Estimation of heat stress in a biscuit producing factory by using Required Sweat Rate index

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Abstract

Biscuit producing factories are hot and humid because of the ovens and hot processes required. Therefore, workers in this industry are exposed to hot environments and are likely to suffer from thermal strain. The Required Sweat Rate (SW_{req}) index was used to assess heat stress on 31 workers from 4 workshops in Tehran, Iran. The objectives of the study were: assessment of workers’ heat exposure, prediction of thermal strain and recommendation of preventive measures. Data on personal characteristics and workers’ thermal perception were collected by questionnaire. Climatic parameters were measured directly and SW_{req} was calculated. Six workers from two workshops were exposed to excessive heat load. The results of the SW_{req} index were in agreement with workers’ thermal perception. Investigation showed that thermal conditions of the kneader from rusks workshop which had the most severe thermal conditions, might be modified in different ways. Reduction of clothing thermal insulation is a simple low cost/no cost solution to eliminate excessive heat exposure in the current situation.

Keywords: Heat stress, required sweat rate index, biscuit factory, thermal strain

1. Introduction

Heat is a significant and sometimes major environmental problem for many workers in almost all industries that use ovens, dryers, cutting torches or other heat-producing equipment. Heat stress occurs when a worker’s environment, clothing and physical activity interact to produce a tendency for body temperature to rise. The body’s thermoregulatory system then responds in order to increase heat loss. This response can be powerful and effective, but it can also produce a strain on the body which leads to discomfort and eventually to heat illness and even death. It is, therefore, important to assess hot environments to ensure the health and safety of workers.

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In a hot working environment, it is important to ensure that the conditions do not make excessive physiological demands upon the workers. This generally involves making an objective assessment of the heat load in relation to physiologically based criteria. The most fundamental problem in this assessment is the number of factors which contribute to the heat load on the worker. In addition to the climatic factors of ambient temperature, humidity, radiant temperature and air movement, the worker’s clothing and metabolic rate should also be considered in any thorough assessment of heat stress (Morris, 1995).

Heat strain results from the worker’s physiological responses to the imposed heat stress and is influenced by individual characteristics. If the various contributing factors are integrated in the form of a heat stress index, heat stress assessment is easily conducted. A heat stress index is a single number which integrates the effects of the six basic parameters in any human thermal environment such that its value will vary with the thermal strain experienced by the person exposed to a hot environment (Parsons, 1998). So, it forms a link between heat stress and worker strain and enables the latter to be predicted from primary measurements.

Having determined the index value, it is assessed against established criteria. Three types of evaluation criteria are available based on acute health effects, comfort, and performance (Morris, 1995). In an industrial context, the first criterion has been widely recognized and used.

Required Sweat Rate index (SWreq) is a rational heat stress index, which is a result of further theoretical development of Heat Stress Index (HSI) and Index of Thermal Strain (ITS). This index uses an improved heat balance equation to calculate the amount of sweating required to maintain heat balance but, most importantly, also provides a practical method of interpretation of calculations by comparing what is required with what is physiologically possible and acceptable in humans. Extensive laboratory and industrial evaluations of this index led to it being accepted as International Standard ISO 7933 (ISO 7933, 1989). Some researchers believe that the SWreq gives the most reliable prediction of heat strain in industrial conditions (Morris, 1995; Peters, 1995), but some others report that the SWreq has some limitations (Malchaire et al., 1991; Forsthoff et al., 2001; Malchaire et al. 2001; Malchaire et al., 2002).

In the industrial sector, a high rate of heat complaint is reported in the food industry (Malchaire et al., 1990; Meyer and Rapp, 1995). In this group of industries, biscuit producing factories are particularly hot and humid, due to the different kinds of ovens and hot processes used. It is, therefore predicted that workers in this industry are exposed to hot environments and are likely to suffer from thermal strain. Regular assessment of the heat load among the workers in this industry seems essential.

In the present study, the SWreq index was used to assess heat stress in a biscuit factory. The objectives of the study were a) assessment of workers’ heat exposure, b) prediction of likely thermal strain, and c) developing practical and effective preventive measures to reduce heat exposure load in the most severe conditions.
2. Materials and methods

In this study, which was conducted in winter, the typical parameters of the thermal environment, the mean characteristics of the subjects exposed to the working situation and duration of exposure were measured. In total, 31 male workers doing different jobs in 4 workshops participated in this study. Based on time study and observation, the number of work sequences and the duration of each sequence were determined for each worker. In each sequence, climatic parameters were measured.

The SW\textsubscript{req} computer program in BASIC was applied to calculate the SW\textsubscript{req} index in each sequence of work (ISO 7933, 1989). The program allows calculation of the SW\textsubscript{req} and DLE (duration limited exposure) for any sequence or combination of sequences. In all, the program requires 11 parameters as input. These parameters and the methods of their measurements in the present study are described below.

1. Duration of the sequence: thorough observation of the workers’ jobs and time study during the whole working shift.
2. Air temperature (t\textsubscript{a}) was measured with a mercury thermometer 110cm above the floor. All thermometers were calibrated before use.
3. Globe temperature (t\textsubscript{g}) was measured with a standard globe thermometer 110cm above the floor.
4. Wet bulb temperature (t\textsubscript{wb}) was measured using Asman hygrometer.
5. Air velocity (v\textsubscript{a}) was measured using a standard kata thermometer (F=559 and cooling range mean=36.5°C), then calculated using related equations.
6. Metabolic rate (M) was estimated using the classification table given in ISO 7243 (1989).
7. External work (w). In most industrial situations, this is small and can be neglected (ISO 7933, 1989). In this study, external work value was set to zero.
8. Mean radiant temperature (t\textsubscript{r}) was calculated by the computer program based on the following formula:
   
   \[
   t_r = \frac{((t_g + 273) / 100)^4 + z \cdot P0}{0.25 \times 100} - 273
   \]
   
   Where: \( z = 0.4 \cdot t_a ^ 0.25, P0 = t_g - t_a \)  
   
   (t\textsubscript{g} = Globe temperature ºC, t\textsubscript{a} = Air temperature ºC)
9. Partial vapor pressure (p\textsubscript{a}). If the value is introduced as zero, the program calculates it from the basic thermal parameters. In this study, p\textsubscript{a} was calculated by the computer program based on the following formula:
   
   \[
   p_a = 0.6105 \times EXP \left( 17.2 \cdot t_{wb} / (t_{wb} + 237.3) \right) - (t_a - t_{wb}) / 1
   \]
   
   (t\textsubscript{wb} = Wet bulb temperature ºC, t\textsubscript{a} = Air temperature ºC)
10. Body area fraction exposed (A\textsubscript{e}/A\textsubscript{Du}): This is the fraction of skin surface involved in heat exchange by radiation. Based on ISO 7933 (1989), body area fraction exposed is 0.67 for a crouching subject, 0.7 for a seated subject and 0.77 for a standing subject. In this study, the value of this fraction was determined according to the working posture of the worker.
Clothing thermal insulation ($I_c$): the clothing thermal insulation was estimated directly from the data in ISO 7933 (1989). In this study, clothing thermal insulation was estimated to be either 1 clo for light or 1.2 clo for heavy clothing.

In addition to climatic parameters measurements, data on demographic characteristics of the participants, and workers' perception of the thermal conditions of their workplaces were collected by a questionnaire. Thermal comfort was measured by predictive mean vote (PMV) index on a seven-point thermal sensation scale ranging from hot (+3) to cold (-3) and predicted percentage of dissatisfied workers (PPD) was predicted (Helander, 1995).

3. Results

Table 1 presents some personal details of the workers who participated in the study. Because the mean of the participants' job experience in different workshops was >13.3 years, they could be considered as acclimatized subjects.

Thermal characteristics of the general environment of the workshops are presented in Table 2. Measurements were done in different locations in the workshops.

Using the table given in ISO 7243 (1989), physical workloads of almost all workers were evaluated as light to moderate. Only one worker (the kneader from the rusk workshop) had heavy physical work activities.

Table 3 shows the results of workers' perception of their thermal comfort in the form of PMV index. The greatest thermal discomfort occurred in the rusk workshop, where the PMV index had the highest value of 2.2 (Table 3). This result implied that more than 80% of the workers in the rusk workshop were dissatisfied with the climatic conditions of their workplaces and perceived it as hot.

The results of the $SW_{req}$ index calculated for each worker from different workshops revealed that exposure to excessive heat load occurred only in the rusk and the chocolate workshops. Tables 4 and 5 present the $SW_{req}$ index calculated for each worker of these workshops. Note that the $SW_{req}$ values given in Tables 4 and 5 are time weighted averages of the index values for combination of sequences of each participant.

<table>
<thead>
<tr>
<th>Workshop</th>
<th>Age (year)</th>
<th>Job experience (year)</th>
<th>Weight (kg)</th>
<th>Stature (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Biscuit</td>
<td>47.2</td>
<td>7.6</td>
<td>14.2</td>
<td>8</td>
</tr>
<tr>
<td>Rusk</td>
<td>40</td>
<td>9</td>
<td>13.3</td>
<td>7.3</td>
</tr>
<tr>
<td>Wafer</td>
<td>40.5</td>
<td>11.3</td>
<td>16</td>
<td>6.8</td>
</tr>
<tr>
<td>Chocolate</td>
<td>38.6</td>
<td>8.8</td>
<td>15.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Total</td>
<td>40.9</td>
<td>10.1</td>
<td>14.9</td>
<td>7.2</td>
</tr>
</tbody>
</table>
Table 2. Mean value and standard deviation of climatic parameters of the 4 workshops studied and the factory canteen

<table>
<thead>
<tr>
<th>Workshop</th>
<th>( t_a ) (°C)*</th>
<th>( t_d ) (°C)*</th>
<th>( t_w ) (°C)</th>
<th>RH † (%)</th>
<th>( p_a ) (kpa)</th>
<th>( v_a ) (m/s)</th>
<th>n‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biscuit</td>
<td>25.6</td>
<td>2.4</td>
<td>27.1</td>
<td>3.1</td>
<td>21.4</td>
<td>3.1</td>
<td>10</td>
</tr>
<tr>
<td>Rusks</td>
<td>27.9</td>
<td>4.5</td>
<td>26.9</td>
<td>3.3</td>
<td>21.4</td>
<td>3.3</td>
<td>6</td>
</tr>
<tr>
<td>Wafer</td>
<td>21.8</td>
<td>1.4</td>
<td>22.7</td>
<td>2</td>
<td>17.5</td>
<td>1.3</td>
<td>6.1</td>
</tr>
<tr>
<td>Chocolate</td>
<td>22</td>
<td>1.2</td>
<td>23.9</td>
<td>1.9</td>
<td>17.5</td>
<td>1.1</td>
<td>66</td>
</tr>
<tr>
<td>Canteen</td>
<td>21</td>
<td>-</td>
<td>22</td>
<td>-</td>
<td>17</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*No significant difference between the means of \( t_a \) and \( t_d \) was observed (P>0.05).
†Relative Humidity
‡Number of locations measured

Table 3. The predictive mean vote and predicted percentage of dissatisfied workers values in the 4 workshops studied

<table>
<thead>
<tr>
<th>Workshop</th>
<th>PMV</th>
<th>PPD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biscuit</td>
<td>1.14</td>
<td>32</td>
</tr>
<tr>
<td>Rusks</td>
<td>2.2</td>
<td>&gt;80</td>
</tr>
<tr>
<td>Wafer</td>
<td>-0.11</td>
<td>5.2</td>
</tr>
<tr>
<td>Chocolate</td>
<td>1.2</td>
<td>35</td>
</tr>
</tbody>
</table>

Table 4. Values of the calculated Required Sweat Rate index for workers of the rusks workshop

<table>
<thead>
<tr>
<th>Job title</th>
<th>( SW_p ) (g/h)†</th>
<th>( W_p )‡</th>
<th>Allowable exposure time (min)††</th>
<th>Determining limit factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oven operator 1</td>
<td>468.7</td>
<td>0.95</td>
<td>480</td>
<td>-</td>
</tr>
<tr>
<td>Dough mixer</td>
<td>495.6</td>
<td>1</td>
<td>319</td>
<td>EIBT‡</td>
</tr>
<tr>
<td>Kneader</td>
<td>510</td>
<td>1</td>
<td>70</td>
<td>EIBT‡</td>
</tr>
<tr>
<td>Molder</td>
<td>430.4</td>
<td>0.91</td>
<td>480</td>
<td>-</td>
</tr>
<tr>
<td>Oven layer</td>
<td>173</td>
<td>0.56</td>
<td>480</td>
<td>-</td>
</tr>
<tr>
<td>Oven operator 2</td>
<td>251</td>
<td>0.77</td>
<td>480</td>
<td>-</td>
</tr>
<tr>
<td>Packer</td>
<td>126.8</td>
<td>0.42</td>
<td>480</td>
<td>-</td>
</tr>
</tbody>
</table>

*Time-weighted average value for an entire 8-hour working shift.
†Predicted sweat rate
‡Predicted skin wettedness
††Calculated for acclimatized worker at warning level
‡‡Excessive increase of body temperature.

As indicated in Table 4, the dough mixer and the kneader were exposed to excessive heat stress. In the chocolate workshop, the syrup, the toffee, the candy and the cooling table operators were exposed to excessive heat stress (Table 5). The determining limit factor in all cases was excessive increase of body temperature.

The results demonstrated that among the workers studied, the kneader from the rusks workshop was exposed to the most intensive heat stress. Based on the results, after 70 minutes his body temperature is >38°C. The kneader had a heavy physical workload with metabolic rate >230W/m² (Table 6), which could cause increased heat stress. Other workers’ physical workload was evaluated as light or moderate (i.e. metabolic rate <165W/m²).
Table 5. Values of the calculated Required Sweat Rate index for workers of the chocolate workshop

<table>
<thead>
<tr>
<th>Job title</th>
<th>SW(r) (g/h)(†)</th>
<th>(W_p)‡</th>
<th>Allowable exposure time (min)††</th>
<th>Determining limit factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syrup operator</td>
<td>146.8</td>
<td>1</td>
<td>382</td>
<td>EIBT ‡‡</td>
</tr>
<tr>
<td>Toffee operator</td>
<td>444.9</td>
<td>1</td>
<td>158</td>
<td>EIBT ‡</td>
</tr>
<tr>
<td>Candy operator</td>
<td>381.6</td>
<td>1</td>
<td>177</td>
<td>EIBT ‡</td>
</tr>
<tr>
<td>Cooling table operator</td>
<td>306.6</td>
<td>1</td>
<td>133</td>
<td>EIBT ‡</td>
</tr>
<tr>
<td>Toffee roller</td>
<td>161.9</td>
<td>0.71</td>
<td>480</td>
<td>-</td>
</tr>
<tr>
<td>Toffee packer</td>
<td>238.4</td>
<td>1</td>
<td>480</td>
<td>-</td>
</tr>
<tr>
<td>Candy mixer operator</td>
<td>194</td>
<td>0.83</td>
<td>480</td>
<td>-</td>
</tr>
<tr>
<td>Candy molding operator</td>
<td>150.4</td>
<td>0.57</td>
<td>480</td>
<td>-</td>
</tr>
<tr>
<td>Candy packer</td>
<td>140.4</td>
<td>0.56</td>
<td>480</td>
<td>-</td>
</tr>
</tbody>
</table>

* Time-weighted average value for an entire 8-hour working shift.
† Predicted sweat rate
‡ Predicted skin wettedness
†† Calculated for acclimatized worker at warning level
‡‡ Excessive increase of body temperature

4. Application of the SW\(req\) results in heat stress control

One of the main objectives of the SW\(req\) index is the identification of modifications to the work situation which can reduce or eliminate the risk of physiological strain. The computer calculation program of the SW\(req\) allows ready determination of which parameter or groups of parameters should be modified, and to what extent, in order to prevent the adverse effects of heat strain in the workplace. In this study, for practical application of the SW\(req\) index and determination of effective heat stress preventive measure for the kneader who was exposed to the most intensive thermal condition, input climatic parameters of his working conditions were varied. By using the calculation program, the effects of the modifications were investigated.

Table 6 presents the results of the modifications on the SW\(req\) index value together with the current situation for the kneader’s working environment. Note that the kneader’s job consisted of two sequences from the view point of thermal condition: a) working at kneading workstation and b) resting period. For heat stress reduction, only the climatic parameters of the working sequence were modified (Table 2).

As indicated in Table 6, in modification 1 all parameters were kept unchanged but clothing thermal insulation, which was reduced to 0.6 clo. Calculations revealed that this caused excessive heat exposure to be removed.

In modifications 2 and 3, climatic parameters were changed and heat stress exposure in the workplace was, to some extent, reduced (allowable exposure time 172 and 411 minutes, respectively), but the allowable exposure time was still less than 480 minutes (entire 8-hour working shift) and the problem of heat stress existed.
In modification 4, environmental parameters together with exposure time were changed. This resulted in removal of the heat stress problem, and the kneader might work for a full 8-hour shift without limitation.

Comparison of these modifications show that modification 1 (reducing clothing thermal insulation) is the easiest and the most applicable method for improvement of thermal conditions of the kneader’s working environment.

5. Discussion

Thermal conditions evaluation in the biscuit producing factory demonstrated that 6 workers of the rusks and the chocolate workshops (20% of subjects) were exposed to excessive heat load. In the chocolate workshop, hot processes were used to produce different products. In spite of the light physical work activities of the workers in this workshop, they were evaluated to be exposed to heat stress. In the rusks workshop, particularly hot and humid climatic conditions had to exist to enable production of high quality rusks. It is, therefore, predictable that workers in these workshops are exposed to excessive heat load. This was reflected in the PMV index that was given the highest score by the workers of the rusks and the chocolate workshops.

The $SW_{req}$ index seemed to be an appropriate index for evaluating heat stress in the biscuit factory climatic conditions, since the results of the $SW_{req}$ index application were in line with worker’s thermal perception (i.e. PMV index), although no statistical analysis was done to show the correlation. Note that some studies have reported that the $SW_{req}$ index is of limited validity (Malchaire et al., 1991; Forsthoff et al., 2001; Malchaire et al. 2001; Malchaire et al., 2002). Forsthoff et al. (2001) declared that the $SW_{req}$ index was not applicable to climatic conditions with high radiant temperature and proposed a correction to the calculation, for use under these conditions. In the present study, no significant difference existed
between the means of \( t_a \) and \( t_g \) in the workshops studied (Table 2). Therefore, in this study, heat stress estimation by the SW\(_{req}\) index does not suffer from the objection identified by Forsthoff et al. (2001).

One of the most pronounced advantages of the SW\(_{req}\) index is ready determination of optimal measures to prevent heat stress in the workplace. As the results showed, thermal conditions of the rusk workshop could be modified in different ways. Modification 1 (i.e. reduction of clothing thermal insulation) is as a simple low cost/no cost solution and the most applicable way to eliminate excessive heat exposure in the current situation. However, other modifications deserve attention.

The present study was conducted in the winter, when the heat load of the workplace environment was modified by the outdoor climatic conditions. In warm seasons, heat stress in the workplace may be more severe and more workers may be exposed to excessive heat load. Therefore, heat stress in these workplaces should be studied in the warm periods of year.

Although the SW\(_{req}\) index may provide reliable prediction of heat strain in industrial environments (Kahkonen et al., 1992; Morris, 1995; Di Corleto, 2001), it is considered too sophisticated for routine application. In this case, a two stage approach can be devised in which a simple index is used for a preliminary survey of workplace climates and then where necessary (i.e. if the simple index shows high values) more detailed analysis by using the SW\(_{req}\) index to obtain more reliable and accurate results (Kahkonen et al., 1992; Morris, 1995).
References


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