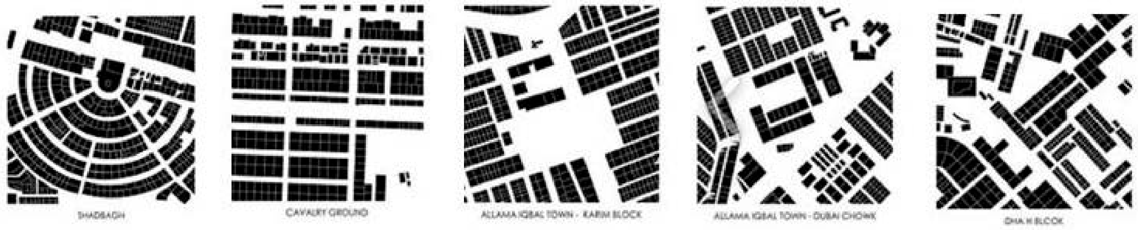

Figure 1 Nolli plans of a sample of residential colonies in Lahore. Density of form and compact nature of planning is clearly visible. (OCCO, 2009)

The primary focus of this study is the largest development authority of Pakistan, The Defence Housing Authority (DHA) within which the development typifies the urban geometry of the city both in density and building form. An initial survey of the sample residential units within the DHA confirmed the translation of the building guidelines is taken literally: in most instances the minimal distance required towards the sides (and the rear of all but the largest plot size) of the residential unit, a mere *passageway* of 1.7m (including boundary wall width) is maintained. Further to this, as the bye-laws limit the height of the boundary wall to 2.13 metres, the facades on at least two sides of all residential units are affected by an obstruction in the form of the boundary wall and close proximity of the neighbouring building.

Table 1. Existing Byelaws for Residential Plots, DHA, Lahore Pakistan (DHA, 2002)

Area (m^2)	Area (sq.yd)	Dimensions (m)	Front (m)	Rear (m)	Side (m)	Side (m)
836	1000	22.86x36.58	6.32	2.55	1.7	1.7
836	1000	30.48x27.43	6.32	2.55	1.7	1.7
418.3	500	15.24x27.43	4.8	1.7	1.7	1.7
211.27	250	10.67x19.80	3.28	1.7	1.7	1.7
104.55	125	7.62x13.72	1.52	1.7	1.7	-

METHODOLOGY: ANALYSIS OF THE EXISTING BUILDING

The current building codes in Lahore have not been designed with a view to develop an environmentally sensitive and sustainable urban form. However an analysis of the buildings created through conformation to the building code will determine a base line of environmental suitability of the code. In order to determine the primary source of uncomfortable indoor conditions, the dissection of the urban form into its basic parts: the building and the urban geometry formed of neighbouring buildings is undertaken.

A random selection of existing residential buildings within the DHA area – providing at least 5 from each plot type, yielded a set of building plans that were then analysed, the significantly atypical disregarded and from the remaining sample pool, a ‘typical’ residential unit selected.

Preference was given to the 500 sq.yd. (418.3m^2) buildings as these are representative of approximately 70% of the residential building size in DHA. Furthermore the byelaws applied to this plot size require the minimum distances of 1.7m from the boundary wall on three sides resulting in greater applicability of any analysis.

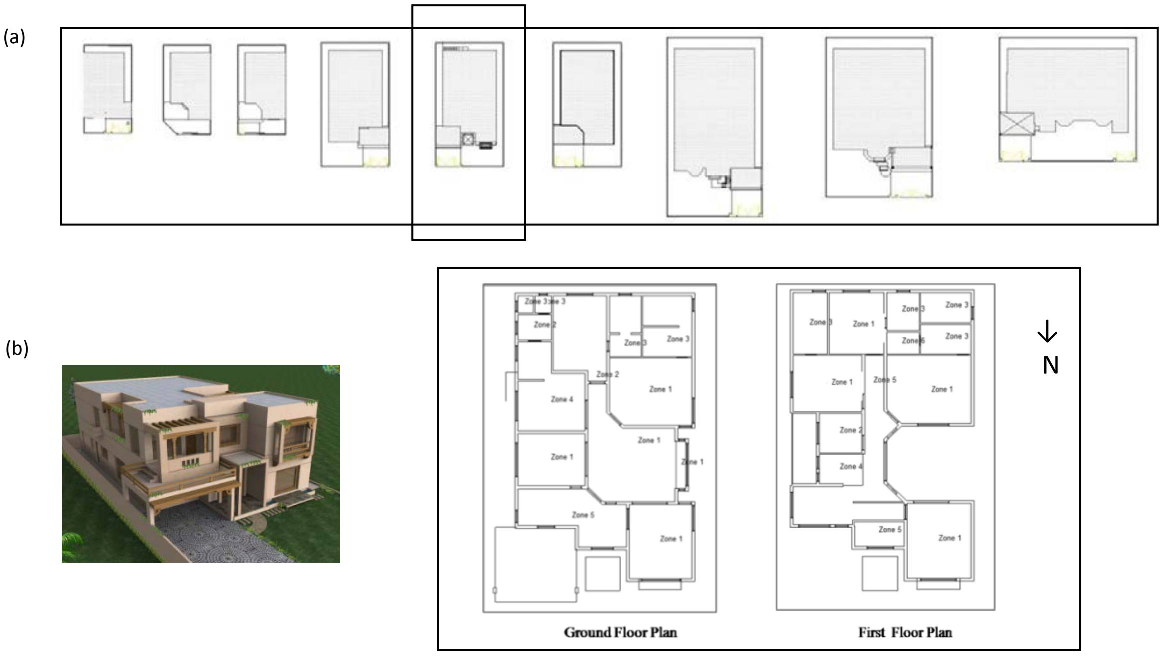

Figure 2 (a) Building footprint of randomly selected existing residential buildings within DHA limits. Prototypical residential unit used for modelling purposes highlighted. (b) 3D model and floor plans of selected residential building.

The typical residential unit selected above is simulated with the EDSL’s (Environmental Design Solutions Ltd) software Thermo Analysis Simulation (TAS). For the purpose of this analysis, the building is modelled in peak summer conditions for one day (day 180/360) with the number of preconditioned days set to 15 (this equates to the building experiencing the environment for 15 days and analysed on day 16, providing a realistic representation of the environmental sensitivity of typical buildings). The building is simulated as unoccupied and without internal gains so as to provide an unadulterated measure of the effect of the outdoor environmental conditions. The internal partitions are taken to be unopened. The building envelope is true to popular construction materials and the apertures are single-glazed with a U-value of 5.7 which reflects occupant preferences based on empirical sales figures: 65% of occupants opt for single-glazed while 35% opt for double glazed. The primary focus of the study is the ground floor level of the building so as to minimise the effect of thermal gains through the roof.

The contribution of the urban geometry:

The typical residential building was modelled under various exogenous influences that together make up the urban geometry of the area. The building was simulated with each parameter in isolation and also incrementally to determine the effect of the urban geometry as a whole, thereby determining which areas need addressing with regard to environmental sensitivity.

These parameters are: the influence of the boundary wall at 1.7m, the neighbouring residence at 3.4m, and the overall effect of the urban-scape (a residential block of 6 houses, with the central one analysed). These simulations showed an expected increase in the internal temperature of the building unit due the introduction of the boundary wall, however there was no significant change to the internal conditions due to changes in distance of wall from the building edge. Furthermore it was found the close proximity of the neighbouring residence had a positive effect on the indoor climate possibly through the shading factor of building. Overall it has been determined that the effect of the urban micro-climate is an increase in the indoor temperature of the residence, by a maximum of 0.6^{o}C.

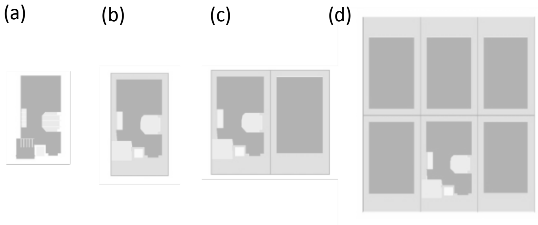

Figure 3 Representative plans of the typical residential building as simulated: (a) building in isolation, (b) with 2.13m high boundary wall at 1.7m, (c) with boundary wall and adjacent building at 3.4m., (d) within a typical block of residential units.

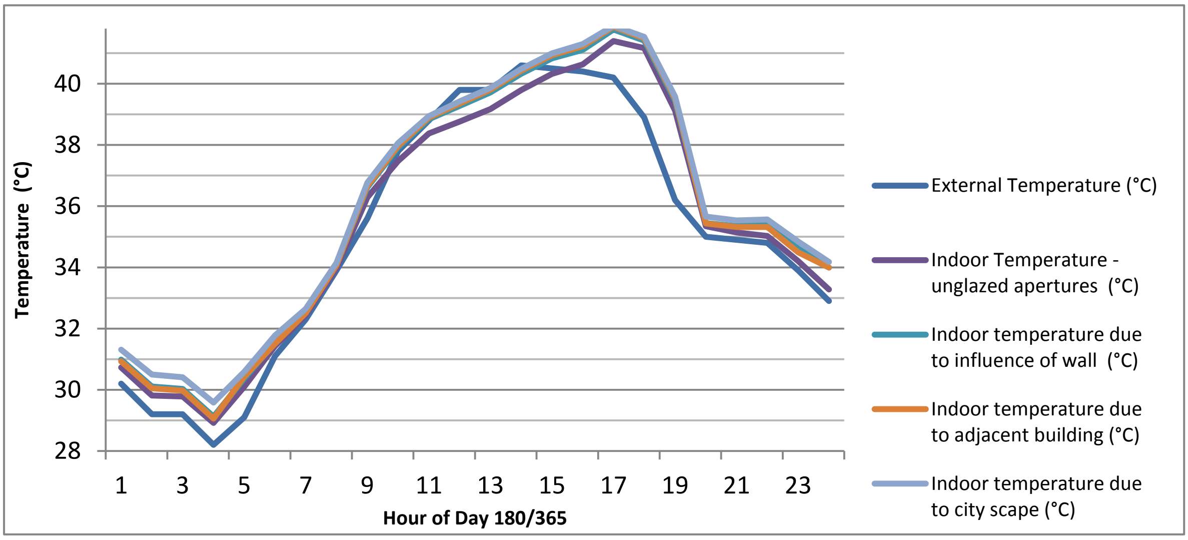

Figure 4 Simulated temperature for 24 hour period over day 180/365 (30th June). Unglazed apertures. Comparison of effect of urban-scape on the indoor temperature.

The environmental sensitivity of the building envelope:

Two preliminary simulations were undertaken for the purpose of developing a baseline for comparison. The first with all apertures opened for 24 hours, with the building unit as an unglazed shell, this simulation showed no significant difference between indoor and outdoor temperatures. The second with the glazed apertures closed for 24 hours where an increase in indoor temperatures by over 3^{o}C signifies the negative effect of the glazed apertures within the building envelope.

In an attempt to mimic typical user behaviour of closing out the harsh intense heat of the day and opening up and airing the inside of the residence during the cooler night, a series of simulations were carried out where the apertures were opened for a few hours of the day. The simulations indicated opening the windows for a period of 12 hours, from 1900 Hrs to 0700 Hrs yields the most significant reduction in internal conditions with the highest indoor temperature (west facing areas) becoming 3.4^{o}C lower than the outside There is however a time-lag between maximum indoor and outdoor temperature of 4 hours (see Figure 5).

The detrimental effect of glazed apertures on the indoor temperature (3^{o}C) is significantly higher than the increase due to the effect of the urban micro-climate (0.6^{o}C) hence further investigation is directed towards the building envelope. For the purpose of assessing the worst case scenario, all further simulations concentrated on the regions of the building most affected by solar gains: the west facing areas. The treatment of the apertures was scheduled as opened for 12 hours: 1900 to 0700.

Overcoming inappropriate glazing:

A simulation was conducted to compare the suitability of double glazed with single glazed apertures in a hot-dry climate. It was determined that double glazed apertures are climatically appropriate as they maintained an indoor temperature 0.5°C lower than single glazed apertures.

A series of simulations were carried out where the building was augmented with various shading devices. These included a 1m deep shade, 2.5m shade, and a 2.5m deep veranda (with walls enclosing the veranda space). A comparison of the effect of such shading devices led to the conclusion that while temporary respite may be achieved from direct sunlight and associated glare discomfort, the change to internal temperature within the building is negligible.

A comparison of the simulations undertaken indicate a reduction of the window area by 50% (to 15% glazing ratio) leads to an improvement of the indoor environment by over 2°C bringing the (maximum) indoor temperature down to 34.8°C –which is an acceptable indoor comfort temperature. The smaller window size results in a slower decrease in indoor temperature at night with the temperature remaining 2.5°C higher than outside temperatures (see Figure 5).

Augmenting passive control: Forced Ventilation

The passive control of the indoor environment is augmented with a degree of mechanical control through forced ventilation. The introduction of cool outside air into the indoor environment results in a reduction in temperature, however the intrusion of dust and insects necessitates control over the quality of air used for ventilation. A solution to this issue is in the form of forced ventilation whereby outside air may be filtered and forced into the indoor environment. This is a variation of the standard supply system of forced ventilation where outside air is brought in and creates a positive pressure (Szokolay, 2008).

The building is simulated to follow the schedule of apertures open during the evening hours from 1900Hrs to 0700Hrs and adjustments are made for an increased air change rate (as a means of controlling air velocity) during the same schedule to mimic the inclusion of forced outside air. Assuming the outside air speed to be 1m/s (the average air speed in Lahore is approximately 4.5m/s for July) (Weatherspark, 2013) the number of air changes through a 2m^2 window (at 15% glazing ratio) and a room of 77m^3 , as simulated, is at 97. A conservatively applied air change per hour value of 50 results in a reduction to the internal temperature by 0.5°C.

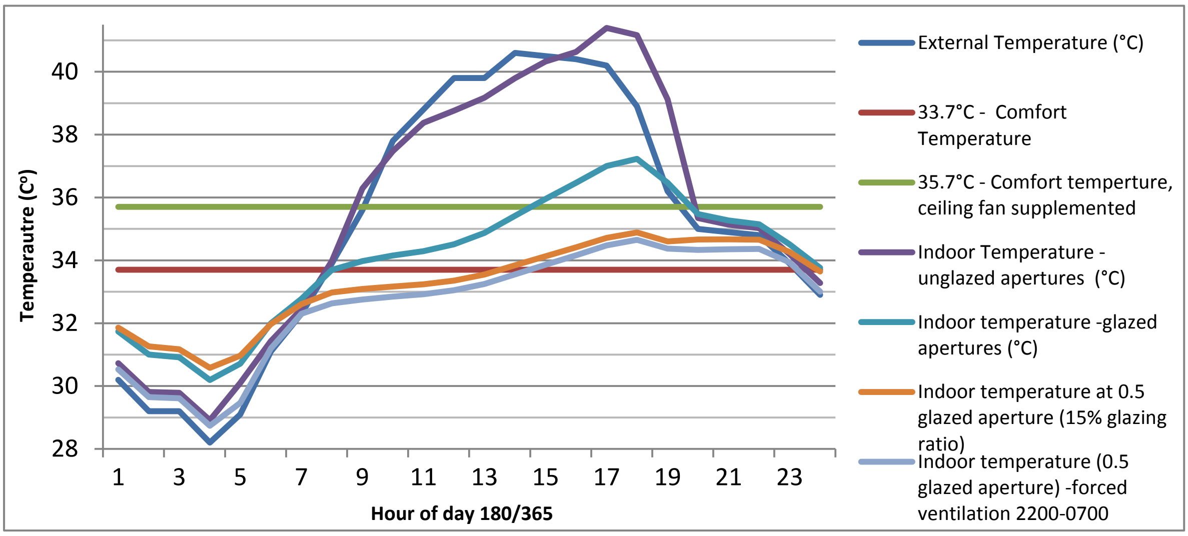

Figure 5 Simulated temperature for 24 hour period over day 180/365 (30th June). Comparison of change in temperature due to change in glazing ratio and with forced ventilation.

A slight modification to the schedule postpones the start of forced ventilation till 2200 Hrs when the outside air temperature has dropped to below 35° with the result of the indoor temperature remaining between the comfortable values of 34.5°C and 28.8°C.

The 1st floor:

The difference between the indoor temperatures of ground floor and a similar space at the 1st floor region is an average of 1.1°C which with the introduction of the passive and mechanical control measures listed above comes down to 0.5°C. The result is a significant reduction in indoor temperatures for both floors and further reductions can be attempted by focusing on the insulating properties of the roof construction.

CONCLUSIONS

This paper has attempted to assess the role of building codes in establishing thermal comfort within the indoor environment. Focusing on hot-dry climates and taking Lahore Pakistan as a case study some shortcomings in the building code are identified, foremost of which is the absence of locally relevant thermal comfort parameters.

Taking the urban geometry and the building envelope as products of the building code, specific contributions of the indoor environment of a typical residential structure were studied through software simulations. The simulations indicated that the urban geometry has both a positive and negative effect on the indoor environment; the effect of the urban micro-climate being an increase in temperature while the close proximity of neighbouring buildings dampening this rise possibly due to their shading effect. The simulations further indicated that the building envelope is responsible for most of the heat gain to the interior of a building and that the primary contributor to uncomfortable indoor conditions are the glazed apertures within the building envelope. It was also determined that through a simple reduction to glazed surface area, augmented with low energy mechanical conditioning (such as ceiling fans and forced night-time ventilation) the indoor environment can be brought to within comfort levels.

The overall focus of the work has been upon the achievement of thermal comfort through the use of passive and low energy measures. The work indicates this is an achievable target for a sizeable section of the population, it thus contributes towards laying the ground work for modifications in building codes to achieve this objective.

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