Anti heat stress clothing for construction workers in hot and humid weather

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Abstract

Summer time in Hong Kong is hot and humid. Record from the Hong Kong Observatory (2010a) indicates that the outdoor temperature and relative humidity in summer time can be as high as 34.9°C and 95% respectively. Construction workers have to undertake physical demanding activities in an outdoor environment which is hot and humid during summer time. Work in such an environment poses a significant challenge for the cardio-vascular system (Marszalek et al, 2005). Construction workers are vulnerable to heat stress in summer as heat stroke has already caused a number of deaths and injuries (Apple Daily, 2010a). Construction safety clothing is gear worn by construction workers to protect them from many potential hazards inherent on the job. Often workers dislike wearing safety clothing because it can be hot, cumbersome and slow down work progress (Donald, 2010). Heat and inappropriate clothing may make workers sweat a lot. Construction workers are at greater risk for heat-related illnesses such as heat rash which is a skin irritation caused by excessive sweating during hot and humid weather (MedicineNet.com, 2010). Proper clothing is essential to combat heat rash and other heat-related illnesses. Comfort in the hot season depends on the choice of fabrics. Clothing should make workers feel cool, dry and comfortable, and more importantly, able to protect them against the damaging UV rays from the sun. Construction work is a tough job which demands additional requirements on clothing. High quality industrial apparel is important for providing a layer
of protection against cuts and abrasions, as well as the environment and weather. Clothing has to be durable with high thread count, reinforced seams, and heavy duty rivets that fit well enough to not present a hazard around moving parts, but still provide flexibility to react on the job site (Palmer, 2010). Obviously, clothing for construction workers during summer time warrants special attention.

The Construction Industry Council (CIC) addressed this important issue by setting up an Informal Task Force on Working in Hot Weather. The CIC has promulgated a set of basic guidelines on site safety measures in hot weather and provided some recommendations on clothing and protective equipment (Section 16 of the Guideline, Construction Industry Council, 2008). The Informal Task Force, however, advocated in the 5th Progress Report of Committee on Construction Site Safety to the CIC that further research on thermal stress measured by established parameters should be conducted to refine the initial guidelines.

The aim of this study is to address this pressing need of the industry by adopting a scientific approach to assess the effects of heat stress on construction workers and to design proper clothing for construction workers accordingly. A set of physiological and environmental parameters, namely oral temperature, skin temperature, ambient temperature, relative humidity, wind velocity, solar infrared radiation and UV radiation, heart rate variability, energy expenditure, minute ventilation, blood pressure and sweating responses will be measured and monitored to find out physiological limit values at different heat exposures. With these parameters in place, proper clothing will be designed and engineered for construction workers to cope with the hot and humid weather by systematic investigating the impact of key factors such as garment style, fit, structures of fibres, yarns and fabrics, and their functional performances/properties such as breathability, ventilation, thermal insulation, IR and UV blocking/transfer, sweat transfer and anti-microbial function.

**Aim of the research**

The aim of this study is to assess the effects of heat stress on construction workers and to design proper clothing for the workers to work in hot and humid weather.

**Objectives**

1. Examine the current dressing pattern of construction workers in hot and humid weather;
2. Identify the shortcomings of the current dressing pattern in dealing with hot and humid weather;
3. Determine the physiological conditions of construction workers when they are subject to different degree of heat and humidity exposure;
4. Design and engineer appropriate clothing for construction workers to meet with the extreme physiological conditions;
5. Evaluate the effectiveness of the newly designed clothing for construction workers.

**Significance and value**

The planet is warming, from North Pole to South Pole, and everywhere in between (National Geographic, 2010). According to the 2007 Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), global surface temperature increased 0.74 ± 0.18 °C (1.33 ± 0.32 °F) during the 20th century. Construction workers have to undertake outdoor work and often in confined spaces. Construction work is a tough job and is physically demanding. This is further exacerbated by the hot and humid weather during summer time in Hong Kong. Construction workers are vulnerable to heat stress in summer as heat stroke has already caused a number of deaths and injuries. Health and safety measures, in particular those related to clothing for construction workers, linked up to scientific and clinical parameters are urgently needed. Although this study applies specifically to the construction industry of Hong Kong, the same methodology could be extended to other industries and to other countries to enhance the health and
well being of workers in general, and to those working in hot and humid weather in particular. Appropriate clothing for construction workers could be established based on a set of physiological and environmental parameters measurable by clinical and scientific methods to combat impending attacks of heat stress. This would be of tremendous value in better safeguarding workers’ health and safety by reducing the occurrences of heat-related illnesses on site.

Background of research

(A) Work done by others

Heat stress can be defined as the effect of heat that would create pressure or discomfort to the human body (Hong Kong Observatory, 2010b). Under normal circumstances one’s metabolism would continuously generate heat energy which would be lost through direct radiation, air conduction and sweating. When people carry out physical activities, more heat energy will be generated and consequently more sweating would result to keep the body’s temperature at norm. In some cases the heat energy may not be sweated fast enough causing the body’s heat to rise resulting in heat stress. Heat stress is very much dependent on air temperature, relative humidity, wind speed and solar radiation. High temperatures will obviously intensify the likelihood of heat stress. An environment with higher humidity will mean that sweating i.e. heat loss would be more difficult. For places such as Hong Kong with high levels of humidity all year round, the likelihood of heat stress can be intensified. Wind speed is also a determining factor towards heat stress. A higher wind speed would ease sweating and hence facilitating heat loss. Furthermore, under high solar radiation i.e. a sunny day body heat will increase. Besides air temperature, relative humidity and wind speed, Kjellstrom et al. (2009) provided a wider range of determinants which would also affect the body’s heat. These include radiant temperature, metabolic heat generated by activity and also clothing.

The hot and humid weather in Hong Kong has meant that heat stroke is particularly common for construction workers in the summer months. Frequent cases of heat stroke have continuously been recorded in recent news reports (Apple Daily, 2010b; 2010c; 2010d). The safety of workers in these environments has become a pressing concern and foremost importance. Studies and guides regarding preventive measures and solutions for workers working under hot and humid weather have been published and provided by government agencies. However, these agencies admitted that further research on thermal stress measured by established parameters should be conducted to refine the initial guidelines (CIC, 2008).

Looking at examples from overseas, the National Institute for Occupational Safety and Health (NIOSH) published their revised report (NIOSH, 1986) regarding occupational exposure to hot environments. In their report it is suggested that work clothing should not be more than a long sleeved shirt and trousers. In conditions where the ceiling limits of heat stress are exceeded heat-protective clothing should also be provided by the employers to the workers. Protective clothing can be water-cooled garments, air-cooled garments, ice-packet vests, wetted over garments, heat reflective aprons etc. The ceiling limit of heat stress can vary depending on the metabolic rate of workers, for example a metabolic rate of 500kcal/h would correspond to a ceiling limit of approximately 34°C, therefore different occupations and work activities will correlate to different ceiling limits.

Previous researchers have conducted studies looking at the effects of working under hot and humid weather. These have mainly focused on the negative effects towards workers, the type of workers that are more prone to the consequences and the effects towards their work ability (Lin and Chan, 2009; Marszalek, 2005; Mohamed, 2003; Hsu et al., 2008). Few studies have focused on providing solutions to these problems.

The occupations and industries at risk of heat stress in Taiwan were studied by Lin and Chan (2009). The findings showed that construction workers accounted for the largest portion of labourers working outdoors, with around
842,000 workers representing 8.1% of the labour force. The researchers of this study added that the problem was aggravated by the hot and humid conditions in Taiwan where the maximum temperature of 30°C and relative humidity of 74% has been recorded. These figures are much lower than those for Hong Kong, where the maximum temperature is 34.9°C and relative humidity is 95% (Hong Kong Observatory, 2010a). Therefore, the risk of heat stress for construction workers in Hong Kong can be considered as more severe.

Marszalek et al.’s (2005) study looked at the work ability of workers of different ages. The participants consisted of 96 men and women from the ages of 20 to 60 years old. Their study concluded that for workers over 45 years of age, the physiological cost of work would be higher whereas the ability to work in hot environments would be lower. In addition, the work ability of workers under heat was reduced for workers with low aerobic capacity (common for older women). Similar to this study, Srinavin and Mohamed’s (2003) work also concerns the productivity of construction workers working under different thermal environments. Their study developed a model to measure productivity of workers under different thermal environments. Again, this study presents a model for predicting trends and realizing the situation of working under different environments rather than trying to provide solutions to potential problems and obstacles.

An interesting study was conducted by Hsu et al. (2008) looking at the physiological changes and fatigue of construction workers working in high-rise buildings. Although, their study was conducted in Taiwan the scenario is quite similar to Hong Kong as the majority of buildings are high-rise. Their findings showed that construction work for high-rise buildings is particularly demanding for the workers physically. Also, the fatigue level of the workers was much increased by working at higher levels due to increase of heart rate, physical workload and at the same time decreasing visual sensitivity. Under such demanding conditions it can be understood that working under hot and humid would only worsen the situation for workers.

Locally, the Construction Industry Council in Hong Kong produced an informative guideline for contractors to protect workers in hot weather (Construction Industry Council, 2008). The guideline specifically describes the roles of each party (i.e. client, contractor, site supervisor and worker) for maintaining safety in hot weather for construction workers. The major risks of working in hot weather are also discussed in detail including fainting, heat exhaustion and heat stroke. Furthermore, some safety measures are suggested, these include appropriate work arrangements, breaks and cool down facilities, drinks, clothing and protective equipment, maintaining health of workers, and also first aid procedures and facilities. For clothing as a preventive measure, the guideline suggests that workers should be encouraged to keep clothing on, wear light coloured clothes, loose fitting clothes, wear clothes made of natural materials, and to wear long sleeves. However, their recommendations are considered as generic in nature and lack scientific measurements.

The Labour Department of Hong Kong has also identified working under heat as a health hazard in construction work (Labour Department, 2004). They stress the severity of working under heat which can cause heat rash, heat cramps, heat exhaustion and heat strokes. Their guidance notes suggest that to prevent heat stress workers should avoid heavy manual work in hot environment. However, this may not always be possible for construction workers where heavy manual work is frequently involved. Other suggestions include using mechanical equipment to assist, work during cooler parts of the day or season. Again, these preventive measures are not always applicable due to the confined working environment and tight working schedule. The guidance notes mention that heat stress can be improved by shelter, blowing fans, cold drinks and rest breaks. Some of these suggestions have already been adopted by construction sites and have shown to be useful for reducing heat for workers. Another feature mentioned in the guidance notes is that the problem of heat stress can be aggravated by impermeable protective clothing. Protective clothing is obviously important for protecting the worker from other common hazards on the construction site such as to uplift awareness, prevent cuts, protect from sun rays, corrosion, vibration etc. But it appears that little has been conducted to design suitable protective clothing which can adequately protect workers from potential hazards including heat stress. The proposed study attempts to fill this knowledge gap to design
appropriate clothing for construction workers based on a set of physiological and environmental parameters measurable by clinical and scientific methods.

(B) Work done by the research team

Albert Chan, Francis Wong, Michael Yam, Daniel Chan and Esther Cheung are core members of the construction safety research group at the Department of Building and Real Estate (BRE). They possess a great deal of research experience relevant to the study, and are therefore competent to bring considerable breadth of knowledge to the issues. They have a sustainable track record in securing research fund from various sources. They have just embarked a research project funded by the Research Grant Council (RGC) to develop a set of good practices and indices that could be implemented by contractors to ensure the health and safety of site personnel working in hot weather in 2009. Another RGC funded project being conducted investigates the safety climate and its impacts on safety performance of repair, maintenance, minor, alteration and addition works. The Construction Industry Institute, Hong Kong (CII-HK) commissioned the BRE team (2006 & 2007) to conduct research examining construction safety involving working at height for residential building repair and maintenance. As a by-product of that study, the research team invented a Rapid Demountable Platform (RDP©) to supplement the use of the traditional bamboo truss out scaffold which notoriously causes fatal accidents. The RDP system has successfully obtained a patent application number (200610009426.9) from the PRC Patent Office and won several awards including: the Outstanding Professional Services and Innovation Awards from the Institute for Enterprise, The Hong Kong Polytechnic University in 2009; the Innovation Achieves Award from the Chartered Institute of Building (CIOB) in Englemere, United Kingdom in 2009; the Gold Medal with the Congratulations of the Jury and a National Authority for Scientific Research Award of the Romania Ministry of Education at the 36th International Exhibition of Inventions, New Techniques and Products held in Geneva, Switzerland in 2008; and the Research and Youth for the High Scientific and Technological Level of the Invention in 2008. Through these studies, contacts with key stakeholders in the Hong Kong construction industry such as government officials, major developers, major contractors, subcontracting associations, and labour unions have been established. Relevant information and findings of these studies will be valuable to the proposed study. Selected publications in construction safety by members of the research team can be found in team members’ CVs attached with this application.

Yi Li is specialized in the areas of clothing thermal comfort. He has carried systematic studies on the physical and physiological mechanisms involved. Theories, models, computational algorithms have been developed to simulate and visualize the thermoregulatory processes of the human body, its interaction with clothing in terms of heat and moisture transfer. On the basis of the models, CAD software has been developed for engineering design textiles and apparel products for achieving optimum thermal comfort and thermal functions. Test apparatus and testing methods have been developed to evaluate the dynamic heat and moisture transfer properties of fabrics, which has been developed and approved as an AATCC standard and a China national standard in 2009, and as a testing standard for China’s import and export control in 2005. Relevant scientific publications are listed in references [22-54]. On the basis of these studies, protective clothing and facemasks for healthcare workers and thermal protective clothing were designed and engineered [61-67]. However, systematic studies on the comfort, anti heat stress function for construction workers have not been carried out.

Del Wong is an accredited exercise and sport physiologist (British Association of Sport and Exercise Sciences, UK) specialized in the physiological limit and training adaptation of human subjects. Since 2005, he published 26 research papers in international peer review scientific journals in exercise physiology, and 3 invited book chapters. He is currently a scientific reviewer for 3 international research journals. In addition, he worked as a fitness coach with a professional football club for 2 years and therefore has substantial experience working and collecting physiological data under hot and humid environment.
Research plan and methodology

The research will combine a comprehensive literature review, content analysis, field study, questionnaire survey, computer simulation and wear trial study and focus group study. The research framework for the proposed study is shown in Figure 1. The proposed research study will span a period of 36 months (from 1 January 2012 to 31 December 2014 inclusive). The research schedule is given in Figure 2.

Objective 1: Examine the current dressing pattern of construction workers in hot and humid weather

An extensive literature review of clothing for construction workers in hot and humid weather will be further conducted. All previous studies related to the proposed study done by other researchers will be consolidated, thereby enriching the understanding of current practices and experiences. The literature will be sourced from international refereed journals, international refereed conference proceedings, books, websites, magazines, newspapers, and so on. This desktop study will provide the background for the research and also form the framework for the development of the questionnaire survey.

In this research study, content analysis will also be employed. Content analysis is frequently adopted to determine the major facets of a set of data, by simply counting the number of times an activity happens, or a topic is depicted (Fellows and Liu, 2008). The first step in conducting content analysis is to use electronic database search engines such as Scopus to identify the literature to be analysed. The second step is to determine the form of content analysis to be used, whether qualitative or quantitative. The choice is dependent on the nature of the research project. In qualitative content analysis, emphasis is on determining the meaning of the data (i.e. grouping data into categories). Quantitative content analysis extends the approach of the qualitative form to generate numerical values of the categorized data (frequencies, ratings, ranking, etc) which may be subjected to statistical analyses. Comparisons can be made and hierarchies of categories can be examined (Fellows and Liu, 2008). The proposed study will adopt the qualitative content analysis approach.

Objective 2: Identify the shortcomings of the current dressing pattern in dealing with hot and humid weather

To identify the shortcomings of existing clothing worn by construction workers in working environment, a systematic study will be carried out by: (1) Collect garments samples from construction workers for analysing the design and measuring the physical properties of the fabrics; (2) Study and analyse the working patterns in relation to metabolic rates and sweating rates; (3) Study and analyse the working environmental conditions such as temperature, humidity, wind velocity and solar UV and IR radiations; (4) Conduct a questionnaire with construction workers on the clothing they worn during work; (5) Carry out a computer simulation to study the potential heat stress level of construction workers in typical working environment in summer by using the models and computer software developed previously [30-51].

Objective 3: Determine the physiological conditions of construction workers when they are subject to different degree of heat and humidity exposures

Repeated on-site measurements will be carried out with front line workers from June to October to capture typical physiological conditions that construction workers may be subject to. Collaboration has already obtained from the developers, contractors, and workers to facilitate these field studies. Environmental data such as wet bulb and dry bulb temperature, globe temperature, wind speed, and barometric pressure will be collected through a Heat Stress Monitor. Concurrent with the environmental data collection, physiological parameters such as oral temperature, skin temperature, heart rates, minute ventilation, energy expenditure, blood pressure and sweating responses will be
measured and monitored through a metabolic cart and heart rate monitor. With these synchronized environmental and physiological data, mean radiant temperature, relative humidity, wet bulb globe temperature (WBGT) and thermal work limit (TWL), can be calculated to assess the thermal stress at different degree of heat and humidity exposures (Brake and Bates, 2002; Bates and Schneider, 2008; Lu and Zhu, 2007).

Heart Rate Variability (HRV) refers to the beat-to-beat alterations in heart rate. Heart rate variation analysis (instantaneous heart rate against time axis) has become a popular non-invasive tool for assessing the activities of the autonomic nervous system (Acharya, et al, 2006). It provides non-invasive, unobtrusive information about modulation of the heart rate by the autonomic nervous system for a variety of dynamic circumstances (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996), including evoked emotions (McCraty, et al, 1995) and exercise (Saito & Nakamura, 1995). Both time and frequency domain measures have been used to assess HRV, but the latter is increasingly the method of choice among investigators. Skin temperature and sweat rates are useful for assessing the severity of heat strain and to estimate tolerance. To dissipate heat from deep body tissue to ambient environment, there should be an adequate heat gradient, i.e. the difference between ambient temperature and skin temperature. When sweating is not effective enough, skin temperature rises and the heat difference is reduced. A high skin temperature and low sweat rate comes together with heat-related symptoms (Lu and Zhu, 2007).

Objective 4: Design appropriate clothing for construction workers to meet with the extreme physiological conditions as identified in the previous objective

On the basis of the findings from previous objectives, clothing for construction workers will be designed and engineered by: (1) Selecting fibres and fabrics based on the testing results of their functional properties such as thermal insulation, thermal radiation, air permeability, water vapour permeability and moisture management; (2) designing different styles of clothing with consideration the coverage ratio of human body, tightness and ventilations; (3) Carry out a systematic computational experiments to predict the heat stress levels and thermal comfort performance of the clothing under the working conditions of construction workers by using the models and computer software developed previously [30-51]; (4) Pre-optimize the designs according to simulation results; (5) Make block patterns for the pre-optimized design and make garment prototypes for pilot testing on the thermal functional performance; (6) Making a certain number of garments for wear trials and field studies.

Objective 5: Evaluate the effectiveness of the newly designed clothing for construction workers

To evaluate the effectiveness of the newly designed clothing, the opinions will be sought from construction workers. Participants will be invited to wear the newly designed clothing during their regular working activities for a number of days. A focus group meeting will then be arranged to seek their opinions regarding the comfort, suitability, practicality, acceptability and safeness of the clothing. Focus group meetings are considered as a convenient, effective way to collect a vast amount of information from a group of participants to supplement the traditional one-to-one interview technique (Haslam, 2003). Focus group meetings will be organized to verify the identified practices from a much wider audience. Vaughn et al. (1996) asserted that focus groups should possess two core elements: 1) a trained moderator who sets the stage with prepared questions or an interview guide; and 2) the goal of eliciting participants’ feelings, attitudes and perceptions about a selected meeting. Each focus group will be moderated by a research team member, who will first make a short presentation of the newly designed clothing and set the stage with the prepared questions. The participants will then be divided into groups of six to ten to sustain lively and active discussion. Other research team members will be assigned to sit in each group to trigger discussions and responses. Each group will then be asked to nominate a rapporteur to present the group’s findings and recommendations at the end of the meeting. The information gathered from the focus group discussions will be analysed, documented and
triangulated with data solicited from other sources before drawing up a conclusion. The findings will be used to evaluate the effectiveness of the newly designed clothing.

References


64. Guo YP (Guo, Yueping)1, Li Y (Li, Yi)1, Tokura H (Tokura, Hiromi)1, Wong T (Wong, Thomas)2, Chung J (Chung, Joanne)2, Wong ASW (Wong, Anthony S. W.)2, Gohel MDI (Gohel, Mayur Danny Indulat)3, Leung PHM (Leung, Polly Hang Mei)3, Impact of Fabric Moisture Transport Properties on Physiological Responses when Wearing Protective Clothing, TEXTILE RESEARCH JOURNAL Volume: 78 Issue: 12 Pages: 1057-1069

Plan for Collaboration

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<tr>
<th>University</th>
<th>Name</th>
<th>Area of contribution</th>
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<tr>
<td>PolyU</td>
<td>Prof Albert Chan (BRE)</td>
<td>Prof Chan is an active researcher in the Construction Safety Research Group. He will take the overall lead in the proposed study and coordinate the research efforts of all research team members.</td>
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<td></td>
<td>Prof Francis Wong (BRE)</td>
<td>Prof. Wong is a qualified building engineer as well as a chartered builder. He has good industrial links and is a well experienced researcher in the area of construction safety. His particular contributions in this research include the structured interviews and the focus group meetings.</td>
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<td>Dr Michael Yam (BRE)</td>
<td>Dr. Yam is a member of the Construction Safety Research Group. He will participate in the structured interviews and assist in the execution of the clinical experimental and field studies.</td>
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<tr>
<td>Dr Daniel Chan (BRE)</td>
<td>Dr Chan is a member of the Construction Safety Research Group. He will assist in the execution of the clinical experimental and field studies. Dr Chan will also participate in the focus group meetings.</td>
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<tr>
<td>Dr Esther Cheung (BRE)</td>
<td>Dr. Esther Cheung is a Postdoctoral Research Fellow and a member of the Construction Safety Research Group. Dr Cheung will be involved in planning, designing, monitoring and reporting of the research activities in the proposed research.</td>
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<tr>
<td>Prof Yi Li (ITC)</td>
<td>Prof. Yi Li is an expert in clothing comfort and functional engineering design. Prof. Li will be in charge of studying the thermal functions of clothing for construction workers, designing and making clothing for testing and field studies.</td>
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<tr>
<td>IEd Prof Joanne Chung (SN)</td>
<td>Prof Chung is an expert in pain and symptom management. Prof Chung will be in charge of the clinical experimental design and the execution of the clinical experimental and field studies.</td>
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<td>Dr Del Wong</td>
<td>Dr Del Wong is a Sport and Exercise Physiologist, Certified Strength and Conditioning Specialist, and Certified Health Fitness Specialist. He will contribute in the experimental design and on site data collection.</td>
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Figure 1 Flow of the Overall Research Framework
### Figure 2 Research Schedule

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<th>Research Activities</th>
<th>2012</th>
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<tr>
<td>1. Research group meetings</td>
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<td>2. Examine the current dressing pattern</td>
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<td>- Literature review and content analyses</td>
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<td>- Data consolidation</td>
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<td>3. Identify the shortcomings of the current dressing pattern</td>
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<td>- Field survey and garment sample collection</td>
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<td>- Testing, data analysis and computer simulation</td>
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<td>4. Determine the physiological conditions of construction workers</td>
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<td>- Collect environmental conditions on-site)</td>
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<td>- Collect physiological conditions from human test specimens</td>
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<td>- Derive thermal work limit</td>
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<td>- Heat rate variation analysis</td>
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<td>- Derive physiological conditions of workers under different environments</td>
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<td>5. Design appropriate clothing for construction workers</td>
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<td>- Design and engineering garments</td>
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<td>6. Evaluate the effectiveness of the newly designed clothing for construction workers</td>
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<td>- Workers to try out the newly designed clothes during their regular work activities</td>
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<td>- Prepare presentation and design discussion topics for focus group meeting</td>
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<td>- Conduct focus group meeting</td>
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<td>Analyses of discussion and presented ideas</td>
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<td>Refinement of clothes (if necessary)</td>
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<td><strong>7. Dissemination</strong></td>
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<td>Produce papers for publication &amp; presentation</td>
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<td>Final report</td>
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