Human thermal comfort for residential buildings in hot summer and cold winter region, a user based approach

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Abstract. Improving the overall performance of residential buildings means exploring and understanding users' needs, expectations and aspirations, as these greatly affect human comfort, health and well-being. This paper investigates thermal comfort conditions, based on quantitative measurements of typical residential multi-story apartment buildings in Palestine, and a qualitative survey of inhabitants' satisfaction with the indoor environment of their apartments. From these data, average perceived comfort indices (APCI) were calculated. The survey shows that inhabitants of each building have different comfort conditions, especially in summer, according to the orientation of the space. Sunshine, air exchange and temperature are perceived as the most influential parameters for apartment comfort. Although the APCI shows a good level of comfort globally, most inhabitants very often feel hot in summer, mainly during the day, and cold in winter, mainly at night. Measurements confirm that inside air temperature always remains below 16°C in winter, below the comfort level. In summer, it remains between 25 and 32°C, outside the comfort zone. The perceived comfort level seems more related to the inhabitants' feeling of powerlessness than to real thermal conditions.

1. Introduction

In the Middle East, especially Palestine and neighbouring countries, residential buildings are the largest building sector and considered as one of the most important building sectors, as they greatly affect human comfort, health and well-being. In 2017, the domestic sector in Palestine accounted for about 38.4% of total energy consumption [1]. In this country, more efforts are needed to evaluate building energy performance and its effects on indoor thermal comfort. Thermal comfort has been defined by ASHRAE [2] as "that condition of mind which expresses satisfaction with the thermal environment". Quantitatively, thermal comfort is exclusively influenced by six variables: air temperature, air relative humidity, air speed, thermal radiation, human activity and clothing type.

Currently, the indices most frequently used to evaluate thermal comfort are the PMV (Predicted Mean Vote) [3] and the PET (Physiological Equivalent Temperature) [4]. However, these purely physical indices are not sufficient to assess microclimatic comfort correctly. Other parameters related to the climatic and sociocultural contexts studied come into play in this assessment, such as thermal

identity, culture and personal characteristics such as gender and education [5]. In addition to the above, De Dear and Bragerb believe that the adaptive model and human acclimatization play an important role, beyond fundamental physics and physiology, in building users' expectations and thermal preferences [6]. Hence, thermal satisfaction, and acceptability are all influenced by matching an occupant's expectations about the indoor climate in a particular context and what actually exists [7].

The APCI (Average Perceived Comfort Index), a subjective index [8], is extremely sensitive to the sociocultural context of the cases studied, and takes into account the degree of satisfaction of local people with different parameters, compared with an ideal reference situation. It is available in different versions addressing overall comfort or one specific aspect (thermal, acoustic, visual, etc.) [9], [10].

This paper aims to define the thermal comfort of a typical Palestinian multi-story residential building based on measurement and a quantitative approach using APCI. The final aim is to identify how to reduce energy consumption, while offering an optimum level of comfort to the inhabitants, and to propose new constructive approaches to designers, which will limit the use of energy-using equipment by occupants in the Palestine and Middle East context.

2. Methodology

To investigate the thermal comfort conditions in typical residential multi-story apartment buildings in Palestine, quantitative measurements were taken and a qualitative survey of the inhabitants conducted, about their satisfaction with the indoor environment of their apartments.

Measurement data collection and questionnaire survey methodologies were carried out in 2 similar selected buildings (Al Maajeen 1 and 2), as shown in Figure 1, located in Nablus city in the northern West Bank (Latitude 32°13' N, Longitude 35°16' E, and altitude 500m). This area has hot summers and cold winters, and relatively low precipitation [12]. Each building consists of a parking basement, five floors of residential apartments and a roof. Each floor is distributed into four apartments (150-160m² each), staircase and an elevator, as shown in Figure 2. No thermal insulation is used in the walls, roof or floor. The glass used for the windows is a 6mm single clear pane with aluminium frames. The building materials are the typical stone, concrete, hollow concrete blocks and plaster walls, with a concrete slab for roof and floors. The occupancy of the selected apartments was representative of the typical Palestinian user intensity in apartment buildings, which is 1-2 persons per room.

Figure 1. Al Maajeen housing project site plan.

Figure 2. Al Maajeen sample for apartment building with selected rooms for measurements.

For the field measurements, three apartments were selected on an intermediate floor to avoid the effects of the exposed roof. Six rooms with different orientations were selected for the installation of Onset HOBO data loggers (Onset, HOBO U12-012 with accuracy for temperature around ± 0.35°C from

0° to 50°C (± 0.63°F from 32° to 122°F) and for relative humidity ± 2.5% from 10% to 90%). These measured the indoor air temperature and relative humidity every hour for 2 weeks for each season as in Figure 2. The results were compared to ASHRAE standard 55 to evaluate the physical thermal comfort conditions. For the outdoor climatic conditions, a mini weather station was installed on the top of the building.

The questionnaire was prepared to evaluate the most important parameters affecting user comfort and the perceived comfort level for the two main seasons (summer 2017 and winter 2016/2017). Four aspects of comfort were considered: thermal, visual, acoustical and functional. Concerning Al Maajeen 1, eight apartment inhabitants participated in the survey in summer and fourteen in winter. Twelve apartment inhabitants answered the questionnaire at Al Maajeen 2 in summer and in winter. From these responses, the average perceived comfort index (APCI) was calculated. The assessments of different parameters are averaged and weighted according to the importance placed on each parameter by the people interviewed. To carry out the calculation, this importance is expressed in terms of correction coefficients Ci, as shown in equation (1). These are defined by ranking the different parameters for well-being (items), according to their importance, on a scale from 1 (Not at all important) to 5 (Entirely important). Thus, the most important item has the highest Ci coefficient and the least important item has the lowest Ci coefficient. $\bar{M}i$ is the average satisfaction across the panel of people interviewed about item i.

$$APCI=\frac{\sum_{i=1}^{n}[Ci(Mi-1)]}{\sum_{i=1}^{n} Ci} \quad (1)$$

The index classifies the spaces studied according to a level of comfort felt from “totally comfortable” to “totally uncomfortable” as shown in Table 1.

Table 1. APCI assessment scale.

APCI Value	0 – 0.59	0.6 – 1.09	1.1 – 1.59	1.6 – 2.59	2.6 – 3.09	3.1 – 3.59	3.6 – 4
Comfort level	Totally comfortable	Very comfortable	Comfortable	Neither comfortable nor uncomfortable	Uncomfortable	Very uncomfortable	Totally uncomfortable

3. Results and Discussion

3.1. Field measurements results

Indoor and outdoor air temperature and relative humidity were measured for the selected rooms for 2 weeks in autumn from Oct 26 to Nov 8/2016 and for 2 weeks in spring from 13 to May 27/2017. The outdoor air temperature and relative humidity vary during the night and the day in the range 11–29°C, 22–98% respectively in autumn and 10–33°C, 20–95% in spring. Indoor air temperature and RH show that air temperature always remains within the range 20–26°C, and RH within the range 30% to 70%. This means that rooms are comfortable most of the time.

For the summer period, 2 weeks from June 25 to July 10/2017 were monitored. The outdoor air temperature and relative humidity vary during the night and the day in the range 19–36°C and 20–95% respectively. The occupants used electric fans and natural ventilation during this period. Results for the indoor air temperature and relative humidity show that air temperature remains between 25–32°C, and RH in the range 30–70%, which means that despite the cooling means the occupants used, the selected rooms were outside the comfort level most of the time, as shown in Figure 3 and Figure 4.

For winter, the period from January 26 to February 8/2017 was monitored. The outdoor air temperature and relative humidity vary during the night and day in the range 2–19°C and 22–99% respectively. The occupants used portable electric and gas heaters during this period. Indoor air temperature always remains below 16°C, and RH in the range 30%–90%. This means that despite the

heating methods occupants used, the rooms were below the comfort level, as shown in Figure 5 and Figure 6.

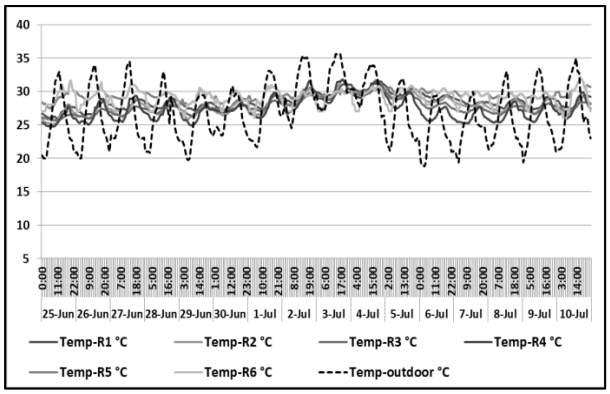

Figure 3. Hourly indoor and outdoor temperature for the selected rooms for 14 days in summer 2017

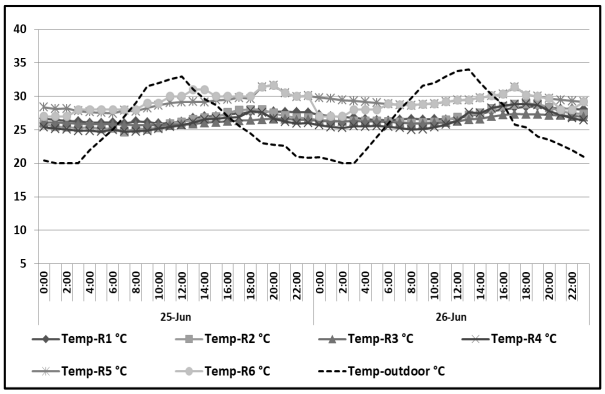

Figure 4. Hourly indoor and outdoor temperature for the selected rooms for 2 days in summer 2017

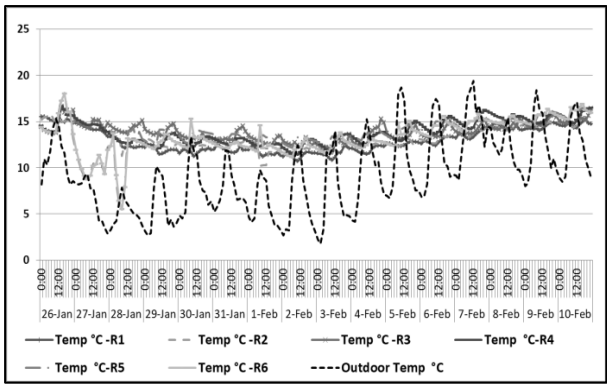

Figure 5. Hourly indoor and outdoor temperature for the selected rooms for 14 days in winter 2017

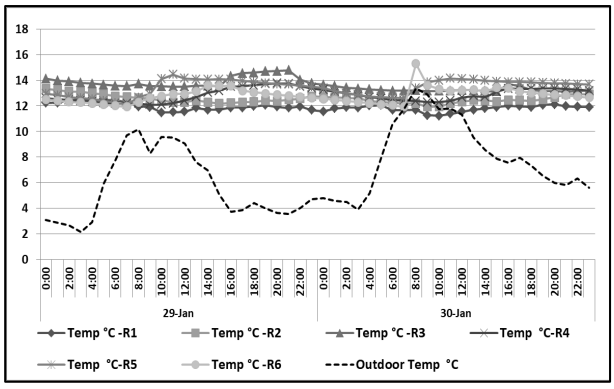

Figure 6. Hourly indoor and outdoor temperature for the selected rooms for 2 days in winter 2017

3.2. Questionnaire survey results

Regarding comfort definition, the results show that the answers are very different between summer and winter for each building and essentially different in summer between the two buildings, as shown in Table 2. The difference between the two buildings appears to be linked with location and orientation. For the Al Maajeen 1 building, the answers in summer are related to the frequent opening of windows, causing the entry of external heat and noise. Al Maajeen 2 is located in the shade cast by building 1. As a result, it is much less exposed to sunlight. Thus the inhabitants express the importance of light and sunshine.

In winter, there is less daylight and sunshine, regardless of the orientation of the building. At the same time, the windows stay closed and there is less air exchange and noise. So, inhabitants from Al Maajeen 1 and 2 define comfort principally in terms of the elements that are least present.

These results corroborate those of previous studies [12], [13], showing that the most important factors for comfort are generally those that are least satisfied. If a need is satisfied then it becomes less important or is ignored. Thus, when we analyse the inhabitants' evaluations of their dwellings, a slight dissatisfaction appears regarding temperature and sound level in summer, at Al Maajeen 1. Regarding the other building, only humidity in summer is unsatisfactory for people. In winter, there is no unsatisfactory factor. However, the results are coherent because the most important elements for comfort get the lower rating.

Table 2. Three most important factors of well-being for inhabitants.

	Summer	Winter
Al Maajeen 1	- A suitable temperature - A satisfactory sound level - Humidity	- A good air exchange - A satisfactory sunshine - Adequate natural light during the day
Al Maajeen 2	- Adequate natural light during the day - The absence of unpleasant smells - A suitable temperature / A satisfactory sound level / A satisfactory sunshine	- A satisfactory sunshine - A good air exchange - A suitable temperature

As we can see in Table 3, Al Maajeen 1 is comfortable in summer and in winter, with a better APCI in winter. Al Maajeen 2 building is neither comfortable nor uncomfortable in summer and comfortable in winter. The most uncomfortable factor in this building is humidity, which is evaluated as uncomfortable in summer. Although they do not express discomfort about temperature, 75% of the inhabitants at Al Maajeen 1 and 66.7% at Al Maajeen 2 are at least occasionally too hot in summer. They feel hot more often during the day than during the night in both buildings. In winter, 78.6% of people at Al Maajeen 1 feel cold occasionally, particularly in the bedroom, whatever the orientation of the apartment and of the room. At Al Maajeen 2, two rooms are occasionally too cold: these are the guest room and the living room for at least 83.3% of people. In the Al Maajeen buildings, inhabitants feel cold more often during the night than during the day.

Table 3. APCI Results.

	Summer		**Winter**	
	Al Maajeen 1	**Al Maajeen 2**	**Al Maajeen 1**	**Al Maajeen 2**
Temperature	1,5	1,58	1,79	1
Sound level	2	1,75	1,57	1,42
Humidity	1,25	2,67	1,5	1,33
Air movement	1,12	1,25	1,64	1,08
Air exchange	0,87	1,25	1,29	1,17
Smells	1,37	1,92	1,21	1,2
Total	1,49	1,75	1,44	1,18

During days and nights that are too hot, inhabitants mostly open the windows or they very often take off some clothes, whatever the building. Fans or air conditioning are used only occasionally. During days that are too cold, inhabitants mostly close the windows or very often turn on the heating whatever the building. During nights that are too cold, inhabitants at Al Maajeen 1 have different behaviours. Conversely, at Al Maajeen 2, the inhabitants take no action against the cold. It is important to highlight that, this building is evaluated as very comfortable regarding the temperature in winter.

4. Conclusions

In autumn and spring, the building envelope performs well in avoiding the variation in outside air temperature and relative humidity and keeps the inside of the building at around thermal comfort level, without the need for heating or cooling except for a very limited time.

The measurements for the hot season show uncomfortable temperatures (25–32°C), but less so than in winter, due to the use of natural ventilation, especially night ventilation. There are consistently numerous inhabitants in both buildings who report being too hot. However, dwellings appear comfortable to their occupants at Al Maajeen 2, which is less exposed to sunlight.

In winter, the building envelope did not perform well to prevent the effect of low outside temperature and high relative humidity, which resulted in an uncomfortable indoor thermal environment. Nevertheless, all apartments are comfortable and satisfactory for inhabitants although many are cold. In this case the occupants try to put on more clothes during the day and more bedcovers during the night to maintain certain levels of comfort.

Because the APCI shows a good level of comfort globally, the perceived comfort level seems more related to the feeling of powerlessness of the inhabitants than to real thermal conditions. In fact, inhabitants know that they cannot change these living conditions, which are the same as they have always known.

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