INDOOR THERMAL COMFORT ASSESSMENT OF RESIDENTIAL BUILDING STOCK IN QUETTA, PAKISTAN

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Abstract

Since last several years Pakistan is facing energy crisis which leads to power-cuts across the country resulting serious disturbance in everyday life. However, residential buildings use more than half of the energy and its demand and usage is continuously increasing. Quetta is the 10th largest city of Pakistan and its urban population is increasing at a high rate. The climate of Quetta is mild to extreme cold in winter and hot in summer which need more heating and cooling for optimal thermal comfort in houses. Energy usage of a household do not only depend on the performance of the building, heating, and cooling systems but also on the life style of the residents. The chosen typology is reinforced cement concrete houses, which is very common and widespread across the country. There is no policy or measures taken at the authority level and most of the houses are not designed by professionals, therefore, the existing houses do not provide optimal indoor thermal comfort. The study consists the monitoring of indoor climate, interviews, and questionnaire. The thermal comfort level was quantified based on the monitored data, and the interviews and questionnaire helped to understand the comfort perception, energy consumption behaviour and life style of the residents. The results show that residential buildings do not provide optimal thermal comfort and residents use active systems to improve indoor thermal comfort which leads to increase in energy usage.

Keywords: Thermal comfort, reinforced cement concrete houses, energy consumption behaviour, comfort perception, housing stock

Introduction

A building must be energy-efficient and provide comfortable indoor environment to the occupants. In uncomfortable conditions the occupants take alternative measures to make themselves comfortable. Such measures include heating or cooling the space by using heaters or air conditioners which is worse than typical heating, cooling and ventilation systems. These alternatives also use more energy and increase the energy usage and the expenses of a household.

Thermal comfort is difficult to measure since it is very subjective and may change person to person and involves a contextual response (Singh et al., 2016; Attia & Carlucci, 2015; Rudge & Gilchrist, 2007; Auliciems, 1981). It depends on several factors such as, air temperature, humidity, radiant temperature, air velocity, clothing, metabolic rate, and every individual experience comfort a bit differentially based on his/ her condition and physiology. According to ANSI/ASHRAE Standard 55-2010, thermal comfort is defined as “that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation” (ASHRAE, 2010). Thermal comfort is also known as human comfort, it is the satisfaction level of the occupants from surrounding thermal conditions and it is an important factor to be considered while designing a building. Generally, thermal comfort is used to indicate whether an individual does not feel too cold or too hot with respect to certain thermal conditions. A cold sensation can be unpleasant when the body is cold but pleasant when the body is overheated. The skin temperature is also not uniform all the time and vary with respect to weather, thermal conditions, activity, and clothing. According to Roshan et al. (2017) it is important to control indoor climate since it affects human life, physical health, and well-being.

While discussing thermal comfort, there are two main thermal comfort models that can be used. The first one was introduced by Fanger based on climate chamber experiment. It is also called PMV/PPD model of thermal comfort. The PMV model consists 7-point thermal sensation scale ranges from (+3) Hot to (-3) Cold. The model was later adopted as ISO standard. The second model is adaptive comfort model. It consists three categories, physiological adaptation, behavioural adaptation and psychological adaptation (Yau & BT, 2014). In this model the occupants adapt the surrounding environment to suite their expectations by changing their metabolic rate (activity), clothing (rate of heat loss) or using control systems (windows, fans, blinds, doors) (Nicol & Humphreys, 2002).

To date, several studies have been conducted on thermal comfort, yet, the problem remained unsolved in several parts of the world. For this study, we investigated indoor thermal comfort of houses in Quetta, Pakistan. There is wide knowledge gap in Pakistan regarding housing and thermal comfort. The study aims to explore the thermal comfort of free running reinforced cement concrete (R.C.C) houses. The objectives of this study are: understanding the satisfaction and thermal comfort perception of the residents, satisfaction with existing heating-cooling systems and energy prices, and to understand the energy consumption behaviour of the residents.

According to Population & Housing Census 2017, Pakistan is the 6th most populous country in the world with rapidly growing population at a rate of 2.4% per year. The total population of the country surpasses 207 million (PBS, 2017). There is also rapid increase in the urban population at an annual rate of 3%, which is highest in the region of South Asia (Kugelman, 2013). Pakistan is facing a serious energy crisis which results in power-cuts across the country (Rauf et al., 2015). The situation extremely disturbs everyday life, business, and economic activities. As of 2018, the housing sector consumes the largest share of the total electricity consumption in the country, i.e. 51% (ESP, 2018). The indoor design temperatures in Pakistan based on ASHARE standards are 21℃ in the heating season and 26℃ in the cooling season irrespective of the location of the building across the country (ENERCON, 1990). It is important to consider context and climate while designing a building.

Therefore, this study identifies the climate conditions in Quetta, their effect on the indoor climate of free running R.C.C houses and indoor comfort level. Moreover, the comfort perception of the residents, their satisfaction from the thermal performance of houses, cooling and heating systems was investigated. The paper is organized into three sections. The first section presents literature review, identifies the research problem and objectives and provides the introduction of study area. Section 2 describes the methods used for this study and section 3 presents the study outcomes and implications.

The study area

Quetta is located at 30.18° North latitudes and 66.95° East longitudes. The terrain of Quetta varies from 1390 metres to 3455 metres above the sea level and the average elevation of Quetta is 1672 metres above the sea level (P&D, 2011; Nicol et al.; 1999). It is the 10th largest city of Pakistan with an urban population of over 1 million which is increasing at a high rate of 5.83% per annum (PBS, 2017). Quetta is the provincial capital of Balochistan. The city has great importance due to its geographical location and it is major economic, trade and communication centre between Pakistan and Afghanistan (Kasi et.al.; 2018). According to Köppen climate classification Quetta falls in cold semi-arid climate (BSk). The climate of Quetta is extremely dry and arid; with hot summer and mild to extreme cold in winter. The city receives Snowfall mostly in the months of December, January, and February. Rainfall is irregular and scanty as Quetta lies out of monsoon region (P&D, 2011). The climate has substantial variations between winter and summer. The extreme recorded temperatures in Quetta are -18.3 ºC in 1970 and 42 ºC in 1998 (PMD, 2018). The city of Quetta witnessed a rapid growth in urban population between the years 1998-2017, resulting in the development of new housing and residential areas.

Methodology

The framework for this study is based on 2 aspects: selection of houses for this study, and monitoring and thermal comfort survey; which are described in detail.

Selection of houses

The existing knowledge and data regarding housing in Quetta is very limited, a housing survey was done to understand the housing conditions, characteristics, typologies and review the available infrastructure regarding energy, water and waste systems (Mahar & Attia, 2018a). It was found that reinforced cement concrete (R.C.C) houses is the most common and wide-spread housing type in the region (Mahar et al., 2017). The common type of houses was selected for further study. 10 houses (large to small) were selected for this study, Table 1. All 10 houses represent the same structural system, i.e. R.C.C frame structure, climate and geographically located in the same city. The houses may have different combination of construction and finishing materials, heating and cooling systems/ devices and housing typology, i.e. attached, semi-attached etc. The houses may also differ regarding number of occupants, and their cultural, ethnic, religious, economic, and educational background.

Table 1. List of the houses selected for study

S. No.	Area of the house (m^2)	Household size
1.	650	11
2.	408	12
3.	307	8
4.	278	8
5.	213.6	7
6.	148	12
7.	130	6
8.	130	7
9.	140	6
10.	63	7

Monitoring and thermal comfort survey

Data was collected through a field survey to understand the indoor climate conditions. The field survey provides “first-hand” data which helps to understand the thermal comfort of residents in their actual daily environment. Normally two types of data are required for such study; objective and subjective measurement data (Wong et al., 2016). For objective measurement, indoor air temperature and relative humidity were monitored simultaneously in all 10 houses. Two data loggers (one each in bed room and living room) were placed in all houses at a position where sunlight, heating and cooling devices do not affect them. The loggers were set to measure indoor temperature and humidity in all 10 houses with an interval of 10 minutes. The measured data was then compared between internal (living room) and external environment. Since various cooling devices were used in the bed rooms so bedrooms can only be compared separately. The monitored data of living rooms in all 10 houses is presented in this study. The ceiling fans remained on during the occupancy hours and windows were mostly left open during summer period for cross ventilation. The Outdoor air temperature and humidity was monitored by safely placing a data logger in a weather-proof box (provided with holes for crossing of the air). It was placed on rooftop of a building at Balochistan University of Information Technology, Engineering & Management Sciences (BUITEMS) Takatu Campus Quetta. The outdoor data was also taken from a weather station at BUITEMS Takatu campus which is being maintained by Alternative Energy Development Board (AEDB), Government of Pakistan with the cooperation of National Renewable Energy Laboratory (NREL) of The United States. The indoor air temperature and humidity were monitored by using HOBO U12-012 data loggers. The purpose was to monitor extreme temperatures, seasonal differences, and the most unfavourable weather conditions. The monitoring for this study took place for 4 weeks, 2 weeks in summer (Jul-Aug 2017) and 2 weeks in winter (Dec 2017-Jan 2018).

Plans of two free running R.C.C houses selected for this survey are shown in Fig. 1(a) and Fig. 1(b). Fig. 2(a) shows the data logger used for the monitoring and Fig. 2(b) and Fig. 2(c) shows the weather proof box used for outdoor monitoring. The outdoor weather station at BUITEMS Takatu campus Quetta can be seen in Fig. 3.

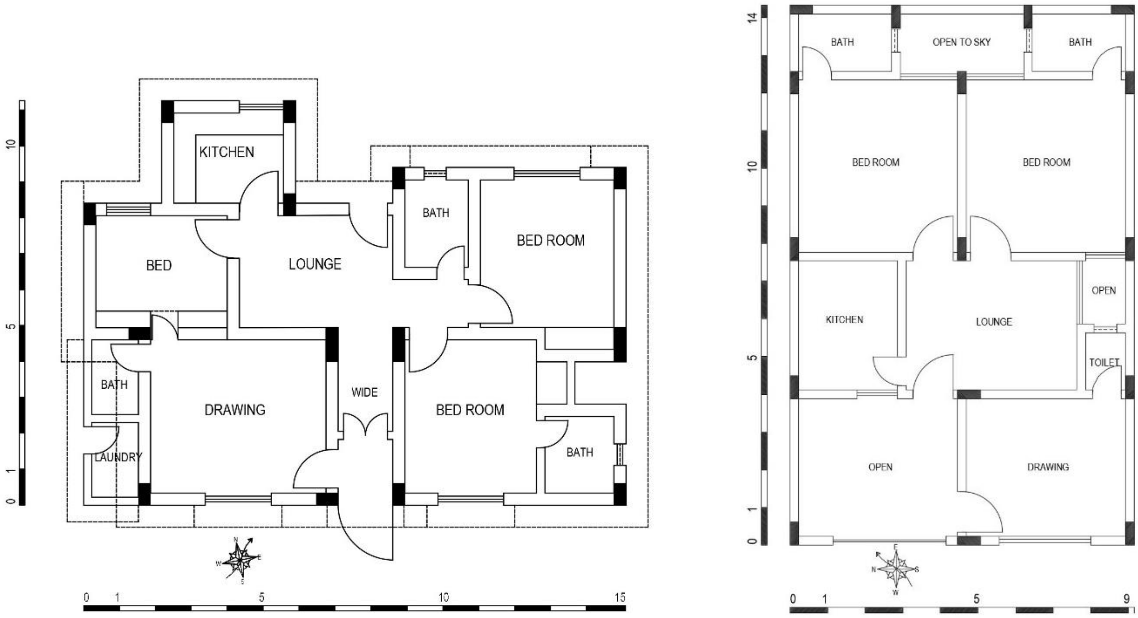

Figure 1(a) and 1(b) plans of two selected houses
Source: (Mahar & Attia, 2018b)

Fig. 2(a) Fig. 2(b) Fig. 2(c)
Figure 2(a), 2(b), 2(c). HOBO U12-012 data logger and box

Figure 3. Weather station on the rooftop

For subjective measurement a questionnaire was formulated, and semi-structured interviews were conducted to understand the comfort perception of the residents. The respondents were also encouraged to provide their opinion and describe the situation further (if necessary). Follow up questions were asked from some respondents to get more detailed response. Plans of all 10 houses were drawn after getting proper details and measurements. The questionnaire includes the questions on socio-demographic information, architectural and construction aspects, HVAC systems, energy prices and problem, behavioural insights, lighting, comfort, clothing, and renewable energy.

Results & Discussion

Field measurement data

The monitoring of indoor climate was done for a period of four weeks, two weeks each in both summer and winter. For summer the monitoring took place from 27/07/2017 to 9/08/2017 and in winter from 27/12/2017 to 9/01/2018. The loggers were activated for delayed start and all loggers were placed in the houses before their launching time. All data loggers started logging data at the same time in all 10 houses, i.e. 00h and continued logging data for 14 days till 23:50 at mid night. All data loggers were set to measure indoor temperature and humidity only. Questionnaires were filled with the help of the residents and semi-structured interviews were conducted. The outdoor temperature and humidity measured during summer period is shown in Fig. 4(a) and 4(b) while Fig. 4(c) and 4(d) shows the outdoor temperature and humidity measured in winter period.

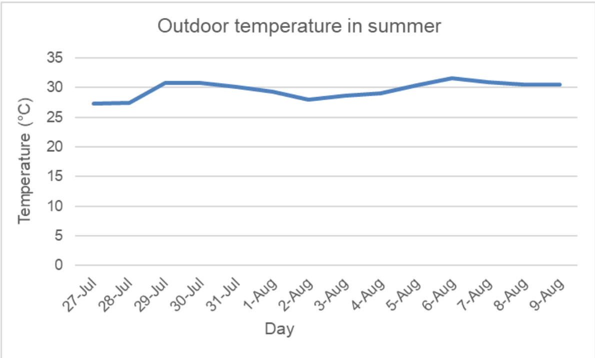

Fig. 4(a)

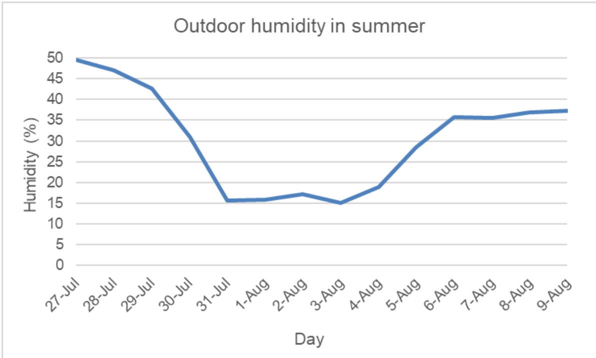

Fig. 4(b)

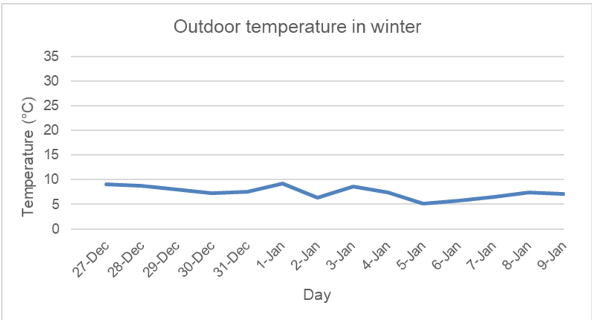

Fig. 4(c)

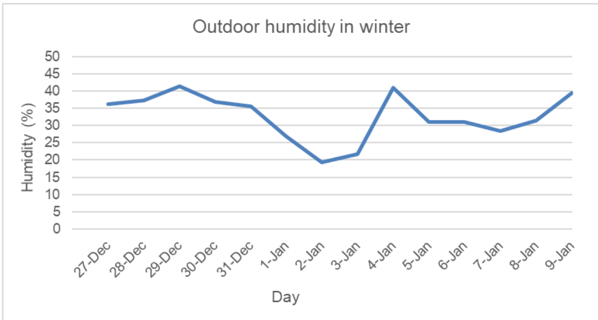

Fig. 4(d)

Fig. 4(a), 4(b), 4(c), 4(d). Outdoor climate conditions (daily) during summer and winter

Fig. 5(a), 5(b), 5(c) and 5(d) shows the measured indoor data and the summary of air temperature (℃) and humidity of all 10 houses (living rooms only) during the monitoring periods in summer and winter. Usually, indoor air temperature follows the trend of outdoor air temperature. If outdoor air temperature increases, then indoor air temperature increases as well. Similarly, when outdoor air temperature decreases the indoor temperature decreases. In summer, the indoor air temperature in all houses varied between 29.5℃ to 34.4℃ during monitoring period which is very uncomfortable. Overall houses 2, 4 and 7 remained warmer during most of the days while house 6 and 9 comparatively showed lower temperatures. The indoor humidity remained lower compared to winter season and varied between 15.5% to 43.5%. Mainly the humidity remained lower in houses 4 and 7 while houses 6 and 9 showed better humidity level than other houses during summer. This shows that at higher temperature the percentage of humidity decreases. We asked the residents of house 2 where humidity level showed no relation with temperature and came to know that there was an underground tank underneath the floor of the room and this might have effect to maintain the humidity level even during higher temperature.

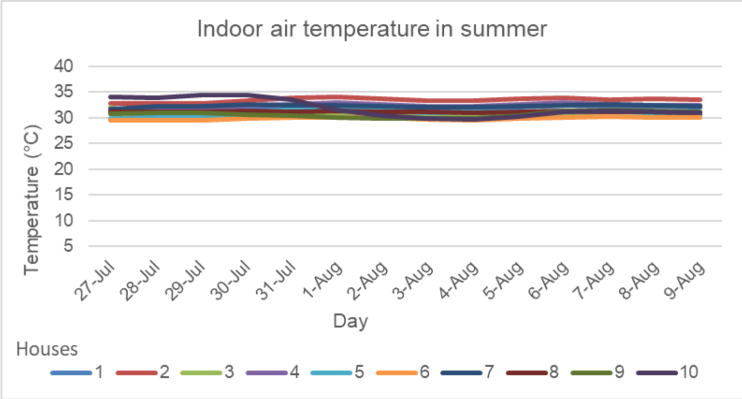

Fig. 5(a)

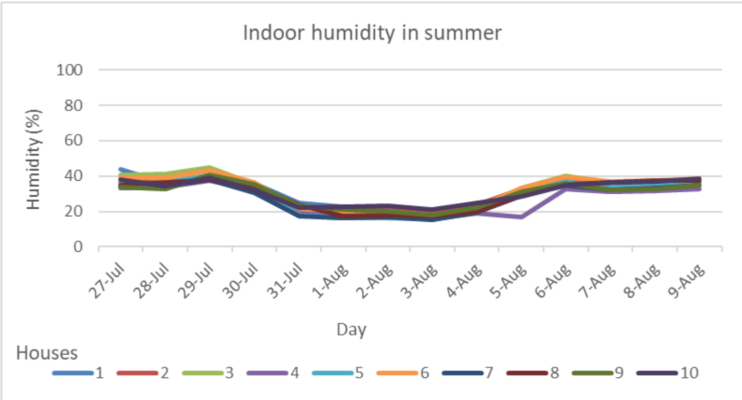

Fig. 5(b)

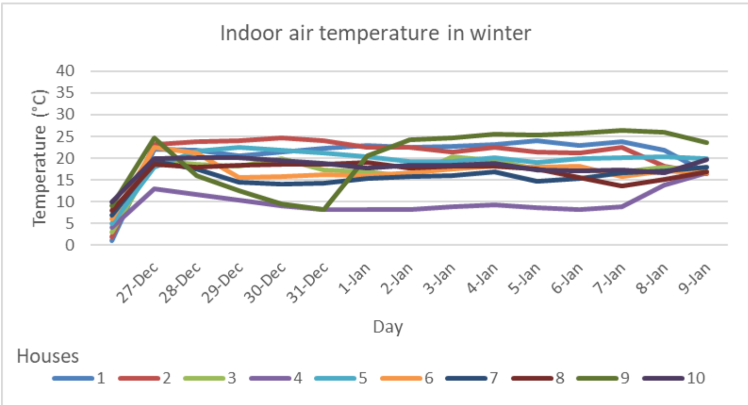

Fig. 5(c)

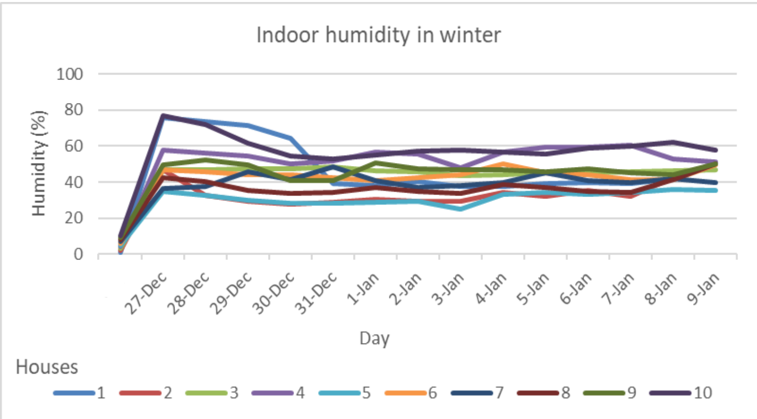

Fig. 5(d)

Fig. 5(a), 5(b), 5(c), 5(d). Indoor climate conditions during summer and winter

The indoor temperature and humidity in winter showed significant variations from summer. The variation in indoor temperature was 8.1℃ to 26.3℃ during monitoring period. Houses 2 and 5 showed higher temperatures than the rest while house 4 showed lower temperature. Humidity in winter varied between 25% to 76.9%, where higher percentages were recorded in houses 1, 4 and 10 while it remained low in houses 5 and 8.

Control systems

Occupants can modify the internal environment by using appropriate control systems. Internal temperatures can be controlled by windows, doors, and ventilators in a naturally ventilated building. In extreme conditions, fans, air coolers and heaters can be used to control indoor temperatures. These systems are discussed here based on the observations and responses of the residents.

Windows

Windows, ventilators, and openings play an important role to control indoor temperature of a building. We asked the questions about opening of windows from the residents of 10 houses. The results are shown in Fig. 6 (multiple answers were possible). It was observed that window controls not only depend on seasons, but it also depends on the factors such as dust particles in the air, electricity outage hours and usage of space. In summer, majority of the houses 60% open windows during evening/ night while windows mainly remain closed during winter in 80% of the houses.

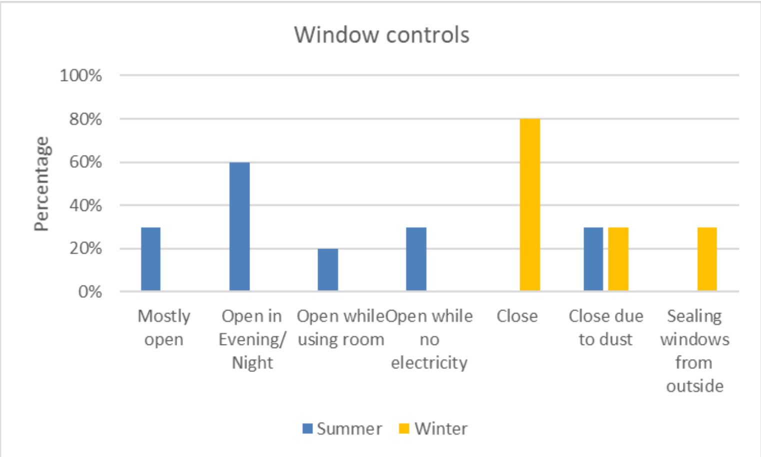

Fig. 6. Window controls in summer and winter

Cooling

Ceiling fans are mainly used in all residential buildings of Quetta and during occupancy hours in summer season to achieve thermal comfort. Table 2 shows the availability of cooling devices in all 10 houses. All rooms including living and dining rooms were furnished with ceiling fans except in house 10 where only bracket or wall mounted fan was used in living room. Ceiling fans remain on for 8-12h per day depending on the occupancy of each house. Exhaust fans are used in all houses to remove warm air from rooms and used in toilets and kitchen to remove smell and smoke. Air coolers are mainly used in the rooms which are warmer than rest of the house. These air-coolers were fixed in the windows and mostly used for 2-3 months in hot season. Houses 3 and 6 use air-conditioners in bed rooms which run 8-12h per day in summer while residents in house 8 do not use air conditioner even it was in working condition.

S. No.	Ceiling Fan	Bracket Fan	Pedestal Fan	Exhaust Fan	Air cooler	Air conditioner
1.	All rooms	2	2	4	1	-
2.	All rooms	-	-	3	2	-
3.	All rooms	-	-	3	-	3
4.	All rooms	1	-	4	-	-
5.	All rooms	-	1	5	2	-
6.	All rooms	-	-	4	-	2
7.	All rooms	-	-	2	-	-
8.	All rooms	-	-	3	-	1
9.	All rooms	-	-	3	1	-
10.	3	1	-	1	1	-

Heating

In winter, the outdoor temperature is much lower, so indoor heating is used to achieve thermal comfort. According to the observations of this study, individual heaters are placed in houses which run between 6-12h per day depending on the occupancy of the residents in each house. Majority of the heaters are operated on natural gas and their continuous combustion increases the CO^2 level affecting the indoor air quality (IAQ). A small portion of window or door is usually kept open for fresh air. Fig. 7(a) shows common type of gas heaters used in Quetta. Gas heating and prices are cheaper than electricity, so people prefer such heaters. Another reason is the unavailability of electricity for few hours/ day and its high prices. Each year some incidents of fire and deaths occur due to use of 1st type of heaters. However, in recent years another type of gas heater is also used in some houses. These heaters operate on both gas and electricity, see Fig. 7(b). These heaters are safe to use and do not create bad effect on the IAQ. Considering the energy issues in Quetta such heaters are not practical for daily use, so occupants always keep 1st type of heaters which can also be used during electricity outage hours. House 9 and 10 uses both types of heaters during winter to heat their indoor spaces. It is common practice to keep second type of heaters turned on during whole night to avoid getting cold while sleeping as outdoor temperature drops during the night.

Fig. 7(a). Gas heater

Fig. 7(b). Gas cum electricity heater

Clothing

The average clothing insulation value based on the responses recorded in the survey is 0.7 clo in winter and 0.4 clo in summer. However, in summer people mostly wear clothes with loose-fitting having dynamic dimensions so the values of clothing insulation can only be taken as indicative. According to a previous study done in five different climate zones of Pakistan, the change about 3.5- 4 °C occurs in comfort temperature with a change of clothing insulation of 0.5 clo (Nicol & Roaf, 1996).

Energy consumption behaviour

It was observed that in every house only 1-2 persons were more concerned about the energy consumption. The behaviour of other family members (67%) was not serious, and they usually leave the heating, cooling devices and lights on while leaving the rooms. During cold winter some residents turn on the heating 1-2h before the occupancy of a room. Heaters remain on in some houses if the room is not occupied for less than 2h during day time. This shows that indoor spaces take more time to heat and can easily get cold due to lack of insulation, improper design, and air leakages etc.

Comfort perception

To understand the comfort level of the occupants the question was asked from all 84 residents of 10 houses. The responses of the residents about their thermal comfort perception in their existing houses are shown in Fig. 8. The results show that majority of the houses do not provide desired comfort level to the residents. In summer, houses are warm and remain cold in winter which leads the residents to use active systems for achieving thermal comfort.

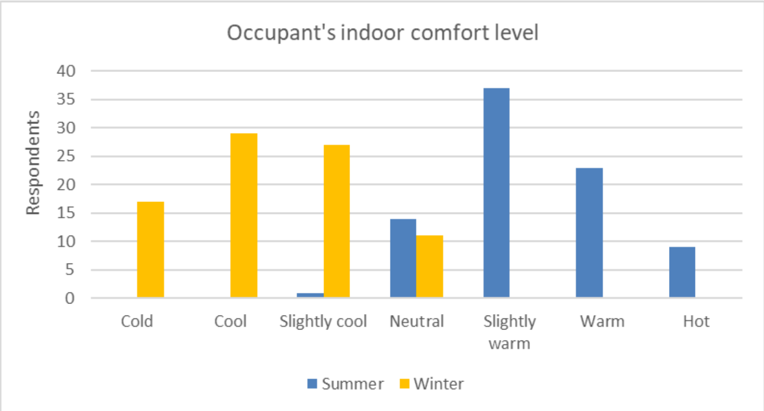

Fig. 8. Indoor thermal comfort level of occupants

Energy

The energy sector of Pakistan is going through a crisis and major changes occurred since last two decades, yet country produces only 2% of its total generated electricity out of renewable sources. Fossil fuels are still used for electricity generation. During FY 2016-17, 33% of the oil was consumed by power sector for the electricity generation which makes power sector second highest consumer of oil after transport. Whereas, power sector remained the largest user of natural gas during Jul 2017-Feb 2018 by consuming 936 million cubic feet per day (MMCFD) which is higher than the gas used by household sector during the same period, i.e. 860 MMCFD (ESP, 2018). This situation increases the overall energy production cost and prices. In recent years, people are more interested in renewable sources of energy. Houses 3 and 4 use solar panels with rechargeable batteries to power their houses during electricity outage hours. Residents of other houses were also interested to use solar energy if they get some subsidy or reduction on the initial cost. It is important to mention that the city of Quetta has great potential for renewable energy generation (NREL, 2007a; NREL 2007b).

As per our survey, the residents seem more satisfied with the prices of natural gas as compare to electricity prices. The satisfaction of the residents from energy prices is shown in Fig. 8.

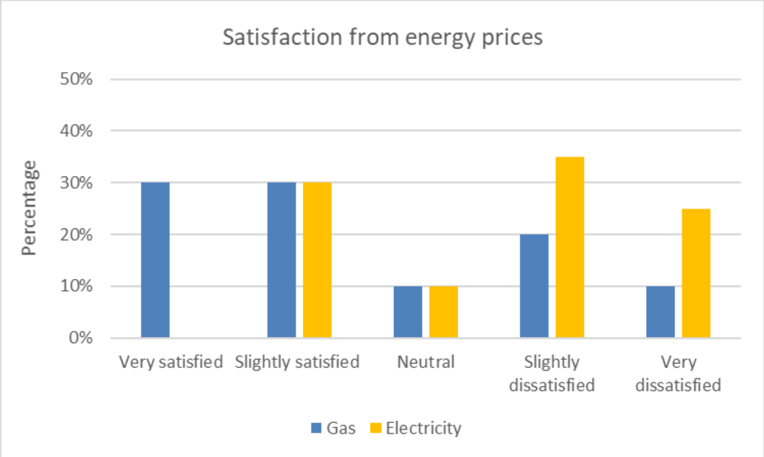

Fig. 8. Satisfaction from energy prices

Conclusion

The study provides valuable insights about the climate of Quetta and its effect on indoor climate of the houses. The indoor temperature is usually dependant on outdoor temperature and follow the similar trends of increase and decrease in temperature. The selected free running R.C.C houses use active systems for cooling and heating in both seasons to achieve comfortable environment. This shows that houses are poorly designed and failed to deal with various range of temperatures. During higher temperature the humidity level decreases which causes more discomfort. It was observed that, in summer the air is mostly dry, and it contains dust particles. This dust causes several health problems and contaminates indoor spaces.

The energy crisis has badly affected the every day life and people are looking for alternate and affordable measure to deal with this issue. However, renewable sources such as installation of solar PV is not affordable for most of the families. Residents are interested to install solar PV if they get some subsidy or reduction on initial cost. On the other hand, low gas pressure is a main problem in cold winter. Residents turn-off heaters during low gas pressure or use gas cylinders to cook their meals. The increasing fuel and energy prices is a big issue to be resolved. Yet, well-off families prefer to use air-conditioning and heating most of the time to achieve controlled environment and thermal comfort. Gas heaters used in indoor spaces increase the level of carbon which affect the indoor air quality. The residents are generally dissatisfied with the thermal comfort level and performance of the houses.

There is lack of legislation at provincial and local level regarding housing. The existing by-laws are not properly enforced in many parts of the city. People can build a house without get planning permission from the authority. The existing by-laws of Quetta Development Authority (QDA) have no energy provisions or considerations which should be included. Due to the high cost of land, resident try to construct on most of the plot area leaving very less and insufficient openings for natural light and ventilation.

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