Designing Comfortable, Low Carbon, Homes in Dammam, Saudi Arabia: The Roles of Buildings and Behaviours

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Abstract

The present paper explores the thermal performance and comfort levels of seventeen air-conditioned homes monitored during the summer of 2013 in Dammam, Saudi Arabia. The comfort of occupants was assessed using the adaptive thermal comfort method. Neutral indoor air temperatures were, in several cases, surprisingly high. Most of the studied homes do not represent thermally comfortable homes as defined within either PMV or adaptive comfort limits. The study reviewed a wide range of factors that might strongly influence neutral temperatures indoors including the properties of dwellings, occupant’s behaviours and attitudes towards high energy demand, loads and costs. This paper outlines the findings of that study and draws conclusions on individual design features of the studied homes that contribute to the comfort and discomfort experienced in Dammam’s dwellings during the extreme summer weather. In late 2015 The Saudi Government hiked the price of domestic energy bills by 60% as a result of low oil prices, putting pressure on ordinary families to economise in their day to day living expenses. The lessons learnt from this study are discussed in relation to the challenge of maintaining comfort in Dammam’s homes while reducing energy used for cooling them.

Keywords: Thermal comfort; architectural characteristics; hot humid climate; air-conditioned homes; residential energy consumption

1 Introduction

Summertime indoor conditions in Dammam’s homes are of increasing concern, due to the potential for increased discomfort and higher energy costs resulting from more extreme outdoor weather. Temperatures as high as 35°C are occupied in Dammam’s dwellings despite the ease with which indoor temperatures can be lowered instantly by adjusting the air conditioning (AC) system. During summer, outdoor and indoor discomfort are exacerbated during extreme hot spells, particularly when dust storms occur that prohibit the use of natural ventilation and the reduce the efficiency of AC systems. The rise in the occurrence of abnormally hot spells experienced in the region during summers and the transition seasons signal the emergence of acclimate that is less predictable and more adverse throughout the year (Tanarhte et al. 2015). Consequently, rising indoor temperatures driver higher levels of discomfort which in turn puts a growing financial burden on families impacting adversely on their lifestyles and standards of living. Similar pressures were key drivers in the collapse of the US and subsequent global economies in 2007 when American homeowners found that rising energy bills meant they could not longer pay their mortgages, providing some evidence that if not dealt with this too could be a major problem for Saudi Arabia (Roaf, 2014). Since the last world economic crisis, the cost
of living has risen remarkably in the region putting households under increasing financial strain to spend more while the income levels remain the same (Albaaz, 2008), with the rising cost of electricity over the last decade making up a considerable portion of the growing wedge between lifestyle aspirations and affordability.

Since all the contemporary Saudi buildings have been primarily designed to be cooled by artificial systems (Eben Saleh, 1998) the region is now recognised as having an AC dependent society (Elsheshawy, 2008), a fact responsible for the very high comparative levels of energy consumption especially in homes. Furthermore, account needs to be taken of the fact that the historically low energy prices in Saudi Arabia have encouraged higher energy demand by consumers (Alyousef & Stevens, 2011). Over the past decade, there has been a dramatic increase in the use of electricity in the residential sector in Saudi Arabia, accounting now for around 50% of the total Saudi electricity consumption (MOWE, 2012). As there are projected to be 2.32 million further new dwellings in the Saudi market by 2020 (Ahmad, 2002), an significant increase in the electricity supplied for residential buildings will be needed in the coming years just to provide adequate indoor conditions in the building stock. Low awareness of energy and environmental issues, evidenced also in this study, leads also to more demanding and energy-intensive lifestyles. A December 2015 60% hike in Saudi Arabian domestic energy prices will disproportionately affect energy costs in low-performance homes, which consequently will put pressure on some families’ budgets for those striving to maintain and affordable the comfort temperature in their homes.

This paper is based on the results of summer time fieldwork undertaken in seventeen homes in Dammam, the capital city of the eastern region of Saudi Arabia, a city with a well-established and growing population, designed to explore such issues on the ground. This study was conducted in three parts: a standard thermal comfort field study established those temperatures at which people reported thermal neutrality in their homes during very hot summer periods. The second part covers an investigation of the characteristics of the house occupants and their behaviours and attitudes towards their own homes. The third section details a physical review of the homes, their services and physical contexts and conditions. It was felt necessary to understand all of these aspects of the homes in order to get a clearer understanding of how their comfort ‘ecosystem’ worked in practice and develop the evidence from which could be drawn useful practical lessons for contemporary designers in the region. This paper outlines the findings arising from the study of the relationship between the physical design features of the Dammam’s homes, and reported comfort, energy consumption and energy costs in the homes.

2 The Field Work Methodology

The Dammam field work was undertaken using a standard longitudinal thermal sampling method (Nicol, Humphreys, & Roaf, 2012) in seventeen air-conditioned homes. The survey involved dwellings that occupied by middle-class families with an average of six people in each home, distributed within a radius of 14 miles within the city. The field measurements and survey were carried out between the 10th to the 31st of August 2013 during an extremely hot season.

This study measured air temperature as its principal physical variable. Air temperatures and relatively humidity were obtained using (KG1001) data loggers that collected and stored

\[\text{Temperature accuracy } +/-1.0^\circ\text{C under 0-50^\circ\text{C; Humidity accuracy } +/-4\%\text{ under 20-80\%}}\]
results automatically in an optional strain choice. The data loggers were fitted in two different places in each dwelling, in the living rooms and the main bedrooms. The positions of the data loggers were located to minimize heat from direct radiation, either from solar radiation, material, mechanical or human sources with a proper distance implemented between the subjects in their normal physical places. Measurements of the environmental data were collected every five minutes.

The researcher developed a software for the comfort survey called “ComfApp” which includes twelve questions operable in all smartphones platforms, making it easier, and more enjoyable, for subjects to vote during day/night time and in any situation in those rooms. As the environmental variables were being recorded concurrently, each volunteer was asked to vote at least twice a day and all of the subjects used the smartphone platform to record their thermal sensation vote. The subjective data were collected over an average of ten days for each household at regular intervals of around eight hours between each vote over the day.

Furthermore, face-to-face questionnaires were undertaken to investigate the characteristics of the dwellers and their behaviours and attitudes towards their homes, such as number of hours/day spent indoors and the use of mechanical ventilation. Questions were also included related to general information about the design and construction of the dwelling. Seeking more in-depth information, semi-structured interviews were carried out for numerous cases, in order to identify specific information that could be compared and contrasted with information gained in the other case study homes. To do this, the interviews were comprised of open-ended questions included to explore occupant’s attitudes and thoughts on the energy performance of their own home, including, for example, factors that influenced their choices to operate a fan or AC rather than open a window. The following sections describe the results of this field study and conclude with discussions on those findings.

3 The Experienced Temperatures and the Reported Thermal Neutrality
The temperature variation recorded during the fieldwork, as shown in Figure 1, ranged between just below 20°C to an unoccupied outlier room temperature of 47°C. Figure 1 has an illustration of a scatter plot of the whole set of the indoor and outdoor temperature recorded during August 2013 in these dwellings. Perfect temperature control could not be expected especially when all of the dwellings had operated different HVAC systems quite possibly with different temperature set points. The mean temperature of the whole sample is 27.2°C, a figure that appears to be well above the European guidelines of maintaining interior temperatures of between 22°C and 24°C. The scatter diagram of the ASHRAE adaptive standard of 80% and 90% acceptability limits of the whole set of measured indoor and outdoor temperatures (Figure 1) indicates that people in Dammam do live in what inhabitants of many other regions of the world would classify as very hot conditions. Surprisingly, 22% of the occupied temperatures that coordinated with thermal sensation votes were above 30°C.

The measurements taken in the summer of 2013 illustrated in Table 1, moreover, provide a valuable insight into the range of mean indoor relative humidity (RH) experienced in the study homes from 41% to 72% RH. These variations might be due to individual houses having different humidity distributions that result from the behaviours of the occupants (cooking, cleaning bathing, use of dehumidifying HVAC etc.) which will modify the humidity.
The mean RH of the whole sample, of almost 60% appears to be higher than the optimal standard of 55% followed as a rule of thumb by HVAC engineers for so long.

Figure 1 Scatter diagram of the ASHRAE adaptive standard of 80% and 90% acceptability limits of the whole set of indoor and outdoor temperature measured in Dammam’s dwellings during the hot season, where the mean indoor and outdoor air temperatures were 27.4°C and 35.4°C respectively.

As the mean indoor air temperature in these homes range between 20°C to 35°C, it is evident that people live in a widely varying range of indoor temperatures, and that they accommodate them in the ordinary course of their day-to-day lives in their homes. Taking into consideration, the responses of all these houses, the thermal sensation votes have significant ($\alpha < 0.015$) positive weak correlation of 0.576 with the corresponding mean indoor temperatures, which indicate that the subjects are adapting to the mean indoor temperatures.

4 Occupant’s behaviour
To explore the occupant’s behaviours, the questionnaire used in the study interrogated the respondent’s behaviours using a distributed survey that garnered four hundred and seventy-two votes from a total number of thirty-five subjects with a gender split of eighteen males and seventeen females. The ages of the subjects ranged from twenty to sixty years, with a mean age of 34 years old. All subjects were in good health during the time of the questionnaires. Calculation of their body mass indices showed that 72% of the subjects were overweight. On average the users stayed indoors at home around twelve hours per day, with women spending on average four hours more there. When asked about their electricity bills, more than the half (57.6%) of the participants replied that they often have high bills during summertime that ranged between £90 to over £200 per month. Despite the fact that the cost of a kWh of electricity delivered to the householder is ranging from only a penny to 29p for the highest consumer, around 62% reported that they considered their electricity bill was overpriced and inflated.
Table 1 shows the variation of all measured thermal sensations of the occupants who have a neutral pint of 0.1. From Figure 2 we can see that of the total 472 valid responses, 134 occupants described themselves as being thermally neutral. 79 respondents were slightly warm and 116 were slightly cool. 143 of the responses, or 27% of the dataset, reported being warm or hot, or cool or cold, (responses of 2, 3, or -2, -3) at the time they recorded their comfort vote. Interestingly, 92 of the respondents, or close to 20% of the dataset, were feeling warm or hot and half of these votes were experiencing a temperature equal or above 30°C. Moreover, around 20% of the latter responses preferred no change on the thermal preferences scale. The standard deviations of the thermal sensation in Table 1, furthermore, provide additional insight into how the perceptions of conditions in different houses vary, clearly influenced by the prevailing indoor temperatures.

During the longitudinal survey, occupants were asked to indicate what environmental controls were activated during the survey voting period. The adaptations noted among the controls include the use of AC, fans, windows and doors. Table 1 lists the mean and standard deviation of the control of AC and fans as well as the opening of windows and doors between the survey votes for all the dwellings. Surprisingly, only 17% of the total observations recorded occupants closing the AC system off at some point during the day of the vote. It indicates that the decision to shut down the AC system was seldom made and in some homes, it was never turned off. The main reasons for shutting the AC system were that the AC was not blowing cool enough cooling due to an over-long operation period, or because some occupants desired to be in the warmer conditions that resulted. However, the length of operation of the mechanical systems of homes in the region may reflect the low price of electricity in Saudi Arabia then. As domestic prices rise it will be interesting to see if the operation period of the mechanical systems is shortened to save money. The use of fans, moreover, were limited to seven dwellings only, and the mean value of operating the fan in those dwellings varied from 0.03 to 0.50. In those dwellings people were found to prefer to have some local air movement a one occupant reportedly preferred the cooling sensation resulting form the use of fans over those provided by activating the AC.
Although all of the surveyed dwellings have operable windows, almost a nil proportion (1%) of occupants operated the windows during the day and those were found in only three of the dwellings. In the other dwellings, windows were fully closed during the heat of the summer but opened at cooler times of the year. However interestingly the doors which opened into uncooled indoor or semi-outdoors areas were often constantly in operation, (10% - 85% of the time) in all dwellings with a mean value of 0.41. The decision to open internal doors to stimulate air movement around the house instead of windows to the outside was perhaps due to the preconception of the adversity of the outdoor condition (i.e. high humidity, temperatures and dust storms) making the opening of internal doors always a more effective choice.

5 A physical review of the homes, their services and physical contexts and conditions in relation to comfort experienced in them
Levels of comfort experienced in the homes, and the extent of adaptations required to achieve that comfort, were patently influence by the design of the individual house itself. The form, orientation, envelopes and construction of the dwellings and their HVAC systems differed substantially from each other as a result of being randomly selected (Table 2) to represent a broad corpus of homes in the region. All homes were differently planned. Some homes had envelopes with very high thermal integrity, high levels of insulation, double-glazing, minimal thermal bridging and efficient HVAC systems. Others had minimal or no insulation, single glazing, air leaks, thermal bridges and inefficient cooling machines. Most of the homes were built of typical concrete block construction, single/double block and externally rendered. All of the houses had operable windows, and all occupants had potential for visual contact with the outside. In the next section the energy efficiency potential of each home, and its actual energy performance are reviewed and the thermal experiences within the studied dwellings are discussed.
Moreover, tracing the behaviour of the mean indoor temperatures in the living and bedrooms of each dwelling in twenty-four hours’ strings, Figure 3, demonstrate the range of temperatures experienced in the different homes vary significantly between the dwellings. The reasons behind these differences in what constitutes occupied, acceptable and reportedly uncomfortable internal temperatures are sought.

![Figure 3 The traces of the mean indoor air temperature in the string of 24 hours in the studied Dammam’s homes during August 2013](image)

One of the most effective strategies for reducing domestic energy consumption and increasing occupant comfort was found to be simply the existence of a high performance dwelling envelope, with sensibly sized openings facing in a good orientation taking in requirements of heat gain and loss, lighting and air movement. Achieving both comfort and low energy consumption demonstrably benefits from ‘whole system thinking’, as they can be seen to result from the sum of many different building parts and behavioural and attitudinal attributes of the occupants. The main physical attributes that appear to determine performance most are discussed below individually and as clusters in the case study houses and include:

1. orientation
2. internal spatial planning
3. allocation and sizing of fenestration
4. day lighting and shading provision
5. cooling and ventilation strategies
6. construction materials
Table 2: The dwellings characteristics, the comfort survey result and electricity consumption details of the seventeen dwellings collected in Dammam during summertime 2013, arranged in ascending order of good house performance recorded in terms of energy consumption per meter square.

<table>
<thead>
<tr>
<th>Dwelling Number</th>
<th>Dwelling Type</th>
<th>Dwelling Age</th>
<th>Building Material</th>
<th>HVAC System</th>
<th>Dwelling Orientation</th>
<th>Double/Single Window</th>
<th>Percentage of Insulation</th>
<th>Annual Bill £/m²</th>
<th>Energy kWh/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Apartment</td>
<td>1</td>
<td>Concrete block</td>
<td>Central HVAC</td>
<td>NE D</td>
<td>N/A</td>
<td>18.70%</td>
<td>Yes</td>
<td>30.4</td>
</tr>
<tr>
<td>2</td>
<td>Apartment</td>
<td>1</td>
<td>Concrete block</td>
<td>Window AC and AC Unit</td>
<td>NE D</td>
<td>Yes</td>
<td>7.70%</td>
<td>22.4</td>
<td>-0.6</td>
</tr>
<tr>
<td>3</td>
<td>House</td>
<td>1</td>
<td>Concrete block</td>
<td>Central HVAC</td>
<td>NE D</td>
<td>Yes</td>
<td>10.80%</td>
<td>25.7</td>
<td>-1.1</td>
</tr>
<tr>
<td>4</td>
<td>House</td>
<td>2</td>
<td>Red bricks</td>
<td>Central HVAC</td>
<td>E S</td>
<td>N/A</td>
<td>19.90%</td>
<td>Yes</td>
<td>27.5</td>
</tr>
<tr>
<td>5</td>
<td>Apartment</td>
<td>5</td>
<td>Concrete block</td>
<td>AC Unit</td>
<td>N S</td>
<td>N/A</td>
<td>19.90%</td>
<td>Yes</td>
<td>26.7</td>
</tr>
<tr>
<td>6</td>
<td>House</td>
<td>2</td>
<td>Concrete block</td>
<td>Fans, Window AC and AC Unit</td>
<td>SE D</td>
<td>Yes</td>
<td>9.70%</td>
<td>27.2</td>
<td>-0.9</td>
</tr>
<tr>
<td>7</td>
<td>House</td>
<td>2</td>
<td>Red bricks</td>
<td>Central HVAC</td>
<td>E S</td>
<td>N/A</td>
<td>19.90%</td>
<td>Yes</td>
<td>27.6</td>
</tr>
<tr>
<td>8</td>
<td>Apartment</td>
<td>5</td>
<td>Concrete block</td>
<td>AC Unit</td>
<td>SW S</td>
<td>Yes</td>
<td>7.90%</td>
<td>23.1</td>
<td>0.4</td>
</tr>
<tr>
<td>9</td>
<td>Apartment</td>
<td>10</td>
<td>Concrete block</td>
<td>Central HVAC</td>
<td>SE S</td>
<td>Yes</td>
<td>11.90%</td>
<td>27.5</td>
<td>-0.1</td>
</tr>
<tr>
<td>10</td>
<td>House</td>
<td>12</td>
<td>Concrete block</td>
<td>AC Unit</td>
<td>NW S</td>
<td>No</td>
<td>31.30%</td>
<td>No</td>
<td>26.8</td>
</tr>
<tr>
<td>11</td>
<td>House</td>
<td>15</td>
<td>Concrete block</td>
<td>AC Unit</td>
<td>SE S</td>
<td>No</td>
<td>31.30%</td>
<td>Yes</td>
<td>28.1</td>
</tr>
<tr>
<td>12</td>
<td>House</td>
<td>22</td>
<td>Concrete block</td>
<td>Central HVAC</td>
<td>SE S</td>
<td>Yes</td>
<td>9.70%</td>
<td>Yes</td>
<td>23.1</td>
</tr>
<tr>
<td>13</td>
<td>Apartment</td>
<td>15</td>
<td>Concrete block</td>
<td>Window AC</td>
<td>SW S</td>
<td>Yes</td>
<td>45.80%</td>
<td>No</td>
<td>26.8</td>
</tr>
<tr>
<td>14</td>
<td>House</td>
<td>28</td>
<td>Concrete block</td>
<td>Window AC and AC Unit</td>
<td>W S</td>
<td>No</td>
<td>48.60%</td>
<td>Yes</td>
<td>31.5</td>
</tr>
<tr>
<td>15</td>
<td>House</td>
<td>27</td>
<td>Concrete block</td>
<td>Window AC and AC Unit</td>
<td>W S</td>
<td>Yes</td>
<td>31.10%</td>
<td>No</td>
<td>28.6</td>
</tr>
</tbody>
</table>

5.1 Orientation

In the extremely hot climate of the Dammam region, southern and mainly western facing windows result in solar gain in the afternoon, evening and at sunset, times of day that coincides with the hottest external temperatures. Overheating of rooms facing south and west builds up gradually from noon onwards. A western/southern orientation was found to be the typically the most uncomfortable one for rooms in Dammam’s homes. In this study, most dwellings appear to have been oriented with little or no consideration of orientation or attention to the solar radiation and the thermal context of the local micro-climate. It is clear in this study that the orientation of the dwelling plays a massive part of the dwelling’s energy consumption. Not surprisingly, two of the highest performing dwellings in this study are oriented with their longer façade facing the North-Northeast, with around 90 kWh/m² energy consumption per annum. However, the seven most energy-intensive dwellings in this study are improperly oriented, with the annual consumption of these homes ranging from 118 kWh/m² to a maximum of 206 kWh/m² per annum.

Proper orientation demonstrably enhances a dwelling’s indoor climate: for well-performing dwellings constraints, as in numbers one and nine, the orientation of the longer façade of the dwellings have a tremendous impact on the mean indoor temperatures and the average daily temperatures of these dwellings was below the neutral temperature found in this study. Properly oriented dwellings with bedroom windows facing between North and East had average daily temperatures of less than 25°C, apart from house number six where the preference of the occupant was to occupy warmer conditions. On the other hand, when a dwelling was improperly oriented, with its bedroom windows facing west, as in cases thirteen and fifteen, the indoor temperatures exceeded the neutral temperature by at least 3K.
5.2 Internal Space Arrangement

The internal layout and room arrangements is fundamentally affect the heat distribution within the spaces in the home. As the western façade is likely to receive maximum radiation at the hottest time of day, and in turn all spaces adjoining this façade will experience the maximum heat gain. A good example was found in dwelling number nine uses the buffer space adequately, with a reasonable internal layout. The closed hall space in the outdoor entrance buffers the guest room and the living room, and the location of the least used guest room to the south, leaving all the main bedrooms to the north, which has worked perfectly. Placing the lounge in the buffered middle of this apartment reduced discomfort, as it limited the heat gain to the most used room. However, the deliberate use of thermal buffering spaces was found in this study to be limited and, in fact, in some cases they were misused. Dwelling thirteen, for instance, has a massive entrance into the guest area oriented to the north, while the main bedroom lying to the west with a mean internal temperature in the evening in this room above 30°C.

A closer study of the design and room arrangements shows that there are a lot of wasted areas in most homes. It is clear that people have little understanding of the thermal and energy implications of room location and zoning. People lend more weight to the value of ‘making a show’ in front of their guests, rather than valuing their own comfort, wellbeing and energy economy in their own homes. In most of the dwellings in the current study, the majlis, or guest reception room, was hardly used throughout the year but its size and location significantly affected the internal layout and orientation of the rooms in the home, being treated as a priority to be displayed prominently to guests. In dwellings number eight and thirteen, the guest sections take up the best location in the houses, oriented to the north, and bedrooms were then oriented to the west and south, significantly increasing energy needed for cooling load those occupied rooms of the dwelling.

5.3 Opening Choices and Solar Access

In considering the orientation of the dwelling, the issue with most climatic impact is the orientation of the glazed openings. Most of contemporary dwellings in the Dammam region seem to be designed with large window openings and with relatively little attention given to the local climate. In fact, in some cases, a window was placed in every possible wall inside the rooms, which may prove to be completely unnecessary.

Windows typically have a higher conductance coefficient than the rest of the building envelope. Therefore, dwellings with a high glazing ratio have greater heat gain, compared to similar homes with a lower glazing ratio. Solar gain through large windows in summer can elevate a dwelling’s indoor temperature well above the outdoor day or night temperature levels and thus cause intolerable conditions indoors and significant thermal stress, consequently increasing the building’s cooling load to compensate for this poor design. In house number fifteen, for example, where the glazing ratio is around 49% of the façades area, the indoor temperature been found usually close to or sometimes higher than the outdoor temperature. There appears in this study to be a clear relationship between the amount of the window opening to wall ratio and energy consumption. The larger the window area is in the façade, the more intense the energy demand for cooling is in the dwellings. For instance, as the size of windows in homes one, five, six, nine, twelve and sixteen is very reasonable, that less than 20% of the façades area, the consumption was 90 - 108 kWh/m² per annum, being the lowest average consumption of all studied homes. Whereas in dwellings three, eight, eleven and fifteen where the ratio of window to façade
wall area ranges between 31% to 49%, the energy consumption ranges between 125 and 206 kWh/m² per annum. Therefore, as one intuitively suspects, the homes with smaller areas of fenestration that are also well oriented, provide much better protection against heat gain during the day.

5.4 Daylight and Shading

It has commonly been assumed that daylight as a natural source of light can be used for the satisfactory illumination of rooms during the day. However, due to the adverse hot conditions from the intense internal heat and intolerable visual glare experienced in Dammam, adaptable shading used at different times of day and year is vital. The current study, however, found that the occupants do not use external fenestration shading at all and rely solely on internal blinds and curtains to just screen the internal glare.

Although not used in the most of the case study homes, trees to the eastern and western sides of the house could create a cooler environment around the dwelling as an alternative shading strategy for the home. Although all homes in Saudi Arabia are surrounded by setback spaces behind walls, creating front, side, and rear yards, it appears that people do not have an interest in planting vegetation around their dwellings to provide shade. The occupant of dwelling number six, however, was very pleased with the planting and pergola he had completed in his house's yard and was very satisfied with the resulting outside environment. Therefore, with the right kind of soil and plants, and perhaps more importantly, with a sustainability-oriented user attitude, it is possible to grow plants properly for adequate passive shading of façades, potentially using grey water from the numerous showers often taken to do so.

5.5 Cooling and Ventilation Strategies

Installing, operating and maintaining an efficient AC system is considered to be more expensive, possibly prohibiting users from adopting optimal solutions. In house number thirteen, with the highest home energy consumption per square metre, an enormous amount, in Saudi terms, was paid for energy of £3.85/m² per annum. The occupant stated that they also spent an excessive amount of money maintaining the AC equipment, of around £400 every six months without the cost of failing parts, due to the fact of it being an inefficient type of AC system, set also in a poor house design. In dwellings number nine and one, the energy costs, for example, are £1.14 and £1.10 per annum, respectively. Taking into account the fact that these dwellings have among the top performance envelopes, these particular two homes also have efficient cooling systems that are periodically maintained with a maintenance contract of around £400 per annum without the cost of failing parts. Accordingly, it is likely that the very cheap operational cost is a result of an efficient AC system in a more highly-performing home.

Sleeping discomfort is a significant issue, exacerbated by high humidity, especially in homes like six and twelve with high indoor temperatures. Standard ceiling fans, however, can create a comfortable environment when temperature and relative humidity levels are high but within acceptable ranges. In house number six, for instance, the occupants were shutting down the air-conditioners for around 20 to 45 minutes every two hours in the day time, even when the indoor temperatures exceeded 29°C and operating the ceiling fan. This house, with its active occupants, was subsequently able to achieve the highest performance and least energy demand per square metre among the studied homes. Whereas in dwelling fifteen, that without ceiling fan, 85% of the sensation votes during bedtime were warm and hot sensation votes preferring much more cooling as the indoor temperature never goes as
low as 28°C until 2am.

The number of operating hours / days required to achieve thermal comfort can be substantially reduced by careful design of homes. It has been found that the air-conditioning in a poorly-designed dwelling (cases eight, eleven, thirteen and fifteen) with an inefficient AC system remains in operation for around nine months through the year, three more months of operating the air-conditioning than in well-designed dwellings. Furthermore, the operation of fans may reduce the number of months of operating the AC system at night, when the outdoor temperature is tolerable with adequate air movement, like in homes numbers six, seven and twelve, the operation of the AC system is limited to six months through the year. Therefore, it is favourable to install fans in bedrooms and all living areas, which would significantly reduce the use of the cooling systems.

5.6 Energy Efficient Construction

Contemporary construction of residential buildings throughout Saudi Arabia is typically with reinforced concrete systems. Various types of concrete products are employed including concrete blocks, floor tiles and precast concrete. Walls in Dammam were found to be constructed with concrete brick of 20 to 25 cm thickness, with very high conductivity and insufficient thermal resistance. Insulating the mass externally, which would significantly improve performance, is seldom done in Saudi Arabia. Most well-performing homes had an external wall thickness of 30cm, whereas almost badly-performing homes had an external wall thickness of 25cm or less, including the insulation, if available. Moreover, most of the studied Dammam's homes seemed to be constructed without benefiting from the available passive summer cooling so they act as a hot bridge rather than a coolth store. Dwellings built fifteen years or more ago had no insulation, except those with high income owners who could build their dwelling to a higher standard. Dwellings without insulation in this study consumed 125kWh/m2 up to 206kWh/m2 whereas all the better-behaved homes had insulation installed.

6 Conclusion

This study has shown that people in the selected homes in Dammam occupied mean indoor air temperatures widely ranging between 20°C to 35°C. The thermal sensation votes reported demonstrated that people largely adapted to be more or less comfortable in the temperatures they occupied. A survey of occupant’s behaviours showed that adaptation was achieved through a range of attitudinal adjustments, behaviours and actions including the use of fans and AC systems and the opening of internal doors and to a lesser extent in summer, windows at different times of day and year.

Perhaps the most useful finding of the work is the extent to which the physical design and construction of the building itself is instrumental in determining the comfort and quality of life of the occupants of the homes. In most cases, the existence of well-oriented, high performance envelopes and internal thermal buffer spaces result in lower energy running costs and higher reported comfort levels. Buffering of living areas from the worst extremes of this often very hot climate was shown to improve comfort levels experienced in the homes. In some cases, the occupant’s comfort was compromised by the desire to provide impressive guest facilities in homes. Good client briefing on design priorities and their impact on comfort and energy use is needed and the benefits of, for instance, smaller and fewer windows and good orientation promoted. Modification of the external environment of a home by creating an external thermal buffer zone, for example the shading of outdoor areas and walls of a home with trees, showed a positive effect on the energy consumption
in the adjacent home. The highest performing homes had higher levels of insulation. Although the energy consumption in the dwellings was not clearly linked to the indoor temperature experienced in them, occupants who pay less per annum were more satisfied with the thermal comfort experienced. Comprehension of what creates and enables comfort to be experienced in the studied dwellings is undeniably a complex phenomenon. While clear connections between the physical condition of the buildings and their services and the indoor thermal environment are evident, however attitudes, social contexts and associated behaviours appear to be leading factors in the recorded occupied temperatures in these homes, and in turn to the everyday comfort, and discomfort, experienced in them.

References