Thermal Comfort Requirements in Iranian Hospitals

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SUMMARY

This paper presents the results of a study to determine the thermal comfort requirements of the occupants in Iranian hospitals. It arrives at its conclusions through consideration of the wide range of metabolic rates and clothing levels experienced by the occupants. The study includes both patients and staff, and only considers patient recovery wards as these are where the greatest range of thermal comfort needs will normally be found. This study uses ISO 7730 as its basis, with reference also to ASHRAE 55 and CIBSE. The main conclusion from this study is that while the occupants of Iranian hospitals can require widely varying thermal conditions to achieve thermal comfort, it is possible to reconcile these different needs.

INTRODUCTION

The term comfort is associated with human health – defined not just as the absence of disease but in terms of a total sense of physical, mental and social well-being [1]. Comparing the comfort levels of sedentary people at home, at work and in a climate chamber, shows that being ‘at home’, in a familiar and under control environment, leads to comfort and makes people less sensitive to temperature [2].

There are two main approaches in thermal comfort standards: The laboratory based method, e.g. Fanger’s PMV-PPD model [3] and the field study method, e.g. the Adaptive Comfort Standard or ACS are the main approaches to thermal comfort researches.

In 1970 through his own equation, Fanger argued that knowledge of thermal comfort conditions was inadequate for environmental engineers involved in the specification of heating, cooling or ventilation technologies and indoor climates [3]. The Predicted Mean Vote (PMV) developed by Fanger provides a method by which the quality of indoor environments can be rated in practice and the degree of occupant discomfort assessed. The presented model by Fanger being used to define the combined conditions (i.e. air temperature, mean radiant temperature, relative air velocity and humidity level) in which the highest proportion of people are likely to be comfortable, for any specified level of activity and clothing [3]. Some international thermal standards such as ISO 7730 [4], still are using the Fanger’s model as the main framework their publication.

Against the laboratory model, other researches aim to account for variations in thermal comfort conditions and perceptions within buildings. Field studies challenge the validity of relatively fixed concepts of thermal comfort, such as those based on heat-balance equations. These results have led some researchers to develop more adaptive models that account for multivariate and dynamic human experiences in the real world [5].
studies on the comfort of people in their natural habitats has been done on factory workers in the 1930s by Humphreys and Nicol [6].

Some of adaptively approaches field studies recorded significant differences between comfort values based on Fanger’s predicted mean vote (PMV) and actual perceptions of comfort in office environments [7], [8]. Differences in the thermal sensation votes recorded of the same group of people -with the same clothing and activity levels [2]. Also Humphreys [9] argues that people are not inert recipients of the environment, but interact with it to optimize their own conditions. The objective for thermal comfort researchers is thus to observe the daily routines, practices and habits of occupants of building to see how they modify and adjust their environments to achieve comfort [9]. Both of laboratory and adaptive methods are represented in the latest edition of ASHRAE’s thermal comfort standard [10].

Reviews on the adaptive models show that these models notice wider bands of temperature where the occupants may still sense the comfort zones, but the adaptive models of thermal comfort are more relative to free running systems buildings. Also being in the ‘comfort zone’ is represented as a threat to worker productivity and organizational efficiency[11], [12]. And, comparison between the static model (PMV) with the adaptive models in thermal comfort show that the PMV model is more accurate in building with HVAC systems and the adaptive models are more relative to buildings with natural ventilation [13]. On the other hand the Iranian regulations for healthcare buildings recommend the air conditioning systems for healthcare buildings, regarding to the hygiene problems and the type of activity and the occupants of these buildings. Based on this argument, this study selected the laboratory method (PMV), to predict the required thermal conditions by the occupants of these buildings.

For the standards used, ASHRAE, CIBSE and Iranian standards indicate the indoor air temperature and relative humidity ranges for thermal comfort achievement. ISO7730 indicates a range for Predicted Mean Vote (PMV) or Predicted Percentage Dissatisfied (PPD) to achieve thermal comfort based on the six variables which define PMV or PPD: air temperature, relative humidity, radiant temperature, clothing and activity levels, and the air velocity [14].

Due to different levels of clothing and activity in patients and hospital staff, these groups require different conditions to achieve thermal comfort [15]. The thermal conditions required to produce thermal comfort are further complicated by the fact that patients with different complaints may be located in the same wards, also a majority of the hospitals’ staff always may stay for a while in the thermal conditions provided in patients’ rooms, due to their activities; so to achieve the best balance of comfort it is necessary to first establish the conditions needed to achieve thermal comfort for patients and staff in hospital.

This paper presents the findings of an investigation undertaken to ascertain:

- those conditions required for thermal comfort by patients and staff of Iranian hospitals
- Potential solutions to improve thermal comfort achievement in these buildings

The study focuses on the Iranian hospital wards and mainly on the patients’ rooms.

**METHOD AND ANALYSES**

Although generally, all the standards referred to for assessing thermal comfort require the measurement of relative humidity and air temperature but the calculation for ISO7730 also
requires clothing and activity levels to be observed and radiant temperature and air velocity to be estimated [16]. Table 1 presents the relevant thermal comfort ranges from the standards.

<table>
<thead>
<tr>
<th>Standard</th>
<th>Recommended thermal condition to achieve thermal comfort</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASHRAE</td>
<td>23 °C&lt;Temp&lt;26 °C and 30%&lt;Rh&lt;60</td>
</tr>
<tr>
<td>ISO 7730</td>
<td>-0.5&lt;PMV&lt;+0.5, PPD&lt;10% and 30%&lt;Rh&lt;60</td>
</tr>
<tr>
<td>CIBSE</td>
<td>22 °C &lt;Temp&lt;24 °C and 30%&lt;Rh&lt;60</td>
</tr>
<tr>
<td>Iranian Regulation</td>
<td>24 °C &lt;Temp&lt;28 °C and 30%&lt;Rh&lt;60</td>
</tr>
</tbody>
</table>

Buildings observation and site visiting have been done in this study to specify the types of occupants and their personal factors including the levels of activity and clothing. This study noticed low levels of activity for patients due to the physical conditions of their bodies. In terms of staff activities the study assumed an average of activities of those staff that are in direct relation with the indoor environment conditions of patients’ rooms.

This study beside the environmental and job protocols, noticed high effects of cultural motives on both groups of occupants - particularly the staff - in terms of clothing in Iranian hospitals. This study assumes that the mixture of clothing types for patients without a blanket cover gives a 0.49 clo, for patients with cover 1.39 clo, and for staff 0.88 clo. This study assumes that the average activity rate for patients is 0.82 met, and for staff is 1.50 met.

The analysis in this study has been undertaken to determine the required thermal conditions in Iranian hospitals. From table 1, ASHRAE, CIBSE [17], and the Iranian regulation[18] indicate just the ranges of air temperature and relative humidity likely to achieve thermal comfort. However we know that the different user groups in hospitals are likely to have quite different temperature and RH requirements to achieve thermal comfort. These differences arise due to the variation in activity and clothing levels between more sedentary Patients who may use blankets to increase their insulation levels, Patients who are not able to use heavy clothing such as blankets because of their medical conditions, and Staff who generally have higher levels of activity.

The first issue to address for a study such as this is whether it is possible to find a range of thermal conditions that are suitable for these hospital users. This study uses the PPD calculation from ISO 7730 as the basis for assessing the different ranges of temperature and RH within which Patients and Staff in Iranian hospitals might achieve thermal comfort for the activity and clothing levels stated above. The study assumes 10 %PPD is an acceptable level [4].

The calculations show that, in theory, by varying the RH and air velocities within reasonably achievable values, that the Air Temperatures needed to achieve thermal comfort conditions for Iranian hospital Staff could be in a range between 19°C to 26°C; that the range for Patients with blanket could be in a range between 22.5°C to 28°C; and that for Patients without blanket the range could be between 27°C to 31.5°C.

Figure 1 represents the practical Air Temperature ranges that need to be achieved for each occupant type. We can see therefore that there is NO easily achievable overlap in acceptable Air Temperature ranges between Staff requirements and the requirements of Patients without blankets. The Patients with blankets are capable of being comfortable in a range of air Temperatures that straddle those for both Staff and Patients without blankets. Figure 1
presents, in graphical form, part of the results of the study where we assessed the variation of PPD with Air Temperature, when the air velocities were varied in a range between 0.1 m/s to 5m/s at a constant 40% Relative Humidity.

![Graph of PPD for staff in hospital with %40 Rh in different air velocities](image1)

![Graph of PPD for Patient with blanket in hospital with %40 Rh in different air velocities](image2)

![Graph of PPD for Patient without blanket in hospital with %40 Rh in different air velocities](image3)

Figure 1: PPD achievements for all users in Iranian hospitals at 40% Relative Humidity with different air velocities.

The study shows that, as expected, higher air velocities extends the upper limit for the temperature range within which occupants can feel comfortable, while lower velocities extend the lower limit for comfortable temperatures. However there appears to be no combination of Air Temperature and Air Velocity which satisfies the comfort requirement of a PPD of less than 10% for both Staff and Patients without blankets. In fact, even if Staff experience a 5m/s
air velocity at the same time as Patients with blankets experience an air velocity of <0.1 m/s we see that it is still not possible to achieve an acceptable common Air Temperature that will provide a PPD of less than 10%.

Assuming that Activity and Clothing Insulation levels are not able to be altered due to work and cultural reasons, the only other option left to try to achieve comfort is that of varying the mean radiant temperature experienced in the space by the different users. This could physically take the form of cooler or warmer floors, walls and ceilings in some areas depending on the predominant occupant of that area. Table 2 presents the results of a theoretical study where we assessed the variation of PPD with radiant temperature, when the air temperatures were varied in range between 20 ºC to 28 ºC at a constant 30% to 60% relative humidity and 0.1 m/s to 0.5 m/s air velocity.

Table 2: Maximum radiant temperature ranges for hospital users in Iran
(All users assumed to be in conditions of: air temperature from 20ºC to 28ºC, air velocity from 0.1 m/s to 0.5 m/s, and relative humidity from 30% to 60%)

<table>
<thead>
<tr>
<th>Users</th>
<th>Maximum radiant temperature range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients with blanket</td>
<td>12.3 ºC to 43.3 ºC</td>
</tr>
<tr>
<td>Patients without blanket</td>
<td>25.6 ºC to 50.5 ºC</td>
</tr>
<tr>
<td>Staff</td>
<td>-4.7 ºC to 35 ºC</td>
</tr>
</tbody>
</table>

The study shows, that to some extent, higher air temperature ranges can be offset by lower radiant temperature ranges within which all occupants can feel comfortable. It appears that theoretically a range of air temperatures between 20 ºC to 28 ºC can achieve the thermal comfort requirements of staff and patients (with and without blankets) if we were able to separately provide the appropriate radiant temperature for each category of occupant.

However, it is not practical to design spaces to achieve these large radiant temperature requirements. So the next part of the study explores what is more practically achievable. Referring to ISO 7730, the PMV and PPD express warm and cold discomfort for the body as a whole. But thermal dissatisfaction can also be caused by unwanted cooling or heating of one particular part of the body. This is known as local discomfort. The most common cause of local discomfort is draught. Local discomfort can also be caused by an abnormally high vertical temperature difference between the head and ankles, by too warm or too cool a floor, or by too high a radiant temperature asymmetry.

Figure 2 shows the percentage dissatisfied as a function of the floor temperature [4]. It is mainly people undertaking light sedentary activity who are sensitive to local discomfort. These will have a thermal sensation for the whole body close to neutral. At higher levels of activity, people are less thermally sensitive and consequently the risk of local discomfort is lower. This means therefore that the Patients will be more sensitive to radiant heating or cooling than the Staff.
For horizontal radiant asymmetry, Figure 3 applies from side-to-side (left/right or right/left) asymmetry, the curves providing a conservative estimate of the discomfort: no other positions of body in relation to the surfaces cause higher asymmetry discomfort [4].

This figure shows that achieving the required radiant temperature via warm walls is likely to be the best way to attain thermal comfort when the air temperature is too cool. When the air temperature is too warm, thermal comfort is best achieved by using a cool ceiling. When reviewing the foregoing work with regard to the activity, clothing levels and physical locations of staff and patients in hospitals, it can therefore be concluded that it might be possible to achieve thermal comfort for both staff and patients (both with and without blanket) by:

- Providing the additional cooling needed for the Staff via the floor (as this is the surface least visible to the patients)
- By providing the additional radiant heating needed by patients via, ideally warm vertical surfaces, but failing these warm ceilings.

Based on the study shown in Table 2 and the recommendations from ISO 7730 regarding local thermal discomfort (Figure 2 and Figure 3), in condition which the three referred groups
of users are placed in separated rooms, the new thermal ranges within which comfort can be achieved for each of the three user groups in Iranian hospitals are as follows:

- **Staff**: air temperature from 20 °C to 22 °C and radiant temperature from 10.9 °C to 29.3 °C  
- **Patient with blanket**: air temperature from 22 °C to 24 °C and radiant temperature from 20.6 °C to 34.2 °C  
- **Patient without blanket**: air temperature from 26 °C to 28 °C and radiant temperature from 25.6 °C to 35.3 °C

Also by using different directional radiant temperatures (cooling via floor for staff and heating via ceiling for patients), there is now an overlap in the required air temperature to achieve comfort for staff and patients (with and without blanket) from 24 °C to 26 °C. By fixing the air temperature from 24 °C to 26 °C, and by using the air velocity from 0.1 m/s to 0.19 m/s for all users [4], the following radiant temperatures are required for thermal comfort achievement in Iranian hospitals.

- **Staff**: directional radiant temperature from the floor from 4.2 °C to 23.7 °C  
- **Patient with blanket**: directional radiant temperature from the ceiling from 17.9 °C to 31.6 °C  
- **Patient without blanket**: directional radiant temperature from the ceiling from 27.8 °C to 37.8 °C

But using directional radiant cooling will drop the temperature to or below dew point in the sources which is used for radiant cooling, then surface condensation will happen [19]. Also forming water in building will lead to mould growth. To minimize the surface condensation in directional radiant cooling, it is necessary to obtain low vapour pressure by ventilation and/or reduced moisture input to the buildings.

The dew point is associated with the relative humidity. A high relative humidity indicates that the dew point is closer to the current air temperature. As the relative humidity reaches 100%, the dew point will be equal to the current temperature. Given constant dew point, when the temperature increases the relative humidity will decrease. It is for this reason that equatorial climates can have low relative humidity yet still feel uncomfortable.

Following equation calculates the dew point in degrees Celsius to within ±0.4 °C. It is valid for:

\[
0 \, ^\circ C < T < 100 \, ^\circ C  \\
0.01 < RH < 1.0  \\
0 \, ^\circ C < Td < 50 \, ^\circ C
\]

Where:

- \( T \): Temperature in degrees Celsius [°C]  
- \( RH \): Measured relative humidity as a fraction (not percent)  
- \( Td \): Calculated dew point temperature [°C]

The dew point temperature is:

\[
Td = \frac{b \times \alpha(T, RH)}{a - \alpha(T, RH)} \quad (1)
\]

Where

\[
\alpha(T, RH) = \frac{a \times T}{b + T} + \ln(RH)
\]

With \( a = 17.27 \)  
And \( b = 237.7 \) [°C]

The uncertainty in the calculated dew point temperature is ±0.4 °C.
Based on the equation {1} and the highest risk of dew point in this research (26 °C for dry temperature and 60% for relative humidity), the dew point is 17.5°C. So this research recommends the presented value in Table 3 for Iranian hospital users for thermal comfort achieve.

Table 3: Recommendations from this study- Acceptable parameter ranges for achieving thermal comfort in Iranian hospitals for different occupant types

<table>
<thead>
<tr>
<th>Users</th>
<th>Air Tem. °C</th>
<th>RH %</th>
<th>Air Velocity m/s</th>
<th>Radiant Tem. °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Staff</td>
<td>24 - 26</td>
<td>30 - 60</td>
<td>0.1 – 0.19</td>
<td>17.5 – 23.7</td>
</tr>
<tr>
<td>Patient with blanket</td>
<td>24 - 26</td>
<td>30 - 60</td>
<td>0.1 – 0.19</td>
<td>17.9 – 31.6</td>
</tr>
<tr>
<td>Patient without blanket</td>
<td>24 - 26</td>
<td>30 - 60</td>
<td>0.1 – 0.19</td>
<td>27.8 – 37.8</td>
</tr>
</tbody>
</table>

DISCUSSION

The different user groups of the hospital had thermal comfort requirements that were difficult to accommodate in one space. Therefore the best solution would appear to be to provide different thermal zones for different user groups in hospitals. In particular, it appears that staff should be provided with work areas in the wards that are controlled to very different conditions to the general wards.

In same indoor thermal condition, operating different radiance temperature for different users in Iranian hospitals, can reconcile their different thermal comfort achievement requirements.

REFERENCES