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A SYSTEMATIC BASIS FOR THERMAL RISK ASSESSMENT

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Introduction

Risk assessment and risk management are essential elements of good working practice - a part of the planning process to improve productivity and to promote worker health and safety. Furthermore, both are increasingly required to satisfy the needs of health and safety legislation. An essential part of risk assessment is job and task analysis - anaylsis which must include an evaluation of the physical environment (noise, lighting, thermal conditions, *etc*) in which the worker is required to operate.

The thermal environment is complex - there are many variables which directly or indirectly affect those exposed. This complexity dictates that the formal risk assessment is conducted thoroughly and systematically and takes account not only of the physical variables which descibe the thermal environment, but also of the interaction between the worker and the environment *ie* of the clothing or personal protective equipment (PPE) worn and of the workers' metabolic heat production.

Parsons (1) suggested one approach to this systematic appraisal - the 'thermal audit'. This is a quantitative method which uses the measured or estimated values of the basic environmental and clothing variables to calculate various routes of heat gain and loss. It is a valuable tool when reliable data are available, when the necessary hardware and software tools are at hand and when the risk assessor has an adequate understanding of the limitations of the assumptions and calculations. However, this quantitative approach may not always be necessary or possible, so we propose here a simplified, qualitative approach suitable for use by those who have to assess thermal risk and propose solutions for thermal risk management.

Method

The method is based on the heat balance equation which is used to describe thermal exchanges between man and his environment. The equation can take many forms. A generalised one is given below:

$$M\ (-\ W) \quad + K_{gain} + C_{gain} + R_{gain} \quad = \quad E + K_{loss} + C_{loss} + R_{loss} \quad \pm S$$

metabolic heat	**environmental variables**	**clothing variables**	**body heat storage**
work rate	ambient dry-bulb temperature Ta	insulation I	
work time	radiant temperature Tg	moisture vapour permeability im	
	humidity RH	design	
	air speed Va	weight	

M = metabolic heat production: W = mechanical work done: K, C and R are heat exchange by conduction, convection and radiation respectively: E = heat loss by evaporation: S = the rate of heat storage (+) or loss (-). Body temperature rises when S is positive and falls when S is negative.

The method takes each set of variables and systematically assesses their contribution first to the thermal risk faced by the worker, and then to possible risk management techniques. In practice it is quick and easy to apply. We have used it successfully on several occasions: one specific case history is briefly described. The approach has 5 (largely intuitive) Steps:

Risk assessment

1 Analyse the work-place using 4 groups of variables:
- describe the work rate and duration → is it constant or can it be intermittent?
- measure, estimate or describe qualitatively the 4 basic environmental variables → are these fixed or can they be varied?
- describe the PPE - the clothing variables → is this prescribed or can it be developed?
- decide a strategy for body heat storage (S) → must the body temperature remain constant, or can it be allowed to rise or fall?

2 Analyse the routes of heat gain and heat loss → assess the relative importance in heat gain and loss of K, C, R and E.

3 Identify which set of variables can be used in risk management → any variable that is not fixed can potentially be used for risk management. K, C, R, E should be analysed as both environmental variables and as heat exchange routes for PPE design.

Risk management

4 Formulate possible control measures → how can variables identified in Step 3 be used?
5 Implement solutions and monitor results → controlled laboratory and work-place tests.

Case history 1 Civilian workers in a hot-wet environment

1 Constant light work: exposure time 1 hour: desirably fixed; could be varied.
Ta = 60°C; Tg = Ta; RH = 100%; Va= 0 m/s; fixed.
PPE is to be custom designed.
Body temperature: desirably to stay constant; essential that any rise is limited to 38°C maximum
2 Heat gain: metabolism = low; conduction = high; convection = nil; radiation = high
Heat loss: evaporation = nil; conduction = nil; convection = nil; radiation = nil
3 The only way to manage this risk is by careful design of the PPE.
4 PPE was designed which had a high level of insulation to reduce conductive heat gain. To maximise conductive heat loss frozen gel heat sinks were worn close to the skin. Cooled breathing gas was supplied to a free-flow hood to promote evaporative heat loss from the head and to minimise respiratory heat gain.
5 Climatic chamber tests showed that up to Ta = 30°C rectal temperature was below the maximum limit. PPE should thus be improved to increase conductive and respiratory heat loss.

Discussion and Conclusions

To simplify Step 2 R and C could be considered together as 'dry' heat transfer. Furthermore, in most work-places in air K is very small so could be ignored in the heat gain analysis. However, it must be included in the heat loss analysis in cold environments, and when considering its use as a route of heat loss in PPE. Extensions of the proposed approach could be to consider separately heat gain and loss by the skin and respiratory routes; and to use the analysis for regions of the body (hands, feet, *etc*) if the work-place is non-homogeneous. The form in which the 5 Steps are applied can be varied according to need and the tools available. For example, paper *pro formae* are adequate but software is more verstile. At its simplest this could be a template or menu; a more complex solution would to link this directly with the quantitative thermal audit (1) and to incorporate mathematical models of human thermal responses to predict body temperature changes and casualty levels.

The proposed systematic approach is a quick and simple first step to thermal risk aasessment and management. It meets the needs of risk assessors not having a deep understanding of thermal physiology. It can also be used by procurers and developers of PPE as part of specification and design processes to allow the speedy fielding of a feasible prototype. However, the method does not replace prototype testing; prototype PPE must subsequently be evaluated in controlled laboratory and work-place tests using both objective and subjective methods. The proposed approach therefore nests with the multi-level system of analysis of PPE suggested by Umbach.(2).

References

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