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# Man-portable personal cooling garment based on vacuum desiccant cooling

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ABSTRACT

A man-portable personal cooling garment based on the concept of vacuum desiccant cooling (VDC) was developed. It was demonstrated with cooling pads that a cooling capacity of 373.1 W/m$^2$ could be achieved in an ambient environment of 37 °C. Tests with human subjects wearing prototype cooling garments consisting of 12 VDC pads with an overall weight of 3.4 kg covering 0.4 m$^2$ body surface indicate that the garment could maintain a core temperature substantially lower than the control when the workload was walking on a treadmill of 2% inclination at 3 mph. The exercise was carried out in an environment of 40 °C and 50% relative humidity (RH) for 60 min. Tests also showed that the VDC garment could effectively reduce the metabolic heat accumulation in body with subject wearing heavily insulated nuclear, biological and chemical (NBC) suit working in the heat and allow the participant to work safely for 60 min, almost doubling the safe working time of the same participant when he wore NBC suit only.



## 1. Introduction

Numerous occupations expose workers to hot environmental settings, where they are regularly subjected to excessive heat stress. In addition to reduced worker performance and productivity [1], heat stress may be an underlying cause for many workplace accidents and injuries, as it impairs mental alertness and concentration [2–4], motor dexterity and coordination [5], muscle fatigue [6,7]. The increased physical discomfort associated with elevated body temperature promote irritability, anger and other emotional states, which often cause workers to overlook safety procedures or to divert attention during hazardous tasks [8]. The tragic death of a United Kingdom soldier who died on duty when trying to dismantle an improvised explosive device in Afghanistan without wearing a heavily armoured bomb suit due to the extreme discomfort caused by heat stress in the high temperature highlighted the need of efficient personal cooling systems. Furthermore, exposure to excessive heat could cause severe symptoms that may threaten of the life of workers. In 2002, 1816 active American soldiers were reported injured from heat related causes [9]. From 1992 to 2006, 68 U.S. farm crop workers were reported to have passed away due to excessive heat stress [10].

Healthy humans regulate core temperature to maintain a near constant level (~37 °C) regardless of environmental conditions. To do this, a balance must be maintained between the heat produced within the body and the heat lost to the environment via a combination of dry heat exchange and evaporative heat loss. Ultimately, the ability to offset increases in core temperature during heat exposure depends on the ability of the body to dissipate heat through skin to the immediate microenvironment surrounding it.

Many cooling technologies have been employed to manage heat stress in daily activities, which can be classified into space cooling and personal cooling according to the immediate subject of cooling. Space cooling is the cooling of the interior space of a building or a room and is implemented at a relatively large scale. In occasions space cooling is very costly, impractical, or even impossible. Such cases include the hot outdoor environments and large work spaces such as steel mills, foundries, mines [11] and metallurgy plants. In these occasions, personal cooling (PC), which is designed to cool the immediate surroundings of the wearer, is more practical and cost-effective. PC acts directly on the microenvironment of the individual and is also referred to as microclimate cooling (MC). In scenarios where impermeable protective clothing is required, personal cooling garment also serves as the most effectively means of heat stress management [12–14].

Three different types of PC garments have been developed in the last several decades: i) fluid cooled garments (FCGs), also known as refrigeration aided PC systems, ii) phase change material (PCM) cooling vests, and iii) evaporative PC devices, also known as evaporative cooled garments (ECGs). FCGs employ air, water or non-toxic aqueous solutions as the coolant and are generally recognized as the most efficient PC technologies at present [15].

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