Overheating and health risks in refugee shelters: assessment and relative importance of design parameters

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Abstract: There are now more than four million refugees living in camps around the world. The majority of such camps are within inhospitable environments, often with extreme climates. This paper focuses on the thermal conditions of shelters in the Azraq refugee camp (Jordan), subject to an arid climate with high temperatures during the hot season. Due to political and other sensitivities, whole-, or multi-year monitoring of occupied shelters—and hence the empirical determination of overheating—is difficult. Instead, internal conditions in the shelters were monitored for three weeks in summer and used to validate computer models of the accommodation. These models were then used to generate annual predictions of overheating assessed through overheating criteria based on thermal discomfort and physiological indicators of heat stress. Building on these results, the performance of alternative designs specifications or shelter operation strategies were investigated through parametric analysis. The results show maximum indoor temperatures over 45°C. Overheating thresholds were exceeded for more than 20% of the year and physiological indicators suggest the possibility of health-threatening conditions. The use of alternative designs and strategies reduced overheating to nearly 2% of the year, with a steep reduction of severe heat stress indicators.

Keywords: refugees, shelters, overheating, health risk, thermal comfort

Introduction: The current number of forcibly displaced population in the world is among the highest on records of which a third, 20 million, are refugees (UNHCR 2017). The refugees from the Syrian Arab Republic alone represent 23% of the total refugee population with 4.9 million people. As part of the response to this crisis, they are often hosted in camps in neighbouring countries such as Turkey, Lebanon and Jordan. Given the location of camps and the severe conditions experienced in Jordan’s climate, this paper investigates overheating discomfort and potential heat stress risk of refugees in these circumstances.

The thermal performance of shelters, and the indoor conditions they deliver, is a subject with a limited number of studies. One of the key concerns is the actual provision of a shelter as a humanitarian response. This constitutes a challenging task of paramount importance as it needs to deliver rapidly a scalable housing solution to an unexpected crisis of unknown duration. Among the few studies that focused on the thermal performance of shelters, there has been a greater number of studies dealing with cold environments (e.g. Crawford et al. (2005)) than hot ones (e.g. Cornaro et al. (2015)). This results in an underdeveloped area of research considering the number of people involved and the potential risks associated, especially for vulnerable occupants as children, one of the major refugee groups worldwide.
Consequently, this study evaluates the overheating risk in the Azraq refugee camp in Jordan (31.90°N, 36.57°E). Firstly, the application of different overheating metrics for discomfort and heat stress in the built environment is explored. Then, previous metrics are applied in the Azraq context to evaluate whether refugees are exposed to excessively hot indoor conditions regarding discomfort and heat stress. Lastly, the potential of passive strategies to reduce excursions from neutrality conditions to inform potential design improvements to current shelters is quantified. To accomplish these goals, the following hypotheses are established:

1. Refugees in considered shelters are exposed to indoor conditions outside the acceptable range established in the ASHRAE Std. 55 (2016).
2. Refugees in considered shelters are exposed to indoor conditions outside the recommended ranges for heat stress in the Pierce 2-node and Predicted Heat Stress (PHS) physiological models.
3. Current shelters cannot be optimized to avoid overheating discomfort through the passive measures considered.
4. Current shelters can be optimized to avoid severe heat stress through the passive measures considered.

**Methodology**

The study focuses on the Azraq refugee camp because of its exposure to the ‘hot desert climate’ (Köppen-Geiger zone BWh) and because it is based on a well-defined shelter design (figs. 1 and 2). As of April 2017, the camp hosts 53,914 refugees, of whom 57% are under 18 years old. Due to security concerns —among other considerations—, the structure of the camp and the arrangement of shelters cannot be modified. Owing to these considerations, the study was conducted in two phases. The first is a three-week field study, during which surveys and spot measurements of environmental conditions were collected. The second extrapolates annual overheating conditions via building and human thermal simulations.

**Field study**

The field study was carried out from 31st August to 23rd September 2016. Here, randomly selected families completed a thermal and a social survey (n=36). The thermal survey included ASHRAE Std. 55 (2016) guidelines whereas the social one focused on factors such as perceived security, privacy or adaptation opportunities. Shelter units were documented ‘as built’ to track any discrepancies between the original specification and their actual conditions (e.g. shading devices, openings, insulation location, actual occupation...).
**Simulation**

The data collected during the field study was used to calibrate and validate the base shelter simulation. The model is based on the design specification (UNHCR 2016), where the findings of the social survey and shelter inspections completed missing information (e.g. occupancy pattern) or overrode contradictory ones (e.g. as built thermal insulation condition).

The spot measurements of different shelters were combined into a single time series and split into two groups, one to calibrate the model and another one to validate it. Uncertainties regarding model inputs were constrained to the following variables: infiltration (unknown; bounds estimated following construction details), ventilation effectiveness (unknown; e.g. surroundings influence on wind speed or discharge coefficients), occupation (variable between shelters) and U-value (bounded range of conductivity and thickness). A set of 72 simulations were used to calibrate these parameters and then validated with the remaining monitored data (fig. 3, EnergyPlus 8.6). The goodness of fit was evaluated through the peak and mean dissimilarity and the root mean square indicators (2.38, 0.36 and 1.47K, respectively). Given the between-shelter variability and the uncertainties in parameters such as ventilation and infiltration, these results were regarded as adequate for the purposes of this study.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cases</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation [cm]</td>
<td>[1, 5, 10, 15]</td>
<td>Conductivity: 0.04 [W·m⁻²·K⁻¹].</td>
</tr>
<tr>
<td>Thermal mass [-]</td>
<td>[light, heavy]</td>
<td>Light: current shelter composition.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heavy: 215mm perforated brick and plaster.</td>
</tr>
<tr>
<td>Thermal mass location [-]</td>
<td>[internal, external]</td>
<td>Relative position to the indoor space.</td>
</tr>
<tr>
<td>Occupancy [p]</td>
<td>[6, 12]</td>
<td>Original shelter design aims for 6p and surveyed occupation frequently reached 12p.</td>
</tr>
<tr>
<td>Shading [-]</td>
<td>[none, full]</td>
<td>None: current solar exposure (see fig. 1). Full: completely block solar radiation.</td>
</tr>
<tr>
<td>Ventilation strategy [-]</td>
<td>[daytime, always]</td>
<td>Daytime: as needed during 07-23h. Always: as needed (constant occupation).</td>
</tr>
<tr>
<td>Infiltration [-]</td>
<td>[original, reduced]</td>
<td>Original: current shelter estimated infiltration. Reduced: 25% of the previous value.</td>
</tr>
<tr>
<td>Opening effectiveness [%]</td>
<td>[10, 40, 70]</td>
<td>Multiplicative factor for opening areas. 10% is the fitted value in the calibration and 70% a value around illustrative reference levels (ASHRAE 2013).</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3,072 models</strong></td>
<td>Every parameter-case combination.</td>
</tr>
</tbody>
</table>

The validated model was then used to extrapolate annual overheating performance. Given the limitations to monitor typical external conditions throughout the year in this location, the weather files for surrounding ones were used to derive plausible ranges (Guriat (Saudi Arabia), Queen Alia International Airport (Jordan) and Safawi (Jordan)).

In addition, the validated model forms the basis from which to explore design alternatives and shelter operation strategies (table 1):

- ‘Orientation’ and ‘Shading’ focus on a different arrangement of shelter units that alters their solar heat gains globally.
- ‘Insulation thickness’, ‘Thermal mass’, ‘Thermal mass location’, ‘Infiltration’ and ‘Opening effectiveness’ address different design specifications. In the case of
thermal mass, the baseline is the original lightweight construction (IBR sandwich panel with 15mm insulation). The alternative is a heavyweight envelope with a decrement delay\(^1\) of 12h which aims to take advantage of the diurnal swing in desert climates.

‘Occupancy’ and ‘Ventilation strategy’ assume the same building characteristics but with different occupancy densities or operation modes. A minimum ventilation of 8l·s\(^{-1}\)·p\(^{-1}\) is considered despite the purge ventilation strategy.

**Human thermal models**

Refugees do not have access to electricity and the main cooling strategy at building level is natural ventilation. The social survey highlighted that coping mechanisms against heat were mainly to shower, to pour water onto themselves with their clothes on and to spray water on the floor. Other parameters such as clothing were adjusted within certain ranges (average summertime clothing insulation between 0.50±0.07clo (M) and 0.93±0.05clo (F)).

Annual overheating is first evaluated via the adaptive comfort model according to ASHRAE Std. 55 2013 (ANSI/ASHRAE 2016), calculating the running mean as the exponential moving average of outdoor temperature, \(T_{\text{rm}}(\alpha=0.8)\). Discomfort is evaluated through the temperature difference between the internal operative temperature and the adaptive comfort upper limit \((T_{\text{lim}} = 0.31 \cdot T_{\text{rm}} + 21.3)\). Illustrative limits of discomfort are established at 1% and 3% of the annual occupied time since the ASHRAE model does not suggest one. These values are on the lines of European recommendations (BSI 2007; CIBSE 2013) for temperature differences greater than 1K over the adaptive comfort upper limit.

Heat stress is evaluated through two rational thermal physiological models:

1. **Pierce 2-node model**: This is the updated version of the Pierce 2-node model (Gagge et al. 1971; Fountain & Huizenga 1997). It considers air and radiant temperatures, relative humidity, activity level, work efficiency, clothing and air velocity. The ‘discomfort index’ (DISC) is used to report heat strain as this index normalizes the effect of the inputs on the thermoregulatory system in a 7-point scale (-3 severe cold strain, 0 neutrality, +3 severe heat strain).

2. **Predicted Heat Strain (PHS)**: ISO standard method (BSI 2004) to evaluate heat strain through required sweating and changes in the deep body temperatures presented by Malchaire et al. (2001).

The Pierce 2-node and the PHS models present technical barriers for their adoption in building simulation studies. Although the first is included in EnergyPlus, the user must introduce time-varying values for air speed and certain assumptions cannot be adjusted. The PHS is not part of building simulation suites and its implementation is computationally intensive for annual studies in large parametric analyses.

To overcome these issues, the models were implemented and validated numerically in a standalone application. For this study, the air speed has been estimated through the time-varying natural ventilation air flow divided by the cross-section of the shelter unit and fed into the calculation of operative temperatures (ASHRAE 2013). Regarding clothing, the aforementioned average of 0.93clo has been considered as a representative value.

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\(^1\) The time difference between external and internal peak temperatures in a 24-hour period.
Results and discussion

Current shelters

The results for extrapolated annual overheating in current shelters under typical weather conditions are presented in figs. 4 (discomfort), 5 (Pierce 2-node) and 6 (PHS). For the first two, severity is reported in the X axis (binned) and duration is reported in the Y axis for the three locations\(^2\). The PHS model follows an independent assessment scheme.

The discomfort evaluation (fig. 4) shows that the adaptive thermal comfort upper limit is surpassed for more than 20% of the time, well beyond the maximum 1% (annual) or 3% (seasonal) illustrative limits. Of special concern is that more than 12% of the time the overheating is severe (\(\Delta T \geq 4\)), a trend that is consistent in the three locations considered.

The heat strain measured via the discomfort index in the Pierce 2-node model (fig. 5) indicates an unacceptable indoor environment from the physiological perspective, with a cumulative average greater than 20%. Unlike the previous, votes follow a diminishing progression towards greater strain. However, durations in the severest bins are well beyond what is deemed appropriate for comfort conditions.

The PHS provides greater insights to evaluate potential health risks. Here, each day of the annual building simulation is considered independent and simulated from 9 to 17h (a best-case scenario since physiological indicators are reset for the following day). Fig. 6 shows the percentage of days where limits for each variable are surpassed. Despite

\(^2\) GU: Guriat (Saudi Arabia), QA: Queen Alia International Airport (Jordan), SA: Safawi (Jordan).

\(^3\) \(T_{re}\): Rectal temperature limit surpassed, \(S_x\): Sweating limit surpassed for \(X\%\) of the population.
occupants were considered adapted to hot conditions and able to drink water as required, the water loss due to sweat is evaluated excessive for 95% of the population for more than a third of the year and greater than 2.5% for the mean subject. A complementary indicator is the change in rectal temperature. Here, the upper limit of 38°C (ΔT=+1.2K) is surpassed in the three locations (=0.28%, one day, for Queen Alia). Therefore, the evaluation indicates that indoor conditions cause both excessive water loss and changes in the deep body temperature in the refugee shelters under typical weather conditions.

Relative importance of design parameters

The main effects for each of the 23 parameter-case in the 3,072 model variants are presented in fig. 7 for discomfort duration and ranges of internal temperatures in fig. 8. Although this is an overview of performance, it is noticeable how 18 out of the 23 parameter-case span the wide minimum–maximum value range (=2.5% and ≈20%, respectively). This indicates that shelters can be greatly optimized to cope with the hot desert climate despite the limited passive strategies considered.

![Figure 7. Overheating discomfort in proposals: main effects (plot indicates minimum, median and maximum (black segments) and variable distribution (shaded area); illustrative overheating thresholds in red: 1% and 3%).](Image)

Of paramount importance are insulation thickness, thermal mass and shading: they have a determining impact no matter the values of remaining variables. Additionally, they constitute robust solutions that do not depend on occupant behaviours. Changing insulation from 1cm to 5cm onwards almost halves the maximum overheating, although 1cm can deliver 3% overheating if care is taken in every other design parameter. The provision of sufficient thermal mass as to achieve a 12h decrement delay proves to be the most effective solution —even for 12-person occupancy (high internal gains)—, whereas the theoretical maximum shading performs similarly to 5cm insulation. Lastly, the fact that external thermal mass scores a minimum of 4% suggest that retrofitting shelter envelopes from the exterior could be an effective overheating countermeasure; notwithstanding, internal thermal mass is preferable.
Table 2. Proposals: best, median and worst cases according to annual overheating discomfort duration.

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Insulation</th>
<th>Thermal mass</th>
<th>Thermal mass location</th>
<th>People [p]</th>
<th>Shading</th>
<th>Ventilation</th>
<th>Opening effec. [%]</th>
<th>Infiltration</th>
<th>g</th>
<th>time [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>East</td>
<td>15</td>
<td>Heavyweight</td>
<td>Internal</td>
<td>6</td>
<td>Full</td>
<td>Always</td>
<td>40</td>
<td>Original</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>South</td>
<td>1</td>
<td>Heavyweight</td>
<td>External</td>
<td>12</td>
<td>None</td>
<td>Daytime</td>
<td>70</td>
<td>Reduced</td>
<td>6.4</td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>1</td>
<td>Lightweight</td>
<td>Internal</td>
<td>12</td>
<td>None</td>
<td>Daytime</td>
<td>10</td>
<td>Reduced</td>
<td>20.3</td>
<td></td>
</tr>
</tbody>
</table>

The best, median and worst cases (table 2) are analysed in the same way as the current shelters. Figure 9 highlights how the best case can diminish overheating duration to 2.2% while avoiding severe overheating ($\Delta T \geq 4K$). The heat strain (fig. 10) features an equivalent reduction in overheating, with the median model avoiding the range $[3, \infty)$. Lastly, excessive water loss due to sweating can be completely avoided for the mean subject or greatly diminished for the 95% population and changes in the deep body temperature can be kept below the recommended threshold in every case throughout the year (fig. 11).

Conclusions

The provision of adequate shelter for refugees is becoming an even more pressing issue than ever before given the increasing number of people involved worldwide. Owing to different humanitarian crises, refugees are often allocated in camps subject to harsh environments that can represent a threat to their health and wellbeing. Therefore, this paper presented the study of indoor thermal conditions in the Azraq refugee camp (Jordan)
to evaluate the annual overheating risk of refugees from a discomfort and health risk perspective. Based on a three-week field study during summertime in the camp, overheating exposure was evaluated through adaptive thermal comfort and physiological models for heat stress. Extrapolated annual conditions via building and human thermal simulation suggest that refugees are subject to overheating for more than 20% of the year, surpassing recommended physiological thresholds for heat stress. Building on the efforts of involved agencies, the study presented a parametric analysis of passive strategies in 3,072 shelter variants. Results indicate that considered measures can reduce overheating to 2.3% of the year, with a drastic reduction in associated heat stress.

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References


