THE ROLE OF CONSTRUCTION WORK UNIFORM IN COMBATING BODY HEAT STRAIN: A CASE STUDY IN HONG KONG

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The Role of Construction Work Uniform in Combating Body Heat Strain: A Case Study in Hong Kong

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CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

_________________________ (Signed)

YANG YANG (Name of Student)

STATEMENT OF THE CONTRIBUTION

This study is originated from a General Research Fund (GRF) project titled "Anti-heat stress clothing for construction workers in hot and humid weather", and an Occupational Safety and Health Council (OSHC) Research Grant project titled "Study on the effectiveness of personal cooling equipment for protecting workers from heat stroke while working in a hot environment", of which the author is a team member. The author has extended the work as a part of her PhD study. As the key research personnel of the research team, the author was involved in the entire experimentation process of laboratory experiment (as shown in Chapter 4) and field survey (as shown in Chapter 6). The author was also involved in data collection and data analysis under the guidance of the principal supervisor and other team members. The author's individual contribution is mainly embodied by the execution and generalization of field experiment as shown in Chapter 5. Meanwhile, developing a methodology in conducting intervention development research is another key contribution of the PhD study as shown in Chapters 2, 3 and 7.

ABSTRACT

Construction workers in Hong Kong are subjected to heat stress because of the irreversible hot weather, strenuous physical work, and prolonged work duration under direct sunlight. A series of guidelines and practice notes that safeguard laborers working in hot weather have been promulgated and implemented. However, these precautionary measures are commonly derived from well-recognized international standards; thus, lacking theoretical and empirical evidences in relation to the specificities of the region, meteorology, and population. Consequently, the effectiveness and practicality of these guidelines remain vague, which may lead to improper and inefficient implementation of these control measures and even unwise safety investment. In this respect, re-engineering appropriate heat stress prevention strategies are urgently necessary.

Wearing appropriate summer clothes is one of heat stress control measures suggested by the local industrial guidelines. Nevertheless, research on the effectiveness and practicality of such work clothes in combating heat strain has received little attention to date. Consequently, the criteria of *appropriate clothing* remain ambiguous and lack a definite justification. To bridge this research gap and to solve a practical problem, the research team of the Hong Kong Polytechnic University designed and engineered an anti-heat stress work uniform with comprehensive consideration of fabric properties and smart clothing design. This initiative requires further assessment on the benefits of wearing this work uniform to combat body heat strain.

The present study aims to facilitate heat stress intervention development research in construction. The major objectives are to set a research framework for intervention development research, to assess the benefits of wearing the anti-heat stress uniform on combating heat strain, and to provide recommendations on formulating precautionary measures against heat stress. Based on a well-established research framework, the efficacy, effectiveness, and acceptability of the anti-heat stress uniform and a commercially available trade uniform are examined through a randomized control trial in the laboratory experiment, a randomized control trial in the field experiment, and in a field survey, respectively.

The key findings of the laboratory experiment indicate that the anti-heat stress uniform could significantly alleviate thermo-physiological and perceptual strain at certain time of exercise and post-exercise recovery periods. The results of the field experiment reveal that perceived heat strain of construction workers across four trades is significantly alleviated, as evidenced by the significant interaction effect between clothing type and work trade. Furthermore, overwhelming support for the anti-heat stress uniform has been obtained from 189 construction workers in the field surveys, as proven by the pleasant subjective sensations on this uniform.

The current study presents a fresh perspective on the further improvement of heat stress intervention development research in construction. It contributes holistic research strategies and credible research findings that can enable both researchers and practitioners to improve work practices through developing an industry standard. Moreover, this study heightens awareness of the importance and value of conducting heat stress intervention research prior to formulating solid guidelines and fosters better communication and collaboration between academics and practitioners. These impacts stimulate and nurture the growth of the promising heat stress intervention research area.

LIST OF PUBLICATIONS

Journal papers (Published and accepted)

1. Chan, A.P.C., Yang, Y., Wong, D.P., Lam, E.W.M., and Li, Y. (2013). Factors affecting horticultural and cleaning workers' preference on cooling vests. *Building and Environment*, 66, 181-189.
2. Chan, A.P.C., Yang, Y., Wong, F.K.W., and Yam, M.C.H. (2013). Dressing behavior of construction workers in hot and humid weather. *Occupational Ergonomics*, 11, 177-186.
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5. Chan, A.P.C., Yang, Y., Guo, Y.P., Yam, M.C.H., and Song, W.F. (2015). Evaluating the physiological and perceptual responses of wearing a newly designed construction work uniform. *Textile Research Journal*, DOI: 10.1177/0040517515591773.
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3. Yang, Y., and Chan, A.P.C. (2015). The role of work uniform in combating perceptual strain of construction workers. *International Journal of Biometeorology*, Under review.
4. Chan, A.P.C., and Yang, Y. (2015). Advancing the methodology in development research on heat stress intervention in construction. *Construction Management and Economics*, Under review.
5. Chan, A.P.C., Wong, F.K.W., and Yang, Y. (2015). From innovation to application: a case study on the "Cooling Vest Promotion Pilot Scheme" in Hong Kong. *Accident Analysis & Prevention*, Under review.
6. Chan, A.P.C., Yang, Y., Wong, F.K.W., Yam, M.C.H., and Wong, D.P. (2015). Hybrid cooling vest for reduction of physiological strain under a hot and humid environment. *Journal of Strength and Conditioning Research*, Under review.
7. Chan, A.P.C., and Yang, Y. (2015). Characteristic analysis of construction-related injuries of the HZMB-HK project. *Journal of Safety Research*, Under review.

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1. Chan, A.P.C., Yang, Y., Wong, F.K.W., Yam, M.C.H., Lam, E.W.M., Wong, D.P., Guo, Y.P., Li, Y., and Hu, J.Y. (2013). On-site wear trials to determine construction workers' preference for two types of cooling vest in combating

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2. Wong, F.K.W., Yang, Y., and Chan, A.P.C. (2014). Personal cooling vest from discovery to delivery: a case study in Hong Kong. The 1st International Workshop on Systems Thinking in Workplace Safety and Health in Construction-Theory Meets Practice, 4th-5th Dec 2014, HuaZhong University of Science and Technology, Wuhan.
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LIST OF GLOSSARY AND VARIABLES

A	Age (year)
A_D	Body Surface Area (m^2)
ACGIH	American Conference of Governmental Industrial Hygienists
AHSU	Anti-heat Stress Uniform
AICc	Akaike's Information Criterion
ANN	Artificial Neural Network
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
API	Air Pollution Index (unit)
ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
ASTM	American Society for Testing and Materials
BPM	Beats per Minute
C_b	Specific Heat Capacity of the Body Issue ($kJ \cdot kg^{-1} \cdot °C^{-1}$)
CIC	Construction Industry Council
CLO	Clothing Type
CS	Comfort Sensation (unit)
DBP	Diastolic Blood Pressure (mmHg)
DH	Drinking Habit
EC	Energy Consumption (unit)
EE	Energy Expenditure (kcal/min)
ESI	Environmental Stress Index (unit)
$H_{micro\text{-}back}$	Microclimate Humidity at the Back (%)
$H_{micro\text{-}thigh}$	Microclimate Humidity at the Thigh (%)
HKCA	Hong Kong Construction Association
HKO	Hong Kong Observatory

HKPolyU	Hong Kong Polytechnic University
HI	Heat Index (°C)
HR	Heart Rate (bpm)
HR_{max}	Predicted Maximal Heart Rate (bpm)
HR_r	Minimal Heart Rate during rest (bpm)
HR_w	Heart Rate Measured during Work (bpm)
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LMM	Linear Mixed-effects Model
N/A	Not Available/Mentioned
NIOSH	National Institute of Occupational Safety and Health
MV	Minute Ventilation (L/min)
OMMC	Overall Moisture Management Capacity (unit)
OSHA	Occupational Safety and Health Administration
OSHC	Occupational Safety and Health Council
PBF	Percentage of Body Fat (%)
PeSI	Perceptual Strain Index (unit)
PhSI	Physiological Strain Index (unit)
PPC	Personal Protective Clothing
PPE	Personal Protective Equipment
PSI_{HR}	Physiological Strain Index based on Heart Rate (unit)
REDA	Real Estate Developers Association of Hong Kong
RER	Respiratory Exchange Rate (unit)
RH	Relative Humidity (%)
RHR	Relative Heart Rate (%)
RHR'	Resting Heart Rate (bpm)
RMANOVA	Analysis of Variance with Repeated Measures
RMSE	Root Mean Square Error
RPE	Rating of Perceived Exertion (unit)

$\dot{S}$	Rate of Heat Storage ($kJ \cdot m^{-2} \cdot hour^{-1}$KJ•m)
SBP	Systolic Blood Pressure (mmHg)
SH	Smoking Habit
SR	Solar Radiation ($W \cdot \bullet m^{-2}$)
T	Time (min)
TRADE	Trade Uniform
TS	Thermal Sensation (unit)
TWL	Thermal Work Limit ($W \cdot \bullet m^{-2}$)
T_a	Air Temperature (°C)
T_b	Body Temperature (°C)
T_c	Core Temperature (°C)
T_{calf}	Skin Temperature at the Calf (°C)
T_{chest}	Skin Temperature at the Chest (°C)
T_{ca}	Ear Canal Temperature (°C)
$T_{forearm}$	Skin Temperature at the Forearm (°C)
T_{in}	Intestinal/Core Temperature (°C)
$T_{lateral\ chest}$	Skin Temperature at the Lateral Chest (°C)
T_{sk}	Skin Temperature (°C)
T_{thigh}	Skin Temperature at the Thigh (°C)
U_{SG}	Urine Specific Gravity (unit)
US Army	United States Army
VO_2	Oxygen Consumption (ml/min/kg)
WBGT	Wet Bulb Globe Temperature (°C)
WHO	World Health Organization
WS	Wet Sensation (unit)
WTO	World Trade Organization

CHAPTER 1 INTRODUCTION

1.1 INTRODUCTION

This chapter sets the background, clarifies the research problem, formulates the aim and objectives, illuminates the significance and value of the current study, and outlines the research approaches.

1.2 BACKGROUND

1.2.1 Heat-related casualties in the Hong Kong construction industry

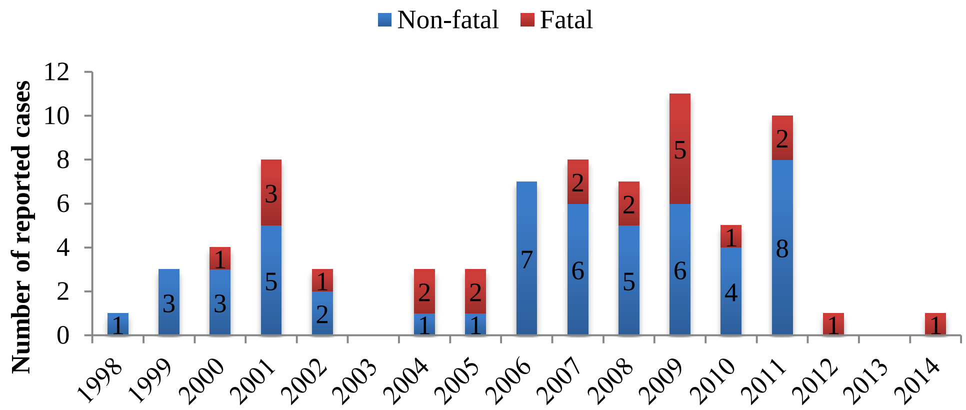
Climate change is associated with a warming of 0.85 °C in global mean surface temperature over the period 1880–2012 (IPCC, 2013). Apart from the rise of ambient temperature, global climate change is projected to increase the frequency and duration of extremely high temperatures (Kravchenko et al., 2013). As a result of the exacerbation of thermal constraints and adaptations, global warming is one of the potential causes of the detrimental effects on human general living and working environments (WHO, 1990; Kalkstein and Smoyer, 1993; Easterling et al., 2000; Kjellstrom et al., 2009; Balogun et al., 2010). These impacts may include the increase of the risk of heat stroke (Bouchama and Knochel, 2002) and the exacerbation of a wide range of heat-related illnesses (Kravchenko et al., 2013).

The local climate change varies depending on geographic and climatological characteristics (Kjellstrom et al., 2009). Tropical and subtropical areas during summer seasons routinely experience high climatic temperatures and high humidity levels that are further intensified by global warming (IPCC, 2007). Moreover, rapid urbanization associated with urban heat island effect also substantially raises fast and high levels of local temperatures (Oke, 1973; Rizwan et al., 2008). Thus, heat exposure poses crippling effects on human health and well-being in tropical and subtropical regions, particularly those in cities and urban areas (Lucas et al., 2014). Hong Kong (22°18N, 114°10E), which is located in the subtropical south China coast in the East Asian monsoon region, is a typical city that has high urbanized level and subtropical climate. An increase of 0.16°C per decade was observed from 1985 to 2014 (HKO, 2015a). The nature of urbanized and climatic conditions in Hong Kong generally exhibits inherent and inevitable threats to human safety and health.

In conjunction with hot and humid weather, occupational settings that involve strenuous physical workloads and prolonged work duration potentially pose excessive heat load for working people (Pérez-Alonso et al., 2011). Thermal and/or cardiovascular load will continue to rise if the excessive heat generated within the body is not fully dissipated (Chen et al., 2003), which can lead to the impairment of physiological, mental, and behavioral functions (González-Alonso et al., 1999; Nybo and Nielsen, 2001; Hansen et al., 2008; Hargreaves, 2008). Apart from productivity loss and the consequent economic effect, heat stress as one of the major occupational hazards can provoke deleterious repercussions on health and even result in potential lethality (Hancher and Abd-Elkhalek, 1998; Inaba and Mirbod, 2007).

Construction workers are more susceptible to heat stress than other working people (Helander, 1991), as evidenced by the higher frequency of the reported heat-related casualties in the local construction industry (Chan et al., 2013a). As shown in Figure 1.1, 23 fatal cases and 52 injuries induced by heat stress were reported within the span of 15 years in Hong Kong. Among these cases, heat illnesses generally included heat cramps, heat exhaustion, and heat stroke, which were associated with painful cramping in the muscles, emesis, confusion, and vertigo, followed by unconsciousness, convulsions, and eventually deaths. In particular, one fatality and two injuries occurred when workers fainted because of heat stroke and then fell from height. These incidents imply that heat stress may be the potential causal factor (Bonauto et al., 2007) and even an initial cause of many other accidents (Pérez-Alonso et al., 2011; Rowlinson et al., 2014). The alarming heat-related accidents in the local construction industry have raised overwhelming concern and compelled government agencies, industry, and the academia to develop and implement appropriate precautionary measures that can protect workers against heat stress.

Figure 1.1 The reported heat-related casualties in the Hong Kong construction industry



Sources: Heat-related casualty cases in the construction industry of Hong Kong were collected from over 110 newspaper cuttings between 1998 and 2014.

Database: WiseNews.

Search method: Keywords for "construction sites/workers and heat stroke" (in Chinese), Region: Hong Kong (http://libwisenews.wisers.net/wisenews/index.do?new-login=true)

A total of 75 cases in the construction industry between 1998 and 2014 were obtained.

1.2.2 The current heat stress precautionary measures in Hong Kong

Formulating appropriate heat stress precautionary measures is one of the major concerns of researchers and practitioners from both moral and economic perspectives (Miller et al., 2011; Kjellstrom, 2000). Controlling heat stress may offer multiple benefits, including decrease in accidents and morbidity rates, prevention of the corresponding financial and legal issues, increase in productivity, and improvement of the sense of social well-being (Ayyappan et al., 2009; Edwards and Bowen, 1998). In this respect, it is of importance to implement proper precautionary measures to conquer heat stress in workplaces. The government and the industry have taken initiatives to lay down a series of precautionary guidelines and fundamental practice notes to safeguard workers laboring in hot weather. Significant progress has been achieved in the extensive development of control measures in Hong Kong over the past decade (Table 1.1).

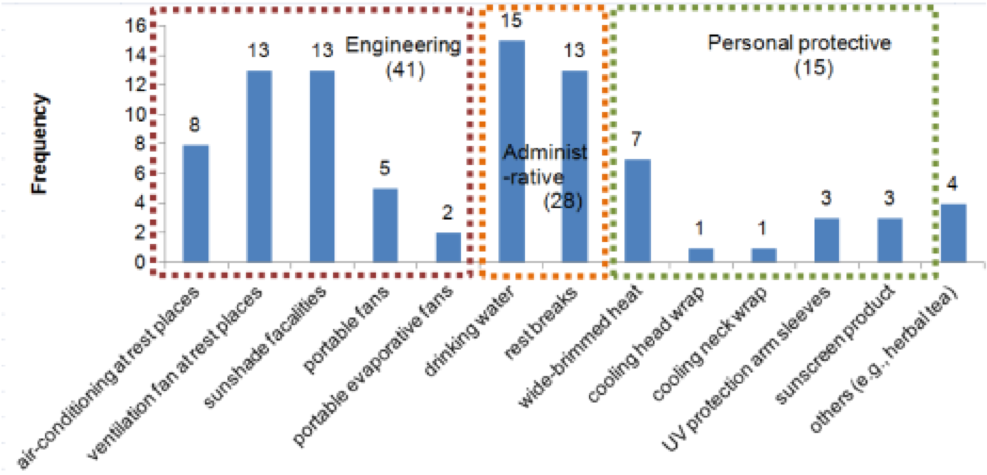
Table 1.1 Guidelines and practice notes for working in hot weather in Hong Kong

Organization	Year (latest version)	Title
Architectural Services Department	2011	Guidance Notes on Safety Measures for Working in Hot Weather
CIC	2013	Guidelines on Site Safety Measures for Working in Hot Weather
HKO	2015b	Cold and Very Hot Weather Warnings
Labor Department	1998	Heat Stress (Chinese version only)
	2004	Guidance Notes on Health Hazards in Construction Work
	2009	Risk Assessment for the Prevention of Heat Stroke at Work
	2010	Checklist for Heat Stress Assessment at Construction Sites
	2014	Prevention of Heat Stroke at Work in a Hot Environment
OSHC	2008a	Prevention of Heat Stress (Chinese version only)
	2008b	Safety Precaution in Hot Weather (Chinese version only)
	2012	Occupational Safety and Health in Very Hot Weather (Chinese version only)

A series of heat stress precautionary measures incorporating environmental engineering controls, administrative controls, and personal protective controls (OSHA, 1999) have been addressed in these guidelines and practice notes. Based on the understanding of the current industrial guidelines for working in hot weather as well as the implementation of control measures among the 15 surveyed construction companies, an overview of the practicality of each type of heat stress precautionary measure is presented. Environmental engineering controls are often utilized to mitigate or eliminate hazardous exposure to the physical environment. The provisions of natural or mechanical ventilation allow air circulation through a confined working space to remove excessive heat and provide enough oxygen. Shields or insulation at workplaces help workers avoid exposure to direct sunlight and mitigate radiation heat source. Portable cooling equipment, such as portable blowers and air fans, can deliver continuous air and remove heat in the work area. The provisions of air conditioning at rest places may promote post-work recovery or pre-work cooling, as well as improve thermal comfort through the distribution of the cooled air to an occupied space. Portable blowers and fans without cool air often work by enhancing convection and evaporation transfer between the human body and the surrounding environment. However, evaporation may be affected, to a large extent, by the water vapor pressure gradient of the atmosphere that is determined by relative humidity and air temperature (Mackay and Matsugu, 1973), whereas convection can be influenced by the gradient between the ambient and the body skin temperatures (Havenith, 1999). Hence, the provisions of portable blowers and fans become less effective when the surrounding environment is highly humid or when the temperature gradient is slight. Although environmental engineering controls are prevalent at construction sites (Figure 1.2), they are not always practical in outdoor working sites because congested site conditions may preclude the installation of blowers or shields that can cover the whole site area

(Pandolf et al., 1995). Additionally, meteorological monitoring is scarcely employed at construction sites in Hong Kong, although it is suggested as a reliable and practical approach in predicting the level of climatic heat stress that workers are subjected to at working places (e.g., Yi and Chan, 2014a; Chan et al., 2012a, 2012b, 2012c; Bates and Schneider, 2008).

Figure 1.2 Precautionary measures for working in hot weather implemented in the fifteen surveyed construction companies



Source: A questionnaire survey titled *Study on the effectiveness of personal cooling equipment for protecting workers from heat stroke while working in a hot environment – Follow-up survey (Summer 2013) – For management staff* in the project of The OSHC Research on Effectiveness of Personal Cooling Equipment – Extended Study (OSHC Research Grant No. CM/4R/2011-01). A total of 15 construction companies were involved in this questionnaire survey.

Administrative controls are the assigned or rescheduled work practices and policies implemented by the employer, which aim to reduce the magnitude, duration, and/or frequency of worker exposure to risk factors (Federal Register, 2001). The prevalent administrative controls among the 15 construction companies include the provisions of adequate water intake and enough rest breaks (Figure 1.2). Maintaining adequate hydration is one of appropriate strategies to lessen the adverse effects of heat stress on the human body (Miller and Bates, 2007a) because dehydration is associated with deleterious health effects, such as heat stroke (Bates and Schneider, 2008). A proper work-rest schedule can maximize the labor productivity and minimize the occurrence of heat stress (Yi and Chan, 2013a); thus, contributing to the improvement of the comfort, health, and performance of working people (Genaidy and Al-Rayes, 1993). Health education programs are advocated as an effective means in changing the sun protective behavior of outdoor workers (Borland et al., 1991); however, the effectiveness and implementation quality of these programs in the local construction industry has not been documented yet. Body heat strain monitoring for physiological or perceptual parameters is also scarcely implemented at construction sites in Hong Kong, even though earlier studies have documented that this approach is contributory to estimate the heat strain levels of workers (e.g., Yang and Chan, 2015; Tikuisis et al., 2002). However, the effectiveness of administrative controls is often dependent on worker compliance and consistent supervisory enforcement (Barnes, 2011).

Personal protective control may become practical in preventing heat stress when environmental engineering and administrative controls are not feasible and effective in reducing such risks to acceptable levels (REDA and HKCA, 2005; Bernard et al., 2000). This control is inclusive of personal protective clothing (PPC) and the other relevant personal protective equipment (PPE) that can protect individuals from hazardous exposures (e.g., excessive heat exposure, hazardous materials). The effectiveness of a wide variant of personal cooling garments that enhance a cooler microclimate surrounding the person (Nunneley, 1970; Pandolf et al., 1995) has been extensively documented in the fields of military, firefighting, sports, and occupational settings (e.g. Hadid et al., 2008; Selkirk et al., 2004; Arngrïmsson et al., 2004; Furtado et al., 2007; Choi et al., 2008). The implementation of personal cooling garments in the Hong Kong construction industry is limited because of the uncertain benefits and evident costs (Wong et al., 2014a). The commonly used PPE on Hong Kong construction sites included cooling wraps, wide-brimmed hat, UV protective arm sleeves, and sunscreen (Figure 1.2). Nevertheless, the frequency of the usage of PPE was much less than that of utilizing the other measures among the 15 surveyed companies. Through the unconcealed videotaped observation and supplement questionnaire survey, Chan et al. (2013a) pinpointed that inappropriate dressing behaviors and insufficient personal protection, such as semi-nude behavior and low frequency of using head/arm shades (Figure 1.3), might serve as alarm signals of high risks of skin cancer due to the direct exposure to the ultra violet. This calls for thorough attention to design and engineer appropriate summer work uniform for construction workers. Overall, the benefits of personal protective controls in combating human heat strain remain arguable because of the limited scientific research on addressing this issue in the construction industry.

Figure 1.3 Examples of inappropriate dressing behaviors

Bareness

Wearing shorts

Source: Video clips obtained from a series of field studies between 2010 and 2011 in the research project titled *Experimental Research on Health and Safety Measures for Working in Hot Weather* (RGC Project No. PolyU510409).

1.2.3 Introduction of the two types of work uniforms

Scientific research on ascertaining the role of summer work uniform in helping construction workers combat heat strain is lacking. Inappropriate dressing behavior potentially induces inherent risks of heat stress among construction workers (Chan et al., 2013a). In this regard, designing an appropriate summer work uniform for construction workers, which considers both scientific rigor and practical problem solving, is urgently necessary. The Hong Kong Polytechnic University research team initiatively designed and engineered an anti-heat stress uniform (AHSU, including a short-sleeved shirt and a pair of long pants) based on comprehensive consideration of fabric properties and smart design (Chan et al., 2015a; HKPolyU, 2014). This newly designed uniform is compared with a commercially available trade uniform (TRADE) that is commonly worn by construction workers (Figure 1.4) to determine the efficacy, effectiveness and acceptability of AHSU. The fabric properties of each uniform are given in Table 1.2. The t-shirt of AHSU has better ability in moisture management and air permeability than that of TRADE, while the pants of AHSU have better ability in moisture management than that of TRADE. Meshed reflective strip in the t-shirt of AHSU has superior air permeability, while reflective strip in TRADE is airproof. In addition to the fabric properties, the smart design of AHSU exhibits as a loose-fitting design (Figure 1.5) and different front and back design of meshed reflective strips (Figure 1.6). Subsequent to gaining understanding of the fabric properties of these two work uniforms, further evaluation of their effects on human heat strain would be conducted to determine whether AHSU is adept at alleviating body heat strain compared with TRADE.

Figure 1.4 Appearance of AHSU (left) and TRADE (right)

Table 1.2 Fabric properties of the two types of uniform

Fabric properties (Testing standard)	TRADE			AHSU			
	Polo shirt	Long pants	Solid reflective strip	Polo shirt–Main body	Polo shirt – meshed fabric on the sides of the body	Long pants	Porous reflective strip
Fiber content	65% cotton, 35% polyester	100% cotton	100% polyester	100% Coolmax fiber	100% polyester	60% cotton, 40% polyester treated by Nano-siliver iron	100% polyester
Fabric structure	Plain knitting	Twill weave	Coating	Bird-eye structure	Warp knitting	Twill weave	Coating
Thickness (mm)[a]	0.83	0.57	0.14	0.62 [c]	0.62	0.48 [c]	0.18
Weight (g/m^2)[a] (ASTM D3776, 2013)	197.36	257.37	218.67	154.13 [c]	153.45	195.04 [c]	207.51
Overall moisture management capacity[a] (SN/T 1689.1-2005; Hu et al., 2005)	0.51	0.08	N/A	0.80[c]	0.63	0.86 [c]	N/A
Air resistance (kPa•s/m)[a] (KES-Kawabata Evaluation System)	0.14	1.92	∞	0.06 [c]	0.03	1.96	0.034
Water vapor permeability (g/m^2/day)[b] (ISO 15496, 2004)	600.53	507.44	N/A	593.13	N/A	530.58	N/A

Note: a: average value on 10 fabric samples;

b: average value on 5 fabric samples;

c: $p<0.05$ indicated the significant difference in (main body) fabric properties between TRADE and AHSU as tested by univariate ANOVA

Figure 1.5 Size (unit: cm) specification of TRADE and AHSU (in middle size)

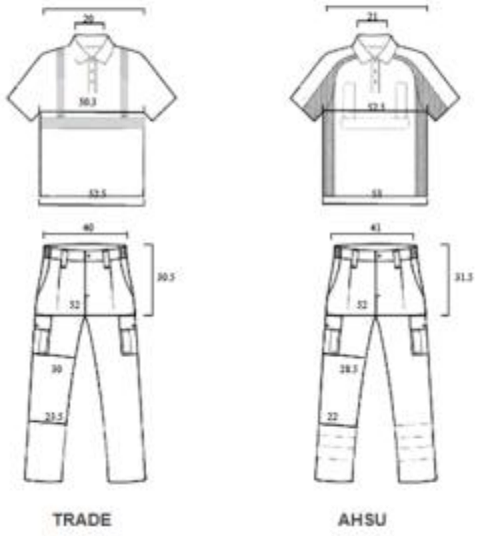


Figure 1.6 Different front (left) and back (right) design in AHSU

1.3 RESEARCH PROBLEM

Most existing precautionary guidelines conventionally take the recognized international standards (e.g., NIOSH, 1986) as action-triggering benchmarks (Rowlinson et al., 2014). However, these guidelines are lacking of validity under varying geographical, cultural, and socioeconomic contexts, which may result in the overestimation or underestimation of the risk of excessive heat exposure (Rowlinson et al., 2014; Rowlinson and Jia, 2014; Lucas et al., 2014). Developing regional guidelines with continuous updates can advance knowledge of the effect of global climate change on work-related heat stress (Rowlinson and Jia, 2014). Re-engineering and implementation of effective intervention strategies with a robust scientific basis become extremely important in the management of heat stress risk in construction (Rowlinson et al., 2014). The process of quantifying heat stress/strain can contribute to the facilitation and development of appropriate heat stress prevention strategies for the regional-specific requirements. A set of good practices and sound advices have been formulated based on employing scientific rationale and methodologies at regional sites (e.g., Bates and Schneider, 2008; Bates et al., 2010; Miller et al., 2011; Chan et al., 2012a; Chan et al., 2012b; Yi and Chan, 2013a; Yi and Chan, 2014a; Rowlinson and Jia, 2014). However, the existing guidelines are some "dos and don'ts" actions (Yi and Chan, 2013a) that lack definite criteria to assist in identifying the effectiveness and practicality of personal protective measures on helping workers combat heat stress. Owing to the limited industry standards, the effectiveness and practicality of these guidelines have been questioned particularly because they involve ambiguous terms, such as wearing thin, air-permeable, light-colored clothes made of natural fabrics (CIC, 2013).

A significant body of literature has been dedicated to research on clothing thermal performance based on both theoretical and empirical analyses. However, research methodologies and application scopes for such clothing are well documented in the field of sportswear and impermeable clothing but are rarely given attention on general work clothes. Even though laboratory experiments can provide reliable evidence supporting that wearing appropriate clothing can alleviate body heat strain under tightly controlled conditions (e.g., Kwon et al., 1998; Brazaitis et al., 2010), the results may not always be feasible for formulating guidelines to manage heat stress in real-life settings (Budd, 2008) because of the varying environmental and physical conditions.

This situation heightens the overwhelming need to conduct occupational intervention research that will enable researchers, practitioners, and policymakers to develop acceptable and feasible interventions that can be rigorously delivered to the target population (Lindenberg et al., 2001). Intervention research has been widely employed in the applied disciplines, such as occupational epidemiology, psychology and behavior, clinical medicine, and social science, to name a few. Nevertheless, construction has not been the subject of intervention research largely because of the complexity of the industry, which is marked by diffused control, small employer firms, temporary worksites, multi-employer worksites, temporary employment, and numerous trades (Ringen and Stafford, 1996). In general, occupational intervention research can be divided into three consecutive phases, namely, development, implementation, and impact phases (Goldenhar et al., 2001). Intervention development research is fundamental prior to intervention implementation and impact phases (Goldenhar et al., 2001). Developing an efficacious, effective, and diffusible strategy is a paramount need in the intervention development phase (Camp, 2001). In the current study, efficacy refers to the effects of an intervention under tightly controlled conditions and effectiveness denotes its effects under real-world settings (Shannon et al., 1999). A diffusible intervention is associated with its acceptability to wide population (Camp, 2001). Limited effort has been exerted so far to elaborate on the rationale, methodologies, and practicality of the intervention strategies, such as wearing the appropriate work uniform (e.g., AHSU), in the construction field. Intervention development research herein is proposed to determine the benefits (e.g., efficacy, effectiveness, and acceptability) of AHSU as a heat stress intervention.

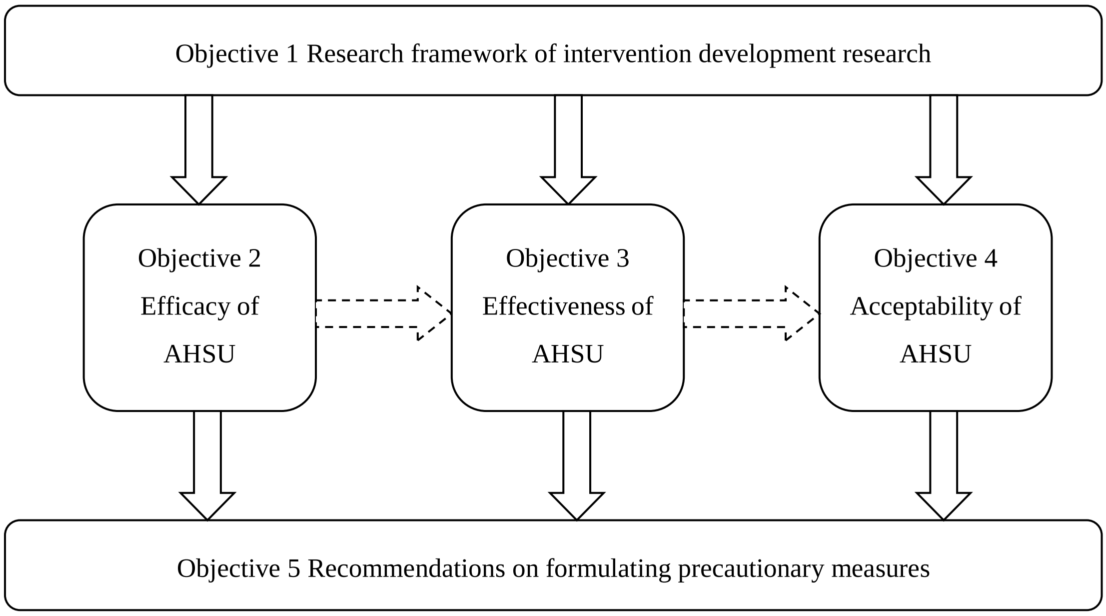
1.4 RESEARCH AIM AND OBJECTIVES

The present study aims to facilitate development research on heat stress intervention in construction. The specific objectives are as follows:

1. To set the research framework for conducting intervention development research.
2. To assess the efficacy of AHSU on combating heat strain.
3. To evaluate the effectiveness of AHSU on combating heat strain.
4. To examine the acceptability of AHSU when diffusing to wider population.
5. To formulate recommendations on formulating precautionary measures for working in hot weather.

As depicted in Figure 1.7, the study begins by establishing the research framework for conducting the heat-stress intervention development studies (Objective 1). Based on Objective 1, a series of research activities are executed for evaluating the efficacy, effectiveness, and acceptability of an intervention strategy – wearing AHSU (Objectives 2-4). Finally, recommendations on formulating precautionary measures against heat stress in the construction industry are proposed (Objective 5).

Figure 1.7 Relationships among the objectives



1.5 SIGNIFICANCE AND VALUE

Construction workers are at a high risk of suffering from heat-related casualties regarding the verifiable reported incidents in Hong Kong. There is a paramount need to formulate and implement proper precautionary measures to protect workers from heat stress. The existing guidelines and practice notes for working in hot weather are arguably lacking in scientifically rigorous standards that are valid and practical to implement in the Hong Kong construction industry. Thus, this study attempts to provide a well-structured research framework that is verified through a case study and to facilitate the delivery of an industry standard. This research aims to advance heat stress intervention development research in construction, which may give researchers, practitioners, and policymakers a fresh and profound insight that can allow the formulation of tailor-made precautions for safeguarding labors working in hot weather.

The work uniform, which acts as an evaporative barrier and a protective mechanism, is an integral part of work life (Li, 2001; Gavin, 2003). Little attention has been paid to engineering appropriate summer work clothes for construction workers. As a consequence, the capability of such work clothes to attenuate the detrimental effects of heat stress and to improve wearing comfort remains questionable. The current study is expected to contribute to facilitating a holistic assessment on the role of summer work uniform in combating human heat strain.

Occupational intervention research plays as an important role in the formulation and development of effective and practical intervention strategies to improve the health and well-being of working people. At present however, heat stress intervention research in construction has received little attention. Conducting intervention research enables researchers and practitioners to facilitate a comprehensive evaluation of the specific intervention measure toward the generation of convincing outcomes. It is anticipated that this study will contribute to developing heat stress intervention research in the field of construction and furnishing a solid and replicable research process for future studies.

1.6 RESEARCH APPROACH

This study adopts multiple methods and approaches to assemble research data and generate relevant information. A comprehensive literature review on intervention research was conducted. The randomized controlled trials in the laboratory experiment were executed to determine the efficacy of AHSU in 2014 (from March to May). The effectiveness of AHSU was ascertained by the randomized controlled trials in field experiment in during summer time in 2014 (from July to August). The field surveys consisting of human wear trials and questionnaire surveys were administered between July and August of 2014 to determine the acceptability of AHSU. Finally, recommendations on formulating precautionary measures against heat stress in the construction industry were proposed. Further details on research methodology are amplified in Chapter 3. Figures 8 and 9 depict an overall flow chart of this study and the sequence of chapters, respectively.

Figure 1.8 Research flow of the study

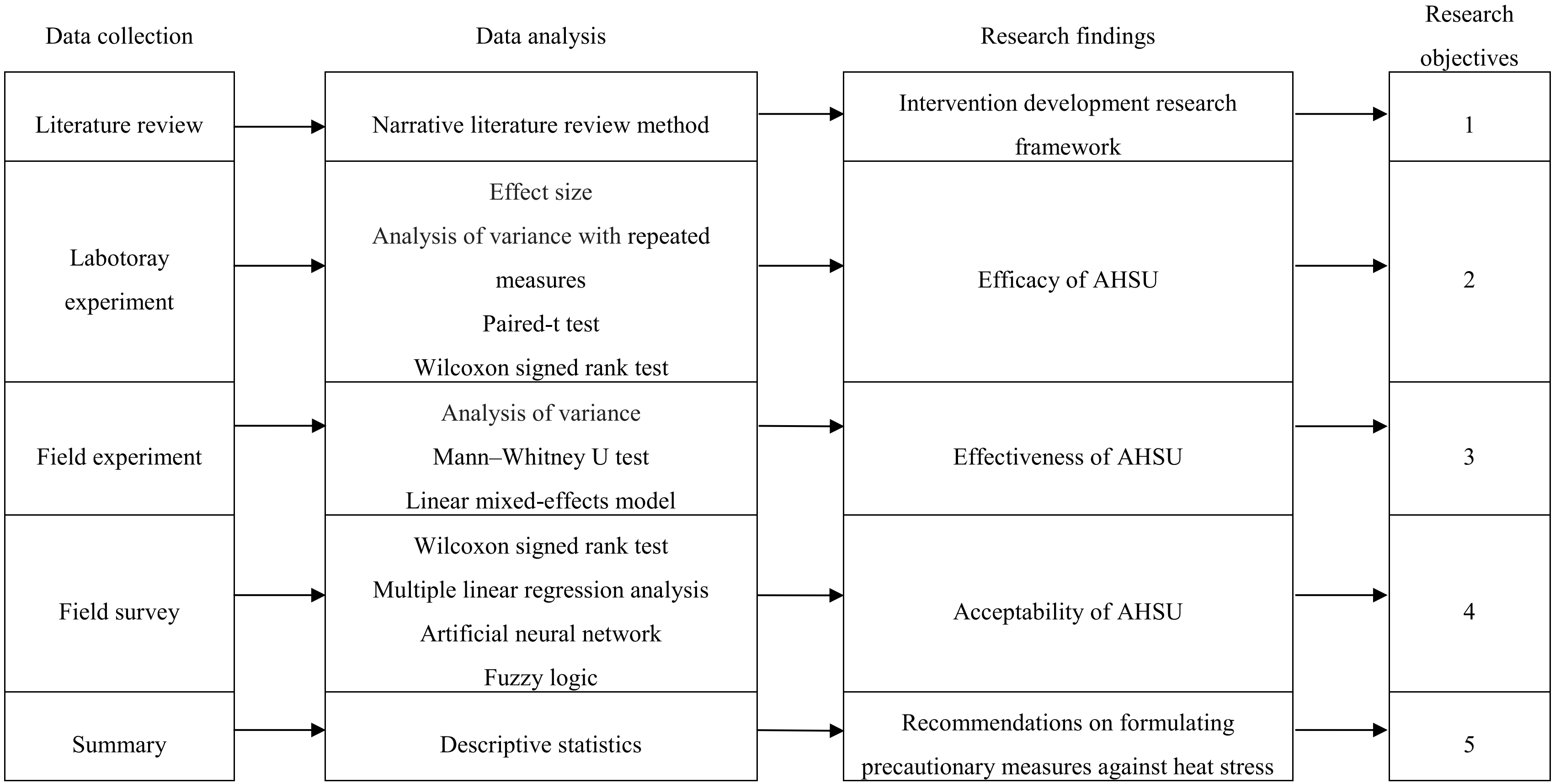
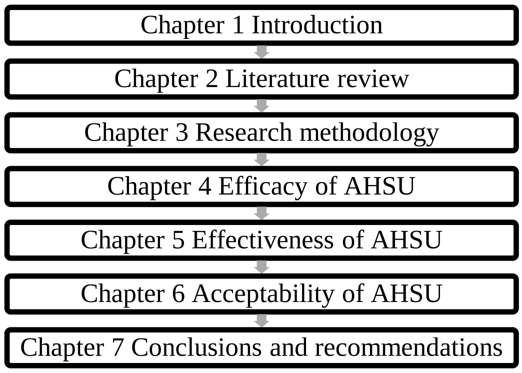


Figure 1.9 Sequence of chapters in the thesis



1.7 CHAPTER SUMMARY

Heat stress exerts detrimental impacts on worker safety and health, as evidenced by the alarming heat-related casualties in the Hong Kong construction industry. The local government and the industry have expressed grave concern on working in hot weather through promulgating and implementing a series of guidelines and practice notes. Nevertheless, the effectiveness and practicality of these precautionary measures in combating body heat strain are arguable in terms of the lack of regional specifics and definite standards. To facilitate practitioners and policymakers in developing effective and feasible precautionary measures against heat stress, this study attempts to develop a research framework that will be verified through a case study – the role of summer work uniform – that is expected to give a fresh insight on heat stress intervention studies in construction.

The objectives of this study include setting the research framework for conducting intervention development studies, evaluating the efficacy, effectiveness, and acceptability of the newly designed anti-heat stress uniform (AHSU) on combating body heat strain, and formulating recommendations for formulating precautionary measures for working in hot weather.

CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

This chapter reviews the literature that has laid the foundation for the research objectives set in Section 1.4. The literature review mainly focuses on the following three areas:

2.2 DEVELOPMENT RESEARCH ON HEAT STRESS INTERVENTION IN CONSTRUCTION

This narrative literature review aims to provide a commentary on the impacts, problems, shortcomings, contradictions, or controversies (Baumeister and Leary, 1997) in heat stress intervention research in the construction industry.

2.2.1 Selection of data sources

An extensive desktop search was performed to identify heat stress intervention development studies in the construction industry. These studies were reviewed comprehensively to achieve the Objective 2 of this study. Research articles published in peer-reviewed journals between 1988 (Goldenhar and Schulte, 1994) and January 2015 were retrieved from the prevalent multi-disciplinary databases (Springer, Scopus, Science Direct, EBSCOhost, IEEE Xplore, MedLine, Web of Science, Wiley Online Library, Taylor and Francis Online) to gauge the nature and extent of intervention research. Search keywords included “heat stress” AND “construction industry” OR “construction workers”. Snowballing was also adopted using the retrieved citations to perform a new search based on the article's bibliography, authors' names, and the 'related articles' search option (Shachak and Reis, 2009). Commentaries, editorials, discussion letter, reviews, reports, and unpublished working papers were excluded, along with papers written in languages other than English. Full-length papers and abstract only meeting the following inclusion criteria were selected for the final analysis: 1) developing one or more heat stress control measures in the construction industry, and 2) adopting empirical research methodologies based on data systematically collected from experiments or observations and analyzed results via primary or secondary research efforts (Hale and Haworth, 1988; Pasadeos et al., 1997; Lazaraton, 2000).

2.2.2 Results

A total of 20 peer-reviewed papers met the inclusion criteria. The reviewed articles related to heat stress intervention research in the construction industry are outlined in Table 2.1. These studies concentrated mainly on developing one or more appropriate heat stress intervention strategies. Moreover, these articles were generally conducted at the site level rather than at the national and international levels and their scope was neither company- nor industry-wide. This literature review intends to determine the general category to which the intervention belongs, to outline the employed methodologies, to summarize the major findings, and to present the limitations of these studies.

Category scheme is useful for describing the general focus of the intervention studies. Three types of heat stress control measures, namely, administrative, environmental engineering, and personal engineering controls have been clarified by the OSHA (1999) and the NIOSH (1986). The results indicate that current research directions focus mainly on developing and stipulating appropriate administrative intervention strategies, such as rescheduling of work rotation, provision of water, and monitoring human heat strain. Strategies for developing these interventions have focused on the process of quantifying heat stress (causes) and strain (consequences) to formulate a proper intervention. This process can be derived from the human thermo-regulation status under exercise-heat stress. For instance, Bates et al. (2010) and Miller and Bates (2007a) investigated the hydration status of construction workers in Abu Dhabi and Australia and advised that interventions are required to ensure that workers under extreme heat stress conditions maintain adequate levels of hydration. Chan et al. (2012a, 2012b), Yi and Chan (2013a, 2014a, 2014b), and Rowlinson and Jia (2014) proposed work and/or recovery thresholds after examining body heat strain limits arising from multiple heat stressors (e.g., meteorology, work and individual characteristics) in the Hong Kong construction industry. Heat strain monitoring systems are recommended to safeguard construction workers under safe physiological thresholds (Yabuki et al., 2013; Yang and Chan, 2015; Chan and Yang, 2015).

Environmental heat stress monitoring is a prevalent topic that has been well documented in previous studies (Miller and Bates, 2007b; Pérez- Alonso et al., 2011; Yi and Chan, 2014a; Montazer et al., 2013). The Wet Bulb Globe Temperature (WBGT) and the Thermal Work Limit (TWL) are two of the most widely used environmental monitoring indices in construction sites. However, the limitations of using these environmental indicators have been recognized. The reliability of these indicators remains debatable under different environmental conditions (Budd, 2008), and their environmental threshold must be compatible with personal characteristics, such as work pace, hydration status, and acclimatization status (Bates and Schneider, 2008; Miller and Bates, 2007b). Thus, these environmental thresholds may be invalid because of the changes in the boundary thresholds. Limited efforts have been exerted to develop other types of environmental engineering strategies, such as provision of air fans and working under the shade, although industrial guidelines acknowledge the importance of adopting these measures. Sound scientific evidences that could ascertain the effectiveness of these measures in aiding workers to combat heat stress have not been well documented.

Personal engineering interventions attempt to provide personal devices to protect working people from heat stress. Heus and Kistemaker (1998) conducted human wear trials in laboratory experiments to examine the efficacy of a new work uniform in reducing physiological and perceptual strain. However, the effectiveness of this novel work uniform in a real-work setting and its feasibility in construction sites has yet to be verified. Although Chan et al. (2015b, 2015c) conducted a series of questionnaire surveys to address the acceptability and practicality of wearing personal cooling vests at construction sites, the effectiveness of these garments in reducing body heat strain has not been proven. The limitations of these studies must be addressed, and the research methods must be refined for further work.

Intervention research in applied disciplines has been performed extensively, particularly in the fields of occupational epidemiology, psychology and behavioral science, clinical medicine, and social science (e.g., Evanoff et al., 2003; Krause et al., 1999; Camp, 2001; Smedley and Syme, 2001). Nevertheless, the construction industry has not been the focus of intervention research largely because this complex industry has markedly diffused control, small employer firms, temporary worksites, multi-employer worksites, temporary employment, and numerous crafts (Ringen and Stafford, 1996). In particular, little effort has been exerted on elaborating on the rationale, methodologies, and practicality of the intervention strategies for heat stress prevention in the construction industry. This condition may be disadvantageous to formulating solid and proper strategies to aid construction workers in combating heat stress. Several limitations have been identified from previous occupational intervention research, including unclear theoretical basis, deficient research methodologies, and difficulty in applying the outcomes to practice (Goldenhar and Schulte, 1994; Goldenhar and Schulte, 1996). Limited efforts have been exerted to develop heat stress intervention in the construction industry, and interests from the scientific community in studying heat stress intervention strategies have only awakened to develop in recent years. The lack of sophisticated research methodologies may be one of the major difficulties in conducting such a study. Previous studies employed more of a "try it and see" strategy based on the intuition and experience of researchers (Campbell, 1986). Several methodological problems in occupational intervention studies continue to be disregarded, although Goldenhar and Schulte (1994) had underlined these problems two decades ago. In the current development research on heat stress intervention in the construction industry, most studies lack of a control group, and rarely adopt randomized design. Population sampling is also arbitrary without justification on its statistical or practical significance. The reliability of the measurement instruments has also not been calibrated or documented rigorously. Regarding these existing limitations in research methodologies on heat stress intervention studies, there is a pressing need for future works that more fully elucidate a well-structured research framework.

Table 2.1 Overview of heat-stress intervention development studies in the construction industry

Author(s) (year)	Source	Intervention	Study design						
			Regions	Meteorology	Approach	Participant	Major measurements	Analysis	Major findings
Administrative controls									
Bates and Schneider, 2008	J Occup Med Toxicol	Fluid intake Self-pacing Threshold of U_{SG}	The United Arab Emirates	TWL of 189~238 $W \cdot m^{-2}$	Quasi-experiment [field]	22 carpenters, steel fixers, and general laborers	WBGT, TWL, HR, T_{ca}	Correlation analysis	Workers are advised to take enough fluids and to work in self-pace to avoid adverse physiological effects.
Bates et al., 2010	Ann Occup Hyg	Fluid intake	Abu Dhabi and Dubai	Summer	Quasi-experiment [field]	105 construction workers and 81 indoor workers	U_{SG}	Descriptive analysis	Maintaining adequate hydration is the single most important intervention in the management of work in heat.
Chan et al., 2012a	Build Environ	Optimal recovery time	Hong Kong	T_a of 30°C, RH of 75%	Quasi-experiment [lab]	10 males and 4 females	HR, T_{ca}, PhSI, Rest time	Curve fitting	The optimal recovery time after exhaustion in a hot and humid environment is determined.
Chan et al., 2012b	Build Environ	Optimal recovery time	Hong Kong	mean WBGT of 30.8°C	Quasi-experiment [field]	19 rebar workers	HR, T_{ca}, PhSI, Rest time	Curve fitting	The optimal recovery time after

									exhaustion is determined in real-work settings.
Chan and Yang, 2015	Int Arch Occup Environ Health	PeSI monitoring	Hong Kong	Mean WBGT of 31.8 °C	Quasi-experiment [field]	16 male construction workers	RPE, Thermal sensation, Heart rate, PeSI, PSI_{HR}, RHR	Bivariate correlations; Regression analysis	The PeSI is a simple, robust, reliable, and user-friendly tool for heat strain assessment in occupational settings.
Miller et al., 2011	Ann Occup Hyg	Self-pacing	Abu Dhabi and Dubai	TWL of ~190-290 $W{\cdot}m^{-2}$	Non-experiment [field]	105 construction workers	TWL, HR, T_{ca}	Descriptive analysis	Adjusting work rate may be an important protective behavior for workers under thermal conditions.
Miller and Bates, 2007a	Ann Occup Hyg	Fluid intake	Australia	TWL of 190-213 $W{\cdot}m^{-2}$	Non-experiment [field]	Outdoor workers including construction	WBGT, TWL, U_{SG}	Descriptive analysis	Maintaining adequate hydration is suggested for workers in hot conditions.
Montazer et al., 2013	Int J Occup Med Environ Health	Fluid intake	Iran	mean shadow temperature from 23.6-36.5°C	Non-experiment [field]	60 construction workers	TWL, U_{SG}	Descriptive analysis	Monitoring workers' hydration status should be executed in hot conditions no

									matter whether they are exposed to direct sunlight or not.
Rowlinson and Jia, 2014	Ann Occup Hyg	Optimized work-rest regimen for paced work Workers' self-regulation during self-paced work	Hong Kong	mean WBGT of 29.6°C	Non-experiment [field]	216 construction workers from 37 trades	WBGT, HR, T_{ca}, Predicted heat strain model	Curve fitting	The WBGT threshold system can be practical for the management of heat stress risk in the specific localized and regional situations.
Pérez-Alonso et al., 2011	Build Environ	Optimized work-rest regimes	SE Spain	mean WBGT of 19.55-29.76 °C	Non-experiment [field]	N/A	Meteorological parameters	Descriptive analysis; Curve fitting	The proposed work-rest regimes may control the risk of heat stress.
Yabuki et al., 2013	Visualiz Eng	The Construction Workers' Heatstroke Prevention system	Japan	N/A	Computer simulation	N/A	T_c, Risk of heat stroke	Descriptive analysis	The proposed system enables users conduct further action based on the predicted heatstroke risk.
Yang and Chan, 2015	J Ther Biol	PeSI monitoring	Hong Kong	T_a of 34.5°C, RH of 75%	Randomized experiment [lab]	10 males, 2 females	RPE, Thermal sensation, Heart rate, T_c, PeSI, PhSI	Correlation and regression analysis	The PeSI offers considerable promise for physiological strain assessment in hot

									environment.
Yi and Chan, 2014a	J Manage Eng	Heat tolerance time	Hong Kong	Summer	Non-experiment [field]	19 rebar workers	HI, WBGT, TWL, RPE, Time, API, Age, PBF, ADH, SH, EC, RER, RHR’	Multiple linear regression, Model validation	The early warning system can be linked with the local weather forecast based on the heat tolerance time at different degrees of heat exposure.
Yi and Chan, 2013a	Build Environ	Optimized work-rest schedule	Hong Kong	Summer	Data simulation	N/A	Heat tolerance time, Optimal recovery time	Monte Carlo simulation	The proposed optimized work-rest schedule can maximize productive time and safeguard the health and safety of rebar workers at the same time.
Yi and Chan, 2014b	J Comput Civ Eng	Optimal Work Pattern	Hong Kong	Summer	Data simulation	N/A	Heat tolerance time, Optimal recovery time	Monte Carlo simulation	The proposed work pattern not only minimizes the occurrence of heat stress but also maximizes direct-work rates on construction site.
Environmental engineering controls									

Bates and Schneider, 2008	J Occup Med Toxicol	TWL monitoring	the United Arab Emirates	TWL of 189~238 W·m^{-2}	Non-experiment [field]	22 carpenters, steel fixers, and general laborers	WBGT, TWL, HR, T_{ca}	Correlation analysis	TWL is found to be a valuable tool in assessing thermal stress in Gulf conditions.
Chan et al., 2012c	J Manage Eng	TWL monitoring	Hong Kong	mean TWL of 159 W·m^{-2}	Non-experiment [field]	10 rebar workers	RPE, TWL, Time, API, Age, PBF, ADH, SH, EC, RER, RHR'	Factor analysis, Multiple linear regression	The TWL may be an alternative to assist with the management of heat stress risk in construction.
Miller and Bates, 2007b	Ann Occup Hyg	TWL monitoring	Australia	[lab]: TWL 198~154 W·m^{-2} [field]: mean TWL of 199 W·m^{-2}	Quasi-experiment [lab], Non-experiment [field]	8 construction workers	TWL, metabolic heat load, WBGT, HR, T_c, relative perceived fatigue	Descriptive analysis	Corresponding management protocols can be applied with using TWL.
Pérez-Alonso et al., 2011	Build Environ	ESI monitoring	SE Spain	mean WBGT of 19.55-29.76 °C	Non-experiment [field]	N/A	Meteorological parameters	Descriptive analysis; Curve fitting	The validity of the ESI index for determining the heat stress is demonstrated.
Yi and Chan, 2014a	J Manage Eng	WBGT monitoring	Hong Kong	Summer	Non-experiment [field]	19 rebar workers	HI, WBGT, TWL, RPE, Time, API, Age, PBF, ADH, SH,	Multiple linear regression, Model	The WBGT has the highest validity and practicality in predicting the

							EC, RER, RHR'	validation	effects of heat stress on construction workers.
Personal protective controls									
Heus and Kistemaker, 1998	Env Ergon	New clothing system VS. Traditional clothing system	N/A	T_a of 30°C, RH of 70%, SR of 700 $W \cdot m^{-2}$	Randomized experiment [lab]	6 males	T_c, T_{sk}, Sweat rate, Comfort sensation	Paired t test	No differences between New and Traditional clothing were found in physiological or subjective parameters (except comfort sensation) during exercise.
Chan et al., 2015b	J Civil Eng Architect Res	Hybrid cooling vest; Cooling vest with frozen gel packs	Hong Kong	Summer	Field survey including wear trial and questionnaire survey	36 construction workers	T_{ca}, HR, SBP, DBP, RPE, Subjective sensations	Descriptive analysis	The findings contributed to practical application of a cooling vest for construction workers.
Chan et al., 2015c	Facilities	Hybrid cooling vest	Hong Kong	Summer	Questionnaire survey	68 construction workers	Subjective sensations	Descriptive analysis	The design of the cooling vest should be improved prior to its application to wide populations.

Abbreviations: PeSI – perceptual strain indext, PhSI – physiological strain index, PSI_{HR} – physiological strain index based on heart rate, WBGT – wet bulb globe temperature, TWL – thermal work limit, ESI – environmental stress index, HI – heat index, T_a – air temperature, RH – relative humidity, SR – solar radiation, HR – heart rate, T_{ca} – ear canal temperature, T_c – core temperature, T_{sk} – skin temperature, RPE – rating of perceived exertion, DH – drinking habit, API – air pollution index, PBF – percentage of body fat, SH – smoking habit, RHR' – resting heart rate, RER – respiratory exchange rate, VO_2 – oxygen consumption, MV – minute ventilation, EE – energy expenditure, EC – energy consumption, U_{SG} – urine specific gravity, SBP –systolic blood pressure, DBP – diastolic blood pressure, RHR – relative heart rate, N/A – not available/mentioned.

2.3 CLOTHING-BODY-ENVIRONMENT INTERACTION

2.3.1 Heat balance

Heat stress arises from multiple stressors, including the environment, work demands, clothing, and individual physique and neuropsychology (Barker et al., 1999; Nunneley, 1989; Li, 2001; Gavin, 2003). Heat balance is determined largely by a complex interaction between ambient environments and personal factors (i.e., metabolic activity and clothing) (Jay and Kenny, 2010). Environmental heat stress generates heat inside the body, whereas muscular activities increase metabolic rate (Sawka et al., 1995). Heat must then be dissipated from the body to the environment to prevent the body core temperature from increasing to dangerous levels (Sawka et al., 1995).

Environmental heat stress and muscular activity interact synergistically and may limit the physiological systems (Sawka et al., 1995). The heat load inside the body of occupational workers performing physical activities in a hot environment is generated from the elevated level of metabolism and is confounded further by the insulative effects of their clothing (Jay and Kenny, 2010). The process of heat exchange between the human body and the environment becomes complex when a person is clothed (Wan and Fan, 2008). Hence, understanding the dynamic heat and moisture transfer through the human–clothing–environment system and its effect on the transient physiological response is important not only for the well-being of the human body, but also to enable the design of appropriate clothing (Wan and Fan, 2008). The effect of clothing on body thermoregulation may not be singular, but rather compounded with physical work and thermal environment (Wan and Fan, 2008; Gavin, 2003).

Clothing generally forms a layer of insulation that imposes a barrier to heat transfer from the skin surface under hot and humid conditions (Havenith, 1999; Gavin, 2003). Clothing covers a large surface area of the skin and can therefore affect the body thermoregulatory responses to muscular activity (Gavin, 2003). However, this condition does not imply that appropriate dressing behavior for occupational workers should be semi-nude or wearing of mid-length shorts (Chan et al., 2013a). As an integral part of human life, clothing also protects wearers from a hazardous environment (Nielsen, 1990; Pascoe et al., 1994; Li, 2001) and helps the body adapt to the environment (Wan and Fan, 2008).

A stable thermal state can be maintained depending on the balance between heat production from metabolism and environmental heat and heat loss via conduction, convection, radiation, and evaporation (Havenith, 1999). Under hot conditions, conduction plays a minor role unless the body contacts with the cold objects directly (Havenith, 1999). When the surface temperature of the body varies from that in the environment, heat is exchanged via radiation and convection (Havenith, 1999; Jay and Kenny, 2010). However, the gradient of body skin temperature and ambient environmental temperature is small in a hot environment (Livingstone et al., 1987; Havenith, 1999). Hence, evaporation improved by air ventilation and sweating is more important for heat loss in a hot environment (Havenith, 1999). Factors such as relative humidity, low air velocity, protective clothing, or impaired sweating function (i.e., older adults and/or individuals with chronic disease) can restrict evaporative heat loss (Jay and Kenny, 2010). In view of this, the key function of summer work clothing to combat heat strain is the enhancement of the avenues of evaporative heat transfer in hot and humid weather.

2.3.2 Clothing comfort[1]

Wearing comfort is a universal and essential need for individuals wearing summer worker clothes (Li, 2001). It is the subjective judgment of a wearer under certain wear situations (Li and Wong, 2006). It is related to the subjective perceptions of various sensations, which is determined by the interactions among clothing, human body, and ambient environment, and is judged based on physical, physiological, neurophysiological, and psychological processes and factors (Li, 2001; Fourt and Hollies, 1970; Wong et al., 2002). Subjective perceptions, such as, *sultry, damp, clammy, clingy, hot, cold, and nonabsorbent*, commonly pertain to thermal-moisture sensation (Li, 2001). For summer wear and sportswear, thermal-moisture comfort is perceived to be more important than pressure comfort (Li, 2001). Pressure comfort associated with garments fitness, fabric extensibility, and garments style also is an important aspect of wearing comfort (You et al., 2002). Pressure-related sensations include *stiff, soft, loose, lightweight, heavy, and snug* perceptions (Li, 2001). To assess the pressure comfort of garments, smooth of body movement that is affected by fabric compression and resistance (Senthilkumar et al., 2012) should be determined. While fabric weight provides bending force (Griffiths and Kulke, 2002), fabric thickness determines the feeling of the wearer as to the heaviness or stiffness of a garment (Brandt et al., 1963; Mukhopadyhay et al., 2002). Summer work clothes must be designed in such a way that pressure comfort through free body movement can be achieved by reducing fabric resistance to body stretching so that the job performance of workers will not be impeded.

Human perception expressing all relevant senses and concepts must be measured

[1] Presented in a published paper: Chan, A.P.C., Yang, Y., Wong, F.K.W., Chan, D.W.M. and Lam, E.W.M. (2015). Wearing comfort of construction work uniforms. *Construction Innovation: Information, Process and Management*, 15(4), 473-492.

to understand one's judgment on clothing comfort (Li, 2001). Psychological scaling based on the scales of individual words collected from wear experience is an approach of measuring subjective perceptions (Li, 2001). Examples for describing these subjective sensations include, but are not limited to, cold, clammy, damp, clingy, snug, loose, heavy, stiff, thick, rough, smooth, soft, itchy, and scratchy (Hollies et al., 1979; Li, 2001). These perceptions can generally be divided into several underlying factors, such as thermal-moisture comfort, tactile comfort, fabric hand feel, and pressure comfort.

2.4 MEASUREMENTS OF HEAT STRESS AND STRAIN

2.4.1 Measurement of heat stress

Heat stress is associated with the gains or losses in the total heat load within the body imposed by cumulative environmental, physical, and individual factors (Bhanarkar et al., 2005; Moran et al., 2003; O'Brien et al., 2011).

2.4.1.1 Environmental heat stress

Climatological indicators are widely employed for quantifying the level of environmental stress because these indicators are simple and can be easily operated and interpreted. The Thermal Work Limit (TWL) predicts the limiting or maximum metabolic rate of the working people; a thermal environment or the level of physical exertion that construction workers are subjected to can be further classified based on this index (Miller and Bates, 2007b; Chan et al., 2012c). The Wet Bulb Globe Temperature (WBGT) index has been suggested for assessing the environmental stress at construction sites (e.g., Zhao et al., 2009; Yi and Chan, 2014a). The strength and weakness of these climatological indices, however, remain debatable under different micro-environmental conditions and validation methods (e.g., Yi and Chan, 2014a; Farshad, et al. 2014; Miller and Bates, 2007b). The TWL can only be used under limited environmental conditions in which the metabolic rates range from 60 W/m^2 to 380 W/m^2 (Brake and Bates, 2002). The WBGT has been argued to underestimate the stress of restricted evaporation under high humidity or low air ventilation (Budd, 2008). In addition, these environmental indicators are commonly incorporated with human activity, clothing, and various other factors while interpreting their outputs (Budd, 2008). This implies that the use of a single environmental indicator may result in underestimation of the adverse effects of all the stress factors, thereby introducing large errors into the evaluation of heat stress (Budd, 2008; Epstein and Moran, 2006).

2.4.1.2 Exercise-heat stress

In addition to environmental stress, physical activity that generates metabolic heat within the body also poses a high risk of heat stress to working people (Miller and Bates, 2007b). Physical workload imposes the threat of physiological stress (Dishman et al., 1994), further affecting the work-efficiency of workers in field conditions (Maiti, 2008). The physical workload of construction workers is generally evaluated based on their oxygen uptake, energy expenditure (Chan et al., 2012a; Wong et al., 2014b), relative heart rate (Gatti et al., 2014; Maiti, 2008), relative cardiovascular load (Yoopat et al., 2002), or metabolic rate (Srinavin and Mohamed, 2003; Rowlinson and Jia, 2014).

2.4.1.3 Clothing properties[2]

The thermal effects of clothing on physiological responses and exercise performance vary among different garments in the heat (Dorman and Havenith, 2005). The thermal-moisture performance of fabric can be affected by fiber characteristics, fabric structure, chemical treatment, or the resultant physical properties (Onofrei et al., 2011; Öner and Okur, 2014; Ravandi and Valizadeh, 2011). Compared with clothes made of synthetic fabrics, those made of natural fibers such as cotton with good moisture absorption properties (i.e., wicking sweat) are the more comfortable summer apparels (Kotb et al., 2011; Gavin et al., 2001). However, absorbed moisture in these natural fibers is often held firmly (i.e., water regain), thereby hindering moisture transfer (Bakkevig and Nielsen, 1995) and impairing heat dissipation (Dai et al., 2008). Traditional synthetic fibers such as polyester may not be adept at absorbing and transferring moisture. The fabric should be able to transfer sweat in both liquid and vapor forms from the skin and to release them to the environment. Two methods can be used to improve fabric properties in terms of moisture absorption and release: 1) physical modification of the fibers from round cross section to irregular shape to improve moisture wicking by generating more capillaries in the inner fabric (Mukhopadhyay and Fangueiro, 2009) (e.g., Coolmax® fiber), and 2) chemical treatment of fabrics to enhance their moisture absorption and transfer by reducing the water contact angle between the water and fiber (DeMott et al., 2014).

The thermal and moisture performance of clothing not only varies significantly in terms of fabric properties, but are also related closely to clothing design (Nielsen

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[2] Presented in a published paper: Chan, A.P.C., Yang, Y., Guo, Y.P., Yam, M.C.H. and Song, W.F. (2015). Evaluating the physiological and perceptual responses of wearing a newly designed construction work uniform. *Textile Research Journal*, DOI: 10.1177/0040517515591773.

et al., 1989). The use of meshed fabrics and loose-fitting design is highly beneficial for increasing air ventilation, which potentially promotes moisture transfer. By investigating thermal insulation and moisture vapor resistance of 10 short-sleeved t-shirts with varying opening and mesh styles using a sweating manikin, Ho et al. (2008) showed that having openings at the two vertical side panels along the side seams of a t-shirt is the most ideal design for ventilated cooling and thermal comfort in both walking and standing modes. By contrast, the results of wear trials demonstrate that meshed fabric applied at the center of the chest or the back is a superior alternative for obtaining the desired thermoregulatory response and wearer comfort (Zhang and Li, 2010). Under wind conditions, a loose-fitting design can also increase air gap and provide good ventilation, resulting in great convective heat flow from the body to the environment, as compared to tight-fitting clothes (McCullough et al., 1983). Clothing with superior fabric properties and smart clothing design could promote evaporative heat dissipation and improve wearing comfort in hot and humid environment.

2.4.1.4 Personal characteristics

Various individual factors, such as age, gender, hydration level, health condition, medicine, nutrition, acclimatization in the heat (US Army, 2003), work pace (Miller et al., 2011), aerobic fitness (Pandolf, 1978), and alcohol and smoking habits (Grassi et al., 1992) could influence individual’s responses to heat stress. Among these personal characteristics, age and fitness are the most important predictors of heat tolerance, with age being strongly correlated with heat related mortality and morbidity (Havenith, 2005). An aerobically fit individual who is acclimatized to exercise in the heat and fully hydrated may experience less body heat storage and enhance exercise performance (Sawka et al., 1984). Acclimatized workers can tolerate heat stress because of their ability to adapt physiologically as well as their more efficient heat dissipation system (ACGIH, 2009; Rowlinson et al., 2014). The loss of water and salts in ones' body (i.e., dehydration) can cause additional fatigue and aggravate the risk of heat stroke (Wästerlund, 1998). Gender difference in thermoregulation become more apparent in terms of thermal loads (Ashley et al., 2008). Self-paced work in the heat potentially avoids excessive heat strain triggered by inordinate work pace (Miller et al., 2011). Several existing medical issues, including hypertension and previous cases of heat injuries, can also affect one's sensitivity to heat (OSHA, 1999). Smoking habits influence individual's heat dissipation ability adversely through the impairment of the body aerobic capacity, ineffective ventilation of the lungs, and induced cardiovascular diseases (e.g., high blood pressure), which expose the individual to heat-related illness (Benowitz et al., 1982; Grassi et al., 1992; Raven et al., 1974). The difficulties in quantifying the exact consequence of each factor and in identifying interaction effect among these factors (Rowlinson et al., 2014) raise complications in the relationship between heat stressors and body heat strain.

2.4.2 Measurement of heat strain

Heat strain denotes the physiological and/or psychological consequences of heat stress (Sawka et al., 2003).

2.4.2.1 Physiological strain

Thermoregulatory and cardiovascular systems of workers performing both light and heavy work tasks are influenced significantly by both environmental and exercise heat (Maiti, 2008).

a. Thermoregulatory response

The body's ability to thermoregulatory control enables the body temperature to keep stable through heat_dissipation to the environment under hot conditions

(Havenith, 2005). Core temperature is a basic physiological measure of heat strain (Givoni and Goldman, 1972). From a clinical perspective, body core temperature must be held within a narrow range (Ivy, 1944). Core temperature is normally 37.0 ± 0.5 °C at rest, and it can increase by up to 3 °C during exercise-heat exposure (Bruck, 1983; Sawka and Wenger, 1988). Muscle activities can cause an increase in core temperature to nearly 38 °C to 39 °C for moderate work, and occasionally beyond 40 °C for heavy exercise (Havenith, 2005). The regulation of core temperature may be compromised transiently when this temperature presents a dangerously high level (e.g., more than 39 °C) as hyperthermia, with the possibility of heat stroke (Armstrong, 2000) and even death accompanying an elevation of only 5 °C (Pugh et al., 1967). A rapid increase in core temperature appears to limit one's endurance associated with fatigue (González -Alonso et al., 1999; Hargreaves, 2008; Quod et al., 2006).

Skin temperature is associated with the magnitude of heat stress (Brief and Confer, 1971) because it is an important input in controlling the thermoregulatory behavior of humans (Schlader et al., 2009) and is a fundamental factor in heat exchanges between the body and its environment (Mairiaux et al., 1987). Measuring skin temperature is remarkably important for evaluating the thermal balance of individuals working in the heat (Mairiaux et al., 1987). Core temperature is more sensitive to internal heat load (i.e., exercise level) than to changes in ambient temperature (Saltin and Hermansen, 1966). By contrast, skin temperature is more sensitive to environmental heat load than to metabolic rate (Nielsen, 1966; Stolwijk et al., 1968).

The rate of body heat storage is often used as an index of thermal stress (Kakitsuba and Mekjavic, 1987). Heat storage is a change in body heat content that refers to the difference between heat production and heat loss (Wenger, 2003). The amount of heat storage is the product of mean body temperature, body mass, and body mean specific heat (Wenger, 2003). The rate of heat storage commonly increases with exercise intensity, ambient temperature, and humidity (Cheung et al., 2000), and therefore increases with the level of heat stress (Logan and Bernard, 1999). It is related directly to exercise time, exhaustion (González-Alonso et al., 1999) and exercise performance (Tucker et al., 2006). A lower rate of heat storage denotes more effective heat dissipation of the body to the environment (Jay et al., 2008).

Sweat rate, which is another heat stress index (Smolander et al., 1987), is an important thermoregulatory response to physical performance in the heat (Hodgdon and Canine, 1996). The body under exercise-heat stress must sweat continuously until its core temperature returns from dangerous (e.g., hyperthermia) to thermo-neutral levels (Havenith, 2005; Sawka et al., 1995). The sweat rates of workers in hot environment vary between 0.3 and 1.5 liter/hour (Brake and Bates, 2003), which can result in dehydration if adequate fluid replacement is not taken (Bates and Schneider, 2008). However, it has been challenged that sweat rate is not a comprehensive representation of heat strain (Frank et al., 2001).

b. Cardiovascular response

Elevated heart rate can impede exercise performance (Smolander et al., 1987). When intense exercise occurs in the heat, the cardiovascular system simply cannot meet the maximal demands of the skin (to decrease thermal load) and muscles simultaneously (Rowell, 1986; Holtz, 1996). Heart rate data provide reliable measurements of cardiac strain in any environment (Maxfield and Brouha, 1963). Heart rate reflects the physiological strain induced by working in a hot environment (Brouha et al., 1961; Brouha and Maxfield, 1962; Brouha et al., 1963; Smolander et al., 1987).

c. The physiological strain index

The physiological strain index (PhSI) measures heat strain in quantitative terms (Gotshall et al., 2004) based on heart rate and core temperature records of humans (Moran et al., 1998a). The output in this index is scaled from 0 to 10, where 0 represents "no strain" and 10 represents "high physiological strain". At rest, normothermia is considered to be 37.0 ± 0.5°C, and the core body temperature can increase by up to 3°C during exercise-heat exposure (Bruck, 1983). Based on Moran et al. (1998a)'s assumption, the maximal acceptable rise of core temperature during exercise from normothermia to hyperthermia ranges from 36.5°C to 39.5°C. Heart rate during exercise sometimes exceeded the maximum value of 180 bpm. Therefore, the PhSI was calculated with the equation introduced by Moran et al. (1998a) with slight modifications following the suggestions by Tikuisis et al. (2002) (Eq. (2.1)). This modified equation has been widely used (e.g., Hostler et al., 2009; Petruzzello et al., 2009; Rodríguez-Marroyo et al., 2011) for obtaining a more accurate indication of the magnitude of physiological strain that participants have experienced (Morrison et al., 2006). The normal range of core temperature of healthy participants at rest is assumed to vary between 36.0°C and 38.0°C (Wenger, 1999), and the normal range of resting heart rate was between 60 bpm and 100 bpm (Price et al., 2010).

$$PhSI = 5 \times \frac{T_{ci} - T_{c0}}{39.5 - T_{c0}} + 5 \times \frac{HR_i - HR_0}{HR_{max} - HR_0} \qquad (2.1)$$

where T_{c0} and HR_0 are the initial core temperature and heart rate prior to heat exposure, respectively; T_{ci} and HR_i are simultaneous core temperature and heart rate, respectively, taken at any time throughout the experiment; HR_{max} is maximum heart rate of the participant achieved during the entire heat-stress trial.

The PhSI has been proposed to better represent the overall state of physiological strain (Moran et al., 1998a). First, this index includes the two primary determinants of physiological strain associated with heat stress (core temperature and heart rate; Belding, 1970) into the equation. Second, it can differentiate the strain level between clothing types, climates, hydration levels, exercise intensities, genders, or ages (Moran et al., 2002; Moran et al., 1999; Moran et al. 1998b). This index also easily quantifies the strain and compares different heat exposures (Frank et al., 2001).

2.4.2.2 Perceptual strain

The aforementioned objective measurements are sophisticated and can assess heat strain comprehensively (Epstein and Moran, 2006). However, the practicality and application of these strain indices in the workplace remain questionable because of the invasive measurement of body core temperature (normally done by capturing rectal or intestinal temperature), the requirement of expensive equipment (with the aid of core temperature capsule and core body temperature monitors), and physical interaction between investigator and participant (Gallagher et al., 2012). For instance, the Predicted Heat Strain Model and the PhSI have been respectively adopted for determining the maximum allowable exposure time and optimal recovery time of construction workers in hot weather (Rowlinson and Jia, 2014; Chan et al., 2012b). The risks of the usage of ear/canal thermometry in these studies should be acknowledged. The measurement on body core temperature would be more reliable than that on ear/canal temperature; however, recording physiological strain at working sites may be inconvenient and impractical because of its intrusive measurement and cost issues (Rowlinson et al., 2014; Pryor et al., 2011).

Apart from physiological strain, the rise in heat strain under hot conditions is also associated with elevated perceptual strain (Nybo and Nielsen, 2001). Self-determination based on subjective judgment, or the use of questionnaires for subjective fatigue symptoms can be an alternative indicator for predicting the extent of strains or hazards encountered by construction workers (Chang et al., 2009; Bernard and Kenney, 1994).

a. Rating of perceived exertion

Increased physical demands result in considerable amounts of blood being transmitted to the external surface of the body, while relatively less goes to the active muscles, the brain, and other internal organs; consequently, fatigue occurs, and strength and mental capacity may be affected (Da Costa et al., 2012). Physical work performance is accompanied by the subjective feeling of physical exertion ranging from extremely light to extremely strenuous (Naitoh and Kelly, 1993). The Rating of Perceived Exertion (RPE), which is based on subjective assessment, is a simple and valid method for regulating exercise intensity, physical stress, effort, and fatigue in relation to a specific task (Dunbar et al., 1992; Zeni et al., 1996; Coquart et al., 2009; Foster et al., 2001). RPE provides a useful indication of one's capacity to continue a task (Garcin et al., 1998; Hampson et al., 2001). The RPE scale (Table 2.2) uses both verbal anchors and scales that have been reported to possess both categorical and interval properties (Borg, 1998).

Table 2.2 Rating of perceived exertion

Rating	Descriptor
0	Rest
1	Very, Very Easy
2	Easy
3	Moderate
4	Somewhat Hard
5	Hard
6	
7	Very Hard
8	
9	
10	Maximal

b. Thermal sensation

Thermal sensation (TS) measures the perception of individuals under a certain thermal condition (van Hoof, 2008), while thermal comfort reports how the human mind expresses satisfaction when experiencing a specific thermal environment (ASHRAE 55, 1992). These indices are dominated mainly by cutaneous or peripheral thermoreceptors (Kato et al., 2001). TS refers to subjective feelings on the level of warmth of the environment (e.g., warm, neutral, cold) (Maiti, 2014). Uncomfortable thermal feelings in the heat may affect one's physical performance (Færevik, 2010). Thermal sensation scale and numerical categories ranging from 1, ''very cool,'' to 7 ''very hot'' are given in Table 2.3.

Table 2.3 Rating of thermal sensation

Rating	Descriptor
1	Very cool
2	Cool
3	Slightly cool
4	Neutral
5	Slightly hot
6	Hot
7	Very Hot

c. The perceptual strain index

While RPE describes physical stress that may overlook one's feeling toward the level of the warmth of the surrounding environment, TS may limit the verification of cardiovascular stress. The perceptual strain index (PeSI) developed using data of RPE and TS (Tikuisis et al., 2002) can provide a link in bridging the gap between the ease and applicability of direct indices and the comprehensiveness of empirical indices (Epstein and Moran, 2006). The modified mathematical expression based on the equation proposed by Tikuisis et al. (2002) is given by Eq. (2.2). The output is scaled from 0 to 10 where 0 represents no strain and 10 very high perceptual strain.

$$\mathrm{PeSI} = 5 \times \frac{\mathrm{TS_i} - 1}{6} + 5 \times \frac{\mathrm{RPE_i}}{10} \tag{2.2}$$

where PeSI is perceptual heat strain index, TS refers to thermal sensation, and RPE is perceived exertion.

The collective use of RPE and TS may be appropriate for measuring human heat strain because these indices appear to be closely related to the predominant physiological parameters of heat strain (i.e., heart rate, core temperature) (Hostler et al., 2009; Aoyagi et al., 1998; Marino et al., 2004). The PeSI that considers both perceived exertion and thermal sensation was developed by Tikuisis et al. (2002). The applicability and validity of the PeSI have been scrutinized for the past few years. The PeSI differentiates heat strain between fitness levels (Tikuisis et al., 2002), activity levels or protective garments (Petruzzello et al., 2009), but not hydration levels (Hostler et al., 2009) under uncompensable heat stress. Yang and Chan (2015) and Chan and Yang (2015) ascertain the reliability and applicability of the PeSI for assessing heat strain under compensable heat exposure. In terms of its non-invasive measurement of heat strain and unambiguous interpretation of the outputs, the PeSI is expected to offer a practical solution for assessing heat strain under various heat exposures.

2.5 CHAPTER SUMMARY

This chapter has provided a summary of the literature review relevant to heat stress intervention development research in construction, theoretical basis of body-clothing-environment mechanism, and the measurement methods for quantifying heat stress and heat strain. This review has provided a good understanding of existing literature and presented a reliable theoretical basis for developing the research framework of this study.

CHAPTER 3 RESEARCH METHODOLOGY

3.1 INTRODUCTION

The study design and research strategies to achieve the five objectives of this study are presented in this chapter.

3.2 RESEARCH DESIGN[3]

3.2.1 Intervention development research

Intervention study is a type of research that determines the relationship between cause-and-effect and the intervention strategy (Melnyk and Morrison-Beedy, 2012). The need for intervention studies has been increasingly recognized in the field of occupational health over the past three decades (Kristensen, 2005; Goldenhar and Schulte, 1994). Occupational intervention research investigates the effects of planned activities and programs at the worksites by employing scientific research methodologies (Kristensen, 2005). The overall aim of occupational intervention research is to identify the primary safety and health risks and to reduce these risks through industry-wide intervention programs (Ringen and Stafford, 1996). The goals of intervention strategies usually include improved health and well-being of the workers, reduced absence or turnover, reduced morbidity and mortality, increased motivation and job satisfaction, and/or increased productivity (Kristensen, 2005; Teutsch, 1992).

Given that developing an intervention may involve various research fields (e.g.,

[3] Presented in a working paper: Chan, A.P.C. and Yang, Y. (2015). Advancing the methodology in development research on heat stress intervention in construction.

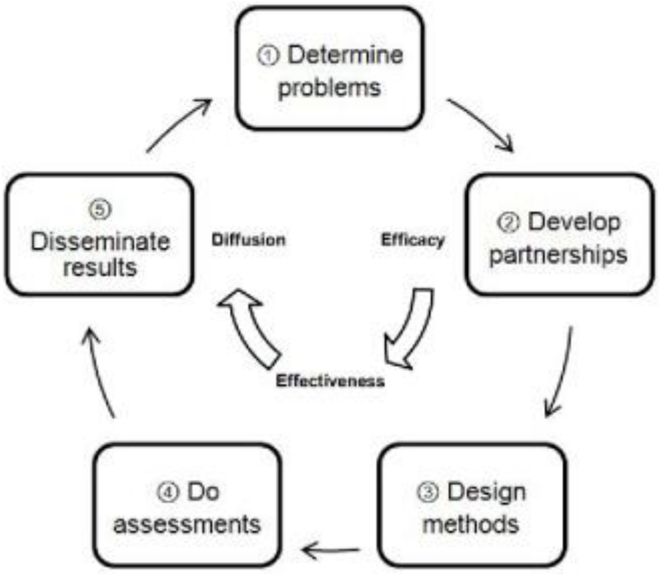
epidemiological, industrial hygiene, and behavioral research) (Goldenhar et al., 2001), this diverse field has attracted various researchers and practitioners who tackle the study subject from interdisciplinary and methodological perspectives. Intervention studies are necessary not only to examine the utility of the interventions to produce the desired effect or unintended outcomes, but also to disseminate convincing evidences to implement the interventions in the workplace (Goldenhar and Schulte, 1994; Kristensen, 2005; Rosenstock, 1996). By conducting intervention development research, an intervention strategy could be established to expand scientific knowledge and to satisfy the needs of practitioners.

The NIOSH has been active in developing a theoretical framework for occupational intervention research and in providing practical guidance (Goldenhar et al., 2001; Robson et al., 2001). The framework emphasizes that a well-designed intervention study could integrate development, implementation, and impact research to establish a cycle of continuous improvement of an intervention (Goldenhar et al., 2001). *Intervention development research* aims to *develop* new or previous interventions that have a rigorous scientific basis and meet the needs of practitioners. *Intervention implementation research* systematically documents the process and quality of adopting an intervention in representative settings. *Intervention impacts research* determines the effects of an intervention on hazardous exposure or casualties, social and economic consequences, and safety climate (Goldenhar et al., 2001). The premise of this framework is that a resource-intensive, time-consuming impact study is conducted after determining whether the implementation procedures are sufficient, while a well-developed intervention may be sufficiently implemented (Goldenhar et al., 2001).

3.2.2 Research framework of intervention development research

Conducting occupational intervention research may be challenging because the complicated, changing, real-world conditions may affect the interventions and their outcomes in occupational settings (Goldenhar et al., 2001). Given the widespread recognition of this situation, establishing a well-structured research framework based upon scientific rigor and practical considerations will justify the applicability of intervention development research. In this study, the proposed framework suggests the necessity of proving the efficacy, effectiveness, and diffusion of the intervention in the development phase prior to the intervention implementation and impact research phases for wide populations. Stolz (1981) advocates that a new technology directed at a social problem would be advanced in light of the demonstration of its effectiveness and generality in an applied research setting and the continuous measurement on a large scale. In this respect, this study adopts the process of *efficacy–effectiveness–diffusion* that has been introduced by Camp (2001) to conduct intervention development research. This process is shown in an integrated 5-D model in Figure 3.1 that is adapted from Goldenhar et al. (2001), Robson et al. (2001), and Camp (2001). This research framework combines the multi-disciplinary perspectives of occupational safety and health and clinical medicine, which may provide a fresh idea on heat stress intervention research. This framework will prove that the specific intervention exhibits a difference, and that the results are generalizable while addressing the resources (e.g., time, funding, and human), feasibility (e.g., political and practical limitations, needs of practitioners), limitations and special research considerations (e.g., legal, ethical, moral issues) (Goldenhar et al., 2001).

Figure 3.1 The 5-D model for conducting intervention development studies



Adapted from Goldenhar et al. (2001), Robson et al. (2001), and Camp (2001).

Efficacy – effectiveness – diffusion transition cycle

Understanding the efficacy–effectiveness–diffusion transition cycle proposed by Camp (2001) is a prerequisite to fulfill the five research tasks. The efficacy of an intervention is the degree to which it has an effect under ideal conditions, whereas the effectiveness of an intervention is the degree to which it has an effect under realistic workplace conditions (Shannon et al., 1999). Analyses of efficacy explore the likelihood that individuals in a defined population will benefit from an intervention under tightly controlled conditions (Camp, 2001). To examine effectiveness in the broadest and most meaningful sense entails investigation of the distribution and effect of an intervention employed in daily operations under uncontrolled real-world settings (Brook and Lohr, 1985). Although the efficacy and effectiveness of the intervention are demonstrated, the success of its implementation to wide population may remain uncertain. Thus, the next step is to solicit the body of evidence-based practice on the feasibility and acceptability of the intervention to a large number of practitioners (Camp, 2001). The efficacy–effectiveness–diffusion transition cycle plays as a key role in determining the research methodology designs and executions of assessment.

Task 1: Determine problems

Background information is generally obtained from theories, practical issues, and previous research (Johnson and Christensen, 2004). Theory-driven research is vital to describe the possible cause–consequence process mediated by an intervention at large (Goldenhar and Schulte, 1996). Such research also provides a conceptual framework for developing appropriate intervention measures by refining the study design and for providing support to the outcomes of the intervention (Lipsey, 1993; Goldenhar and Schulte, 1996). Careful consideration of the intervention measure relevant to practical issues is conducive to further disseminate the intervention to the worksites (Kristensen, 2005). One-off scientific innovation without practical possibilities may be unsuccessfully delivered to practitioners (Chataway et al., 2007). Current knowledge on intervention research regarding research hypotheses, achievements, and even barriers can be scrutinized and generalized from previous research to facilitate the conceptual and methodological development associated with efforts to conduct continuing intervention research (Lipsey, 1993; Goldenhar and Schulte, 1994). Overall, the purpose of this task is to ascertain that intervention development research furnishes both theoretical reasoning and practical potentials. This task can enhance the understanding of the problems and needs of the work site and offer guidance to develop proper interventions.

Task 2: Develop partnerships

Occupational intervention research must be considered within the context of a wide research field, including occupational safety and health, epidemiology, and industrial hygiene, which involves a broad community including labor, the industry, the academia, and government agencies (Goldenhar et al., 2001). A multidisciplinary research team is adept at managing the various theoretical, scientific, technical, statistical, sociopolitical, and practical facets. This team is expected to succeed in producing an integrated picture of the intervention research context and formulating a comprehensive study design, as well as disseminating sound research findings. Occupational intervention research requires close collaboration between researchers and practitioners (Kristensen, 2005). An extensive collaboration between researchers and practitioners is conducive to solve practical problems on the feasibility of an intervention in representative settings. Prior to performing any methodological procedures, this proactive process provides a platform in which practitioners are engaged as intervention participants and become involved in deliberations on the research findings in the following research tasks.

Task 3: Design methods

The methodologies in intervention research have been well documented and elaborated by earlier studies (Shannon et al., 1999; Goldenhar and Schulte, 1994, 1996; Robson et al., 2001). A well-structured study design for occupational intervention research mainly accounts for intervention characteristics, research settings, subject selection, and measurement instruments (Goldenhar and Schulte, 1994). A rigorous scientific protocol with a sophisticated consideration of these facets contributes to the execution of assessments.

Intervention strategies are usually divided into three categories, namely, engineering, administrative, and behavioral interventions. Engineering interventions are engineered from physical manipulations of sources for occupational hazards or routes of exposure to them (Goldenhar and Schulte, 1996). Administrative interventions are management initiatives that modify the work process and/or work exposure of the workers (McGlothlin, 1988). Behavioral interventions attempt to influence the attitude, knowledge, beliefs, or behaviors of workers and employers with respect to work-related hazards or diseases (Goldenhar and Schulte, 1996). Regarding the characteristics of each intervention, researchers should consider the intervention duration, frequency, and intensity (Goldenhar and Schulte, 1994) in the study design. The usage of each intervention should be assessed, which is compatible to the implementation scenario.

Randomized controlled trial (RCT) is the basic methodological paradigm for intervention research (Kristensen, 2005). Intervention and control groups are established to distinguish the outcomes of these groups; randomization is performed to avoid systematic bias and increase the internal validity of the study (Petersilia, 1989). Double-blind trial is important because information bias from the participants and the investigators can be reduced and the placebo effect[4] on the intervention group may be avoided (Kristensen, 2005). Even though blinding and the placebo effect may not be the core elements of the RCT (Kristensen, 2005), their possible effects on the research findings cannot be ignored. The RCT is usually established in the laboratory to examine the efficacy of an intervention under highly controlled conditions. However, the RCT is sometimes difficult to perform in occupational settings. Several restrictions and reasonable arguments, including practical, technical, ethical, political, or financial issues, exist to reject the use of RCT in occupational intervention studies (Goldenhar and Schulte, 1994; Schulte et al., 1996). Nevertheless, methodological problems arising from not using this design cannot be disregarded (Kristensen, 2005). In this respect, the RCT in the field experiment is still an optimal approach to assess the effectiveness of an intervention in real-work settings, whereas the other designs such as quasi-experiment and non-experiment pose major threats to the internal

[4] The medical term "placebo effect" refers to "the psychological therapeutic effect of the treatment, which will depend on many factors such as the belief in the effectiveness of the treatment and the attitude of the patient towards the therapist" (Eccles, 2006).

validity of the study (Goldenhar and Schulte, 1994). The methods to evaluate the acceptability of intervention in occupational settings may include field surveys, case studies, or interviews. These approaches enable researchers to solicit informed opinions from management, supervisors, frontline workers, and organizations regarding the pros and cons of the intervention. This process facilitates learning on both sides (researchers and practitioners) and promotes the implementation of the intervention in the future.

The two important sampling issues in intervention research are subject selection and sample size; the former indicates the generalizability of the findings and selection bias, and the latter may affect the desired outcomes (Goldenhar and Schulte, 1994). To avoid selection bias between volunteers and non-volunteers, random sampling is commonly adopted instead of volunteer selection. The participants are requested to complete a consent form (Appendix 6), and they must have an adequate understanding of the testing procedures and rejection choices. All procedures performed in the study involving human participants should be consistent with the ethical standards of the institutional and/or national research committee. The sample size in intervention research should be sufficient to detect a difference in the outcomes between the intervention and control groups (Goldenhar and Schulte, 1994). A large sample size may increase the accuracy of calculated statistics as close as possible to the true population estimate (Anderson et al., 2009). Sample size is often limited because of research time, funding, or human resources. Statistical power calculations should be conducted for a small sample size, which provide a better idea of the magnitude of the effect that could be detected using appropriate sample sizes, variances, and the selected confidence level (Cook et al., 1979). Inadequate statistical power should be recognized as a limitation of the study, and the results of data analysis should be interpreted cautiously.

The inclusion of information on the reliability and validity of the measurement instruments is essential in occupational intervention research (Goldenhar and Schulte, 1994). The investigators should design reliable and valid tools to measure outcomes appropriately either through observation or self-report to determine the intervention effects. Calibrating the instruments is a critical procedure to guarantee the inter-instrument reliability (Bassett et al., 2012) and data accuracy.

Task 4: Do assessments

A pilot study can be executed to verify the expected results, regulate the execution flow, and identify potential problems in the research settings when corrections and adjustments can still be made prior to performing the study assessment (Lancaster et al., 2004). The four major steps in the execution process are preparation, briefing, measurement, and ending (Yi and Chan, 2013b; Sasson and Nelson, 1969; Singleton and Straits, 2010). Preparation for the assessment considers the intervention object, recruited participants, trained investigators, calibrated and synchronized equipment, availability of study sites, and recruited medical staff (if necessary). The participants should be introduced to the objectives, procedures, and emergency circumstances of research ethics, and they should be given the right to refuse the study (Holloway and Wheeler, 1995; Levine, 1988). The investigator should draw an outline of the events that occur throughout the entire test assisted by automatic recording devices, and record the parameters cautiously if no such technical equipment is available (Yi and Chan, 2013b). The medical staff may accompany the participants throughout the test to manage emergencies if necessary. Upon the completion of the assessment, the participants may be provided a period of rest time for physiological and/or mental recovery. They can leave the laboratory if no discomfort is reported.

Result analysis is conducted after the assessment is completed and the required data are collected. Result analysis is an essential procedure to ascertain whether the proposed intervention is functioning as expected. The types of data analysis are mainly determined by the aforementioned research settings. Descriptive statistics, including frequencies, percentages, means and deviation, typically are commonly used to describe findings from intervention studies. General linear models, including but not limited to paired t tests, univariate ANOVA, analysis of covariance (ANCOVA), factorial ANOVA, multivariate ANOVA (MANOVA), ANOVA with repeated measures (RMANOVA), are widely used to detect the differences between two or more groups under the specific study designs (Goldenhar and Schulte, 1996; Girden, 1992). Correlation and simple regression analyses are utilized to determine the relationship between/among multiple variables. Artificial neural network and fuzzy logic are conventional methods to cope with the non-linear relationship between independent and dependent variables. Mixed-effect model is useful in settings where unbalanced and repeated observations are made (Littell et al., 2006; Rogers and White, 2007).

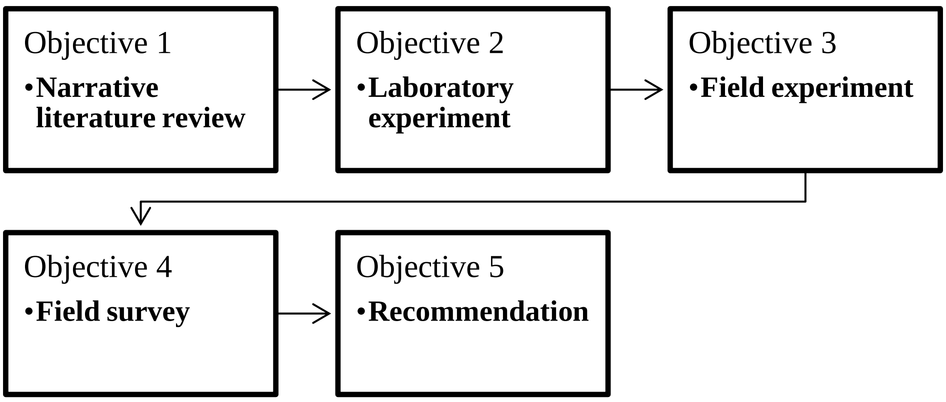
Task 5: Disseminate results

Disseminating the findings closes the intervention research loop in the current phase (Camp, 2001; Goldenhar et al., 2001). Both statistical and practical significance, as well as unexpected outcomes of the study, should be disseminated (Goldenhar and Schulte, 1994). To disseminate research contributions from investigators who work in diverse contexts, replicating successes rather than constantly reinventing the wheel by replicating failures should be emphasized (Goldenhar et al., 2001). The findings should be communicated to intervention participants and relevant non-participants (e.g., stakeholders, safety and health professionals, producers of intervention products, and government agencies) who can act based on the results in an expeditious manner and in a form that is readily understood (Goldenhar et al., 2001).

3.3 RESEARCH PROCESS OF THE STUDY

The research process of this study is delineated in Figure 3.2. After a narrative literature review on current heat stress intervention development research in construction, the laboratory experiment, the field experiment, and the field survey were employed to achieve Objectives 2-4, respectively. The laboratory experiment was conducted to determine the efficacy of the anti-heat stress uniform on alleviating body heat strain under tightly controlled conditions (Objective 2). The field experiment was executed to ascertain the effectiveness of the anti-heat stress uniform on combating body heat strain in real life conditions (Objective 3). The field survey was administered to examine the acceptability of the anti-heat stress uniform diffused to wider population (Objective 4). Finally, recommendations direct at formulating precautionary measures against heat stress were proposed (Objective 5).

Figure 3.2 Research process of the study



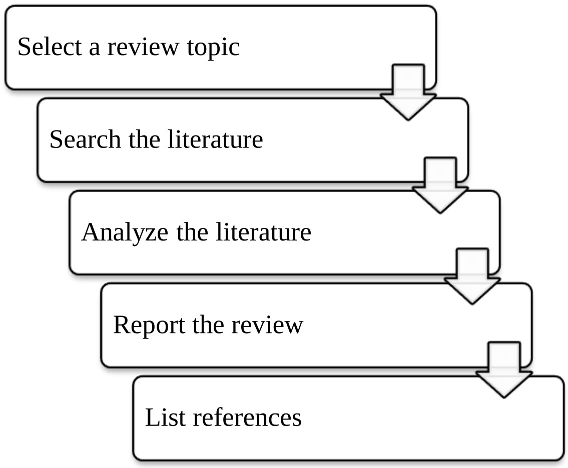
3.4 RESEARCH METHODS

3.4.1 Narrative literature review

Compared with the systematic literature review, the narrative literature review is generally criticized for its lacks of using explicit and strict methodological approach; thus, the quality of the reviewed articles cannot be assessed and the conclusions may be irreproducible and biased (Forrestal, 2014; Palermo, 2013). Despite its weaknesses, the narrative literature review generates valuable theory building, which serves a vital scientific function (Baumeister and Leary, 1997). The narrative literature review scrutinizes current research on a specific topic in both theoretical and contextual perspectives (Palermo, 2013). Two major objectives are formulated in a narrative literature review. First, this type of review outlines a comprehensive background to reveal the current state of existing body of knowledge (Rumrill et al., 2010), which can refine a broad research topic (Cronin et al., 2008). Second, this type of review can stimulate fresh research ideas and directions by identifying gaps or inconsistencies in a body of current knowledge (Cronin et al., 2008) as well as by developing conceptual or theoretical frameworks (Coughlan et al., 2007) for future research and professional practice (Rumrill et al., 2010; Cronin et al., 2008). Thus, narrative overviews contribute to theory and practice by creating great depth and insight in the specific fields (Rumrill et al., 2010; Green et al., 2006). The major contributions of the narrative literature review include: 1) to synthesize or advance theories and research frameworks, 2) to explore the identified and debatable viewpoints in the field, and 3) to develop research strategies that can facilitate theories and field practices (Bellini and Rumrill, 2009).

Figure 3.3 depicts the typical process of performing a narrative literature review. According to the systematic approach proposed by Cronin et al. (2008), the academic exercise starts with a narrow and focused topic, and then broadens the scope as the review progresses. Afterwards, relevant information should be gleaned in a structured way (Cronin et al., 2008); that is, an explicit search method should be identified. Using electronic databases offers access to enormous information that can be retrieved more easily and quickly than using a manual search (Younger, 2004). Justifying the reasons for selecting the databases from numerous electronic databases is also necessary. Manual searches of sources that are specifically related to or likely to cover the topic of interest can also be conducted (Cronin et al., 2008). Snowball literature search is a typical manual search method that can obtain additional articles from citation tracking (Greenhalgh and Peacock, 2005). Keyword search is the most common method to identify the relevant literature (Ely and Scott, 2007). While alternative keywords with similar meanings can elicit further information, combining keywords search *Boolean operators* (e.g., 'AND', 'OR', 'NOT', Ely and Scott, 2007) are useful to combine keywords for seeking accurate information (Cronin et al., 2008). Keywords search obtains expanded information on the concerned topic, whereas defining timeframe is important to determine the extent of the search results, which should be also justified in literature searches. After searching from diversified sources, such as research and theoretical articles, existing reviews, books, and these, the next step is to summarize, classify, and compare the disclosed knowledge on the specific topic (Forrestal, 2014). Analyzing the review can adopt two approaches, namely, dividing the literature into themes or categories and exploring the theoretical and methodological literature (Carnwell and Daly, 2001). The former allows the integration of theoretical and empirical literature, while the latter one discusses the theoretical literature followed by the study of methodological literature as an indication to establish appropriate research design for the specific topic (Carnwell and Daly, 2001). The format of the written report usually contains an introduction, main body, and conclusion (Burns and Grove, 2007). The review report should present the findings that demonstrate a phenomenon or hypothesis in a clear and consistent way (Cronin et al., 2008). Finally, a full bibliographical list of all the books, journal papers, reports and other media that are consulted to in the work (Cronin et al., 2008) should be compiled because the reference list may be a useful source for others researchers who are interested in this topic (Coughlan et al, 2007).

Figure 3.3 Narrative literature review process (Cronin et al., 2008)



3.4.2 Laboratory experiment

For the all experiments and surveys, the participants were provided with work uniforms in proper sizes.

The objective of laboratory experiments is to evaluate the efficacy of clothing on reducing body heat strain during wear trials. For this purposes, a laboratory experiment involves human participants in a tightly controlled environment that is created for a stylized version of a real setting (Colquitt, 2008) and derives precise measurement of the manipulated variables (Perrott, 1979). The laboratory experiment allows for tight control of internal validity (Schafer, 1999).

Randomization in a counter-balanced order is necessary to minimize any potential confounding (Kim et al., 2014) of subject-related variables and wearing order.

A climatic chamber (LabTester, KSON, Taiwan) with a dimension of 3 m × 2.5 m × 2.2 m (length × width × height) is built to simulate the outdoor hot and humid environments. The metrological condition inside the climatic chamber was set at 34.5°C temperature and 75% relative humidity to simulate a stressful environment on construction sites. This environmental condition is calibrated by a heat stress monitor (QUESTemp°36™, Australia) which recorded that the wet bulb globe temperature (WBGT) of 31.65 ± 0.26 °C. Such an environmental condition is usually recorded as a "hot weather warning" by the Hong Kong Observatory (HKO, 2015b). On a voluntary basis, the participants without known health problems will be eligible to take part in the laboratory experiments. The participants will sign written consent form after they are informed of the purpose, the procedure, the potential risks, and the right to refuse of the experiment. The personal information and experimental data will be kept confidential. The medical staff will be engaged to station inside the chamber throughout the whole exercise and provide medical care in case of emergency. During the laboratory experiment, demographic data, physiological and perceptual responses, and objective measurements of body/clothing mass will be recorded.

The sample size of the laboratory experiment is determined by the following procedures. As core temperature is a key parameter indicating thermal stress, this parameter is used to estimate the sample size. When the difference of core temperature between wearing AHSU and TRADE is detected upon the completion of several laboratory tests, the sample size was calculated according the following formula Eq. (3.1):

$$n = \left[\frac{2(\mu_\alpha + \mu_\beta)\sigma}{\delta}\right]^2 \tag{3.1}$$

where n is the required sample size, μ_α=1.96 to ensure the error of probability is less than 5%, μ_β=0.84 to ensure a statistical power of 80%, δ is the difference of core temperature between the two conditions, σ is the standard deviation.

In the current study, the difference of core temperature between wearing AHSU and TRADE is found in the 15^{th} min during exercise was significant examined by the paired t test ($p<0.01$. δ =0.185, σ =0.114) after completing nine laboratory tests. Accordingly, the sample size is N=11.9≈12.

3.4.3 Field experiment[5]

The goal of the field experiment is to examine the effectiveness of clothing on reducing body heat strain in real-work settings. In the current study, the field experiments are necessary in the research on intervention strategies against heat stress on construction sites because the conditions in real-life settings vary from those in contrived laboratory experiments. Based on experimental methodology, a field experiment can enhance the external validity of the laboratory test findings (Davenport, 2012) and retain the cause-effect relationships in fieldwork (Slater, 2005). In a field experiment, one or more independent variables are invariably manipulated (e.g., intervention and control conditions), and some contingent conditions (e.g., the changes of climatic condition and work intensity) cannot be held constant by the investigators (Slater, 2005). A randomized experiment can establish the effect of an intervention more convincingly compared with alternative quasi-experimental evaluation methods with statistical controls

[5] Presented in a working paper: Yang, Y. and Chan, A.P.C. (2015). The role of work uniform in combating perceptual strain among construction workers.

(Farrington, 2003). The outcomes of the controlled variables may be ensured with randomized assignment to avoid systematically biased factors (Petersilia, 1989).

The premise of ascertaining the role of clothing to counter body heat strain is to holistically assess the relationship between body heat strain and multiple heat stressors. As the response to heat stress is strongly influenced by heat acclimatization state (Nadml et al., 1974), age (Havenith, 2005), and work pace (Miller et al., 2011), these factors will be scrutinized in the experiment in the present study. It is acknowledged that filtering all potential influential factors in real-work settings is challenging (Slater, 2005). To determine whether wearing AHSU that can help construction workers combat heat strain, an intervention group and a control group will be formed. The former is assigned to wear AHSU and the latter is assigned to wear TRADE in a counter-balanced order. The environmental, work-related, anthropometric, physiological, and perceptual parameters will be measured during field experiments.

Sixteen field experiments were conducted in four different construction sites (Tin Shui Wai, Siu Lun Street, Wai Lok Street, and Wong Lung Hang) in summer (July to August 2014) in Hong Kong. The criteria for selecting participants are similar to those specified in the laboratory experiment. The participants in the field experiment should belong to the same age group (e.g., youth between the ages of 15 and 25; WTO, 2002), and their heat acclimatization status should be similar.

3.4.4 Field survey

The objective of the field survey is to investigate the acceptability of clothing among construction workers. The field surveys in the current study consisted of human wear trial and a questionnaire survey, which were administered between July and August 2014 at four construction sites (Tin Shui Wai, Siu Lun Street, Wai

Lok Street, and Wong Lung Hang). Human wear trials in actual wear situations can generate highly accurate sensory responses from wearers; thus, judgments can be based on their current experiences instead of their vague memories of past experiences (Li, 2001). Sensory perceptions are powerful tools for judging individual descriptors in perceived sensations (Li, 2001; Hollies, 1989), as gleaned from the questionnaire survey upon the completion of wear trials. The inclusive criteria for participants in the field surveys are similar to those in laboratory experiment. In addition, the participants should perform similar work routines in the two-day trials without disturbing normal operations.

With assistance of site officers in the four construction sites, a name list within a total number of 252 construction workers was collated. To ensure sufficient statistical power for making inferences about a population, the Penn State's Equation was applied to determine the appropriate sample size as shown by the following equation Eq. (3.2)[6].

$$n = \frac{\frac{P[1-P]}{\frac{A^2}{Z^2}+\frac{P[1-P]}{N}}}{R^2} \tag{3.2}$$

where n is the required sample size, N=252 is the number of people in the population, P=0.5 is the estimated variance in population, A=5% is the precision desired, Z=1.96 for confidence level at 95%, R=0.85 is the estimated response rate. Thus, n=179.

3.4.5 Questionnaire survey

The questionnaire survey is an appropriate approach to identify factual

[6] Source from: http://extension.psu.edu/evaluation/tipsheets/general/how-to-determine-a-sample-size

information about the existing object or situation (May, 2001). Accompanied with subjective assessment, subjective impressions on such factual information can be quantified (DiDomenico and Nussbaum, 2005). In textile research, subjective scale is accepted as a proper technique to extract wearers' feelings, perceptions, and opinions on clothing (Li, 2001). However, the drawbacks of subjective measurements should be noted in terms of inconsistencies and wide variations in subjective data (Slater, 1986). The design of subjective scales should consider: 1) commonly recognized attribute to measure, 2) appropriate terms describing the attribute, 3) unambiguous scale to indicate the level of attribute, and 4) a user-friendly rating panel for users (Hollies, 1977). Subjective attributes are commonly divided into thermal-wet-, tactile-, pressure-related sensations (Li, 2001). The polar pairs of ordinal descriptors are used to rank the subjective attribute according to wearers' feeling toward the clothing characteristics (Li, 2001).

The questionnaire surveys are administered to assess subjective responses on work uniforms in the laboratory experiment and the field survey. Regarding the different wearing conditions in the laboratory and work site, the questionnaire survey conducted in the laboratory mainly focuses on evaluating human subjective sensations on thermal-related attributes, and that administered at construction sites takes account for thermal- and pressure-related attributes. The later will provide a whole picture on the acceptability of work uniforms by construction workers. A seven-point Likert scale with polar descriptors is used to quantify the subjective perception on clothing.

3.4.6 Data analysis

Quantitative data were analyzed using the selected statistical analysis methods and the corresponding statistical packages including SPSS 19.0 and 20.0 (SPSS Inc., Chicago, IL, USA) and Matlab 2009a (MathWorks Inc., Natick, Massachusetts, USA).

3.4.6.1 Descriptive statistics and statistical test

Descriptive statistics including mean value and standard deviation or error are employed to quantitatively describe the main features of the collected data (Mann, 2010). Prior to detailed statistical analyses, descriptive data are useful for constructing an overview of the measured and collated parameters obtained from experimentation and survey.

The paired sample t-test is used to assess the statistical significance of the difference between *two related or paired sample means* on a single dependent variable (Hair et al., 2006; Ukaga and Maser, 2004). Analysis of variance (ANOVA) is a general method for analyzing data from designed experiments to compare *two or more group means* (Bolton and Bon, 2009). It is a robust test for variance heterogeneity when sample sizes between or among groups are equal (Glass and Stanley, 1970). Repeated measures of ANOVA are used to compare group means on a dependent variable across repeated measurements of the independent variable (e.g., time, condition) (Krueger and Tian, 2004). Two-way repeated measures of ANOVA are used to analyze the effects of two independent and repeated variables (e.g., time and condition) on a dependent variable (e.g., participants' response) (So and Smith, 2002). The statistical significant levels of main and interaction effects of the repeated variables will be detected via this technique. In the two-way repeated measures of ANOVA, a main effect is the direct effect of an intervention on the dependent variable, while an interaction effect is the joint effect of two independent variables on the dependent variable (de Haan et al., 2007; Mavrikios et al., 2007). Two-way repeated measures of ANOVA are widely employed to detect the differences of the dependent variable between the intervention and non-intervention conditions. For example, this technique is commonly used to determine the efficacy of use of personal cooling equipment on alleviating heat strain, as evidenced by detecting the differences in human physiological responses between intervention (e.g., wearing personal cooling equipment) and non-intervention groups (e.g., Barr et al., 2009; Tyler et al., 2010; Siegel et al., 2012). The efficacy of wearing AHSU on reducing human physiological strain will be determined using two-way (clothing type × exposure time) ANOVA with repeated measures.

Effect size (Cohen's d)[7] is a simple means to quantify the magnitude of the difference between two groups, without confounding with sample size (Coe, 2002). It is calculated according to equations (3.3) and (3.4). The magnitude of the effect, rather than its statistical significance (which is influenced by sample size as shown in the equation (3.2)), can promote a scientific approach to report and interpret the effectiveness of an intervention (Coe, 2002). Cohen's d of <0.2 is classified as a trivial effect, 0.2–0.4 as a small effect, 0.4–0.7 as a moderate effect and >0.8 as a large effect (Christensen and Christensen, 1977). For example, an effect size of 0.8 means that the value in the intervention group is 0.8 standard deviations above that in the control group, and hence exceeds the values of 79% (percentile standing) of the control group (Coe, 2002).

$$\text{Cohen's d} = \frac{\delta}{\sigma_{\text{pooled}}} \tag{3.3}$$

$$\sigma_{\text{pooled}} = \sqrt{\frac{(N_I - 1)\sigma_I^2 + (N_C - 1)\sigma_C^2}{N_I + N_C - 2}} \tag{3.4}$$

where δ is the mean difference between the intervention and control groups,

[7] Source: http://www.polyu.edu.hk/mm/effectsizefaqs/calculator/calculator.html

σ_{pooled} is the standard deviation in a "pooled" value from both groups, N_I and N_C are the sample sizes in the two groups, σ_I and σ_C are their standard deviation.

The differences in non-parametric data between groups will be examined by Wilcoxon signed ranks test. In the current study, the Wilcoxon signed-ranks test is used to analyze *two paired or matched groups* when the normality assumption is violated (Zimmerman, 1996). The Mann-Whitney U test determines the differences between *two unpaired groups* on an ordinal variable with no specific distribution (Perrild et al., 1986). Regarding subjective sensation that is commonly quantified by the ordinal scales (e.g, seven-point Likert scale), the Wilcoxon signed-ranks test is commonly employed to determine the differences in the subjective responses to wearing different garments (e.g., Brazaitis et al., 2010). The Mann-Whitney U test is used to determine the differences in perceptual responses between wearing the AHSU and TRADE conditions in the field experiment.

3.4.6.2 Linear mixed-effects model[8]

In the field experiments with a repeated measurements design, multiple observations conducted on the same participant generally result in the correlated errors. Consequently, multiple responses from the same participant cannot be regarded as independent from each other. This assumption is explicitly violated in traditional regression analyses. With repeated measurements of each participant, an autocorrelation between repeated observations on individuals through time may exist and must be considered when estimating the relationship between factors and responses (Peretz et al., 2002). Therefore, traditional

[8] Presented in a working paper: Yang ,Y. and Chan, A.P.C. (2015). The role of work uniform in combating perceptual strain among construction workers.

regression methods are no longer appropriate for the repeated measurement design. Additionally, the interaction effects among heat stressors on heat strain are usually neglected by the early studies, and thereby leading to probably questionable estimations and interferences.

As the level of heat strain can vary greatly across individuals based on their physique along with different environmental and physical conditions, these variance components should be considered in the evaluation of cause–effect relationships. The mixed-effects model (LMM) enables the estimation of the variance components of exposure levels that are adjusted for individual factors to improve the assessment of hazardous exposure (Peretz et al., 2002). Repeated measures models incorporate specialized variance-covariance structures to account for serial correlations (Littell et al., 2006; Rogers and White, 2007). The time interval between repeated observations can vary across repetitions. The mixed-effects models are robust to deal with unequally spaced data collection points, which do not require equal variances at each time point or equal covariance between all pairs of time points (e.g., sphericity) and are capable of accounting for correlations among repeated measurements (Rooney et al., 2013). The unique advantage of the mixed-effects model is the inclusion of both fixed and random effects (Cnaan et al., 1997). Fixed effects provide estimates of the average responses in a group, whereas random effects (e.g., participant effects) account for the natural heterogeneity in the responses of different participants and allow the estimation of responses for each participant (Peretz et al., 2002). Therefore, mixed-effects models with repeated measures provide a satisfactory estimate of the true (unbiased) effect of an intervention against hazardous exposure.

The statistical form of this model is given by Eq. (3.5). The parameter estimates of this model are shown in Table 5.2.

$$Y_{ij} = \beta_0 + \beta_1 \times X_{1i} + \beta_2 \times X_{2i} + \cdots + \beta_n \times X_{ni} + \cdots + \mu_i + \varepsilon_{ij} \qquad (3.5)$$

where Y_{ij} and X_{ij} are the dependent and independent variables for the i^{th} participant in the j^{th} measure, respectively, β_0 is the constant, β_n (n=1,2,…n) denotes the coefficients of fixed effects, μ_i is the random effect for participant i, ε_{ij} is the random unexplained error.

In this study, LMM is employed to assess the effects of multiple factors including the fixed (e.g., clothing type, work trade, workplace, exposure time, wet bulb globe temperature, and metabolic rate) and interaction effects on human perceptual strain. On this basis, the effectiveness of wearing AHSU on reducing human perceptual strain will be identified.

3.4.6.3 Multiple linear regression analysis

Multiple linear regression analysis is a conventional statistical method to assess multiple factors (e.g., fabric properties, sensory attributes) affecting an overall subjective sensation (e.g., wearing comfort, or preference) on fabrics or garments (Wong et al., 2002; Chan et al., 2013b). Multiple regression analysis is statistical technique that can be used to analyze the relationship between wearing comfort and several sensory variables. The regression equation is expressed as follows Eq. (3.6). This equation describes the relationship between dependent and independent variables, which is used to predict the dependent variable (Rajeevan et al., 1995). The adjusted coefficient of determination (adjusted R^2) is calculated to determine the goodness of fit of the model.

$$Y_{ij} = \beta_0 + \beta_1 \times X_{1i} + \beta_2 \times X_{2i} + \cdots + \beta_n \times X_{ni} + \cdots + \varepsilon \qquad (3.6)$$

where β_0 is the constant, β_n (n=1,2,…n) is the coefficients of independent variables, which denotes the estimated change in the dependent variable Y for a unit change of the independent variables X_1, X_2, …, X_n. ε is the residual error.

Prior to conducting regression analysis, the assumptions of independence, linearity, constant variance and normality can be tested by plotting the standardized deleted residuals against the standardized predicted values, and observed by the normal probability plot which displays cumulative normal distribution as a straight line (Campbell, 2001). It is necessary to identify the best combination of a large number of independent variables while predicting dependent variable. Stepwise regression that can filter the most significant factors is a robust tool to select the best subset models (Rawlings, 1998). Outliers that may influence the reliability and accuracy of the model (Schroeder et al., 1986) should be removed appropriately. In the current study, the variables that entered and remained in the regression equation were determined with the stepwise regression criteria (probability of F to enter = 0.05, probability of F to remove = 0.10). The criterion for identifying and removing the outliers from the model was set as the standard deviation of 2.

3.4.6.4 Artificial neural network

Artificial neural network (ANN) enables the model to learn the behaviors of individuals who judge the sensory comfort (Wong et al., 2003). It consists of neurons, layers, and synaptic connections (Mohaghegh et al., 1995). The feed-forward back-propagation training procedure has been elaborated by Mohaghegh et al. (1995). Input values are multiplied by the initialized synaptic connection weight. The sum of the product of all input neurons and their corresponding synaptic connection weights are then forwarded to each hidden neuron. Each hidden neuron will perform a simple computation by mapping the sum to an output using a non-linear function (usually sigmoid function). The result is then multiplied to the synaptic connection weight between the hidden neuron and each output neuron. The sum of the product from all the hidden neurons will be used to determine the final network. The resulting error between the actual and the predicted outputs that are back propagated through the altered network and synaptic connection weights until the network output reaches an acceptable value.

3.4.6.5 Fuzzy logic

Fuzzy logic is an artificial intelligent technique that can be employed to evaluate clothing comfort (Wong, 2003; Wong and Li, 2003). Fuzzy logic and approximate reasoning can modeling of the way human motivate and communicate by linguistic language understanding and processing (Jager, 1995). This technique linguistically expresses the information and its rules, making the entire modeling process easy to interpret (Wong, 2003). The membership functions and fuzzy rules are the key properties in a fuzzy logic system (Chen and Chang, 2005). Fuzzy logic is adept with formulating subjective judgments to solve classification problems (Chen and Chang, 2005). The assumption of membership functions and detailed algorithms of developing the fuzzy decision tree are shown in Appendix 1.

In this study, multiple linear regression analysis, ANN, and fuzzy logic will be employed to assess the sensory attributes affecting wearing comfort. Consequently, the human psychological process in assessing the acceptability of the work uniform will be elucidated.

3.5 CHAPTER SUMMARY

This chapter has amplified and justified the research methodology employed in this study. The narrative literature review was proposed to perform not only to outline the development and weakness of heat stress intervention development research in construction, but also to refine a research framework for future studies. A 5-D model was employed to comprehensively evaluate the benefits of an intervention strategy. This research framework was verified through a case study of evaluating the effects of wearing a newly designed anti-heat stress uniform, which would be discussed in detail in the following chapters. Afterwards, laboratory experiment, field experiment, and field survey, accompanied with corresponding statistical analysis methods, were adopted to fulfill Objectives 2-4, respectively. Finally, the convincing recommendations were formed based upon the aforementioned findings (Objective 5).

CHAPTER 4 EFFICACY OF THE ANTI-HEAT STRESS UNIFORM[9]

4.1 INTRODUCTION

Construction workers are at a high risk of heat-related illness when they perform physically demanding work and experience prolonged exposure to a stressful environment (Helander, 1991; Maiti, 2008; Pérez-Alonso et al., 2011; Rowlinson et al., 2014). The local government and the industry have promulgated a series of guidelines, practice notes, and programs on the protection against heat stress to safeguard workers in hot weather (e.g., CIC, 2013; Labor Department, 2014). Notwithstanding the advice to construction workers to wear thin, light, and breathable clothing to prevent heat-related illness when performing construction activities in summer (CIC, 2013), scientific research that validates the efficacy of such an appropriate summer work attire is still lacking. To narrow this research gap, this chapter examines the efficacy of the anti-heat stress uniform (AHSU) in alleviating human physiological and perceptual strain under tightly controlled conditions. A series of human wear trials were carried out throughout a rest–intermittent running–recovery cycle inside a climatic chamber that maintains a hot and humid environment. During this randomized laboratory experiment, objective and subjective parameters were recorded synchronously. A comparison between AHSU and a commercially available uniform (TRADE) will clarify the improvement of AHSU in alleviating heat strain and improving wearing comfort.

[9] Presented in a published paper: Chan, A.P.C., Yang, Y., Guo, Y.P., Yam, M.C.H. and Song, W.F. (2015). Evaluating the physiological and perceptual responses of wearing a newly designed construction work uniform. *Textile Research Journal,* DOI: 10.1177/0040517515591773.

4.2 METHODS OF DATA COLLECTION

4.2.1 Participants

Twelve participants (ten males and two females) participated in this experiment. All participants practiced sports two or three times per week and were considered physically active. They had no cardiovascular or oesophageal and other known diseases and were considered healthy. The average age, weight and height of the participants were 21± 3.35 years, 63±6.49 kg, and 173±6.93 cm, respectively.

4.2.3 Protocol of the experiment

The garments were washed each time after wear for reuse and stored at room temperature (23 °C and 60% relative humidity) before the experiment. Each participant reported to the laboratory at the same time of the day on two separate days spaced at least one week. The participants were asked to randomly wear TRADE and AHSU in a counter-balanced order, and to wear the same shoes and underwear for the two-day experiments. The protocol of the experiment is illustrated in Figure 4.1, which included 30 minutes of pre-exercise rest, a period of intermittent running, 6 minutes of active recovery and 30 minutes of passive recovery. Intermittent running was adopted because diverse construction work is largely intermittent by nature (Rappaport et al., 2003). The entire experiment was conducted in a climatic chamber (LabTester, KSON, Taiwan) that controlled environmental conditions as 34.5 °C air temperature and 75% relative humidity.

An ingestible capsule (CorTemp, HQI, America) for measuring intestinal temperature was calibrated per one minute against a certified temperature probe with an accuracy of ± (0.15 + (0.002 × T) °C, Lutron®, Taiwan) in a water cup with temperatures ranging from 30 °C to 42 °C (Edwards and Clark, 2006) to ensure its functionality and accuracy. The pills that fell outside the degree of accuracy of ± 0.1 °C were not used in the test (Barr et al., 2009). Four to six hours before the scheduled arrival, the participants swallowed the calibrated capsule with warm water. They were informed that the capsule would pass through the body after 24 to 36 hours normally. Upon arrival, the participant was briefed on the experiment protocol and asked to indicate the basic demographic information, such as name, height, and age. Then the participant was given a standard snack (260 kcal, 9 g protein, 7 g fat, 41 g carbohydrates) and 3 ml of warm water at 37.00±0.18 °C per kg body weight (Yaspelkis and Ivy, 1991). After obtaining the weight of the uniform and the participant's body mass (with underwear), the participant was dressed with the uniform and then equipped with CorTemp data logger, thermistor sensors (LT8A, Gram Co., Japan), microclimate humidity sensors (Especmic, Japan), and heart rate belt (Polar T34 Transmitter, Finland) for recording the intestinal temperature, skin temperatures, microclimate humidity, and heart rate, respectively.

Upon the completion of the above preparation, the participant entered the climatic chamber. A typical run-down of the experiment is shown in Figure 4.1. After a standard buffer time of 10 minutes, the participant rested on a backless chair inside the chamber for 30 minutes and later performed intermittent running (as shown in Figure 4.2) on a motorized treadmill (h/p/cosmos® pulsar, Germany). The running test was terminated if 1) core temperature reached the 38.5 °C threshold; 2) heart rate reached 95% of the age-predicted maximum heart rate; or 3) the participant became exhausted and requested to stop. After the active recovery of walking on the treadmill for 6 minutes, the participant then sat on chair for passive recovery for 30 minutes. A registered nurse was stationed inside the chamber throughout the whole exercise and provided medical care in case of emergency.

Figure 4.1 A typical run-down of the experiment

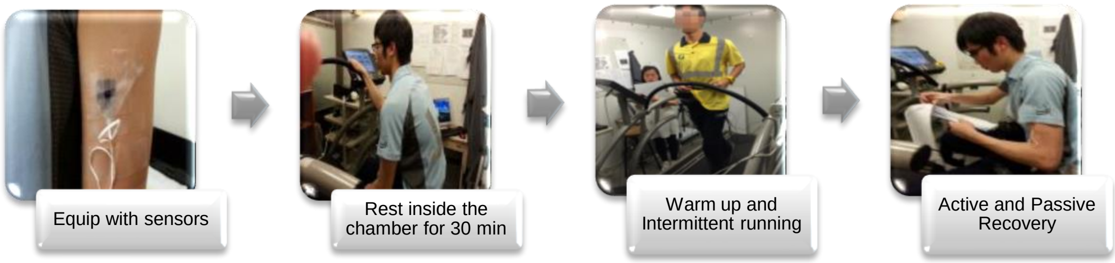
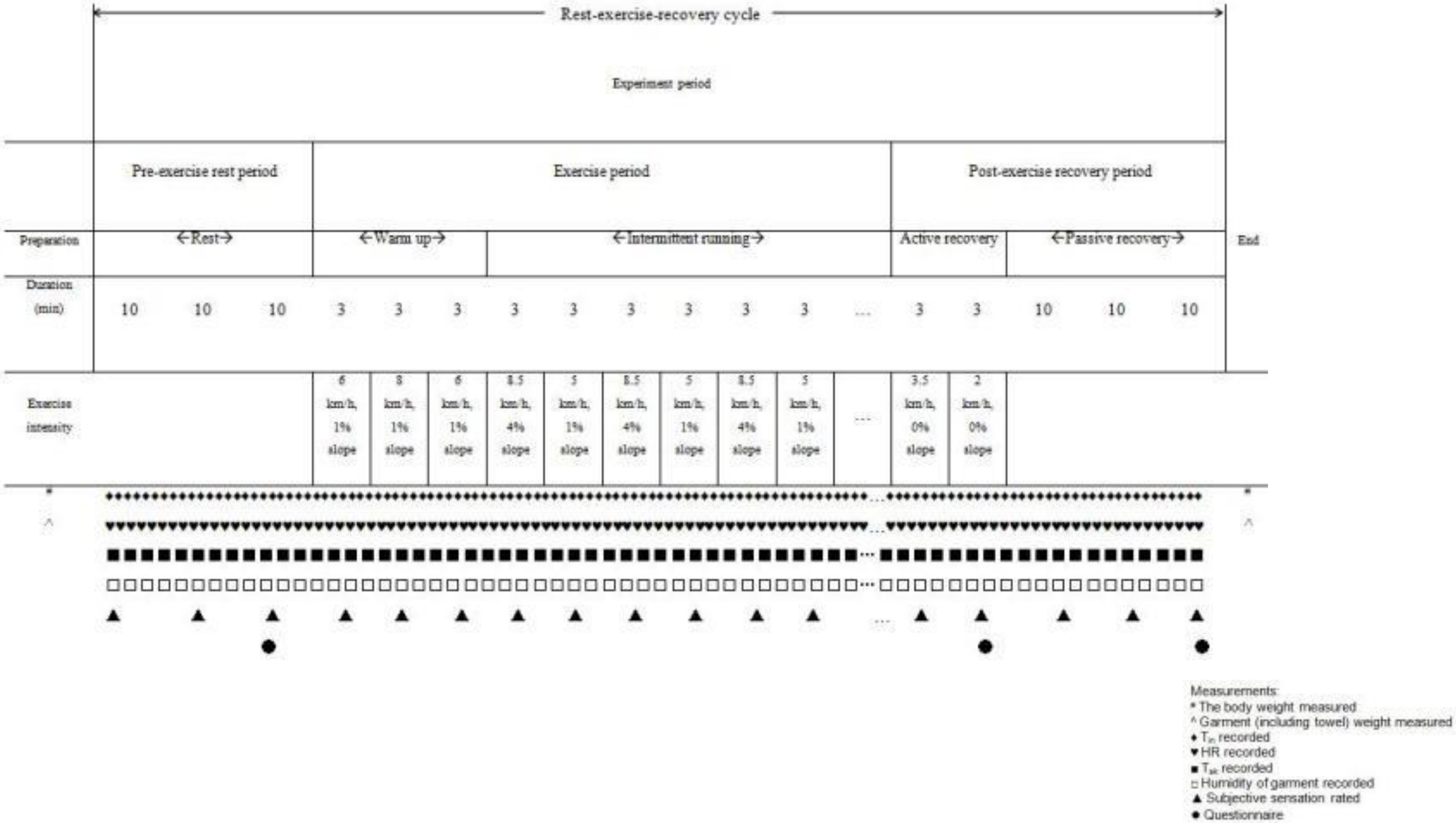


Figure 4.2 Protocol of the experiment and measurements



4.2.4 Measurements and calculations

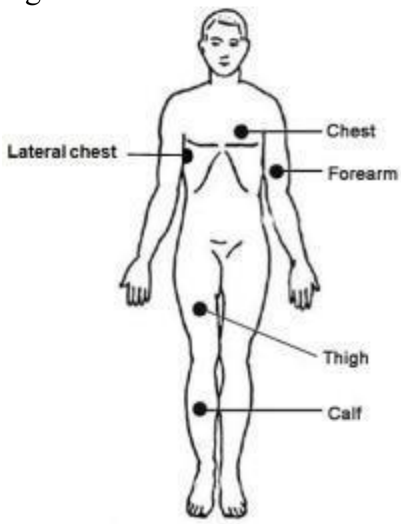
4.2.4.1 Objective measurements

Physiological data and objective measurement of microclimatic humidity were recorded during the entire experiment. Core temperature (T_{in}) was recorded at a frequency of 30 seconds and was connected remotely to a data recorder monitored by a small digital camera inside a bum bag. The bag was attached to the waist of the participant during the entire experiment. Heart rate (HR) was sampled per second. Microclimate humidity at the back and thigh levels ($H_{micro-back}$, $H_{micro-thigh}$) was measured by the humidity sensor at a sampling frequency of 30 seconds. Each thermistor used for measuring skin temperature was calibrated with a heat plate with an accuracy of ± 0.1 °C (Thermo labo IIB, Japan). The thermistors recorded data every 30 seconds and were taped at five sites, namely, chest (T_{chest}), forearm ($T_{forearm}$), thigh (T_{thigh}), calf (T_{calf}), and lateral chest ($T_{lateral\ chest}$) (Figure 4.3). The mean skin temperature ($\overline{T_{sk}}$) was calculated by the Eq. (4.1) (Ramanathan, 1964) and the mean body temperature under hot conditions ($\overline{T_b}$) was calculated by the Eq. (4.2) (Colin et al., 1971).

$$\overline{T_{sk}} = 0.3\ (T_{chest} + T_{forearm}) + 0.2\ (T_{thigh} + T_{calf}) \qquad (4.1)$$

$$\overline{T_b} = 0.8T_{in} + 0.2\overline{T_{sk}} \qquad (4.2)$$

Figure 4.3 Location of the skin sensors on the body surface



The formula of rate of heat storage ($\dot{S}$) is expressed in Eq. (4.3) (Lee and Haymes, 1995). $\dot{S}$ was calculated for rest period, exercise period, post-exercise recovery period, and the whole experiment period.

$$\dot{S} = C_b \times \frac{m}{A_D} \times \frac{\Delta\overline{T_b}}{t} \tag{4.3}$$

where $\dot{S}$ is the rate of heat storage in $kJ \cdot m^{-2} \cdot hour^{-1}$; $\Delta\overline{T_b}$ is the change in mean body temperature; C_b is the specific heat capacity of the body issue, named 3.47 $kJ \cdot kg^{-1} \cdot °C^{-1}$; m is the body mass measured before experiment; A_D in m^{-2} is the body surface area according to A_D=0.007184 × Height(cm)$^{0.725}$× Weight(kg)$^{0.425}$ (DuBois and DuBois, 1916); t is the time interval in hr.

The modified mathematical expression of the physiological strain index (PhSI) is shown in Eq. (4.4) (Tikuisis et al., 2002; Moran et al., 1998a). The output of each strain index is expressed on a scale of 0 to 10, from low to high levels of heat strain (Moran et al., 1998a).

$$\mathrm{PhSI} = 5 \times \frac{T_{ci} - T_{c0}}{39.5 - T_{c0}} + 5 \times \frac{HR_i - HR_0}{HR_{max} - HR_0} \tag{4.4}$$

where T_{c0} and HR_0 are the minimum core temperature and heart rate prior to exercise, respectively; T_{ci} and HR_i are the simultaneous core temperature and heart rate, respectively, taken at any time during treadmill exercise; HR_{max} is the maximum heart rate of the participant achieved; it is substituted into the equation if it exceeds 180 bpm.

The body mass (with underwear) and the mass of the dry t-shirt, pants, and towel were measured before the experiment, by the electronic scale with a precision of 0.01 kg (Sam Hing Scales Fty Ltd., Hong Kong) and the one with a precision of 0.01 g (A and D Company Ltd., Japan), respectively. Upon the completion of the experiment, the body mass (with underwear) of the participant after the sweat was wiped off with a dry towel and the mass of the T-shirt, pants and towel were measured immediately. The participant was subsequently fully rehydrated. Sweat rate in liter per hour (L/h) was calculated by the change in body weight as a function of the experiment duration after correcting for any urine loss and total water intake (assuming water volume of 1 L = 1 kg) (Heled et al., 2004). No participant passed any urine during the experiment. Evaporative sweat loss was calculated as the difference between the body mass change and the garments (including towel) mass change when no correction was made for the water loss from metabolism and respiration (Nielsen and Endrusick, 1990). Sweat efficiency was expressed as evaporative sweat loss divided by total sweat loss (Hasegawa et al., 2005).

4.2.4.2 Subjective measurements

Subjective ratings were taken every 10 minutes during pre-exercise rest and passive recovery, and every 3 min during exercise and active recovery.

Following this scheduled time, the participants were asked to rate their perceived exertion (RPE) on an 11-point scale (Borg, 1998), thermal sensation (TS) on a 7-point scale, wetness sensation (WS) on a 7-point scale, and comfort sensation (CS) on a 7-point scale (Table 4.1). A data collection sheet was used to record the experimental data (Appendix 2).

Table 4.1 Perceptual measurement scales on perceived exertion, thermal sensation, wetness sensation, and comfort sensation

Scale	RPE	TS	WS	CS
0	extremely easy	-	-	-
1	very easy	very cool	very dry	very comfortable
2	easy	cool	dry	comfortable
3	moderate	slightly cool	slightly dry	slightly comfortable
4	somewhat hard	moderate	moderate	moderate
5	hard	slightly hot	slightly wet	slightly uncomfortable
6		hot	wet	uncomfortable
7	very hard	very hot	very wet	very uncomfortable
8		-	-	-
9				
10	maximal			

The perceptual strain index is calculated according to Eq. (4.5) (Tikuisis et al., 2002).

$$\mathrm{PeSI} = 5 \times \frac{\mathrm{RPE_i}}{10} + 5 \times \frac{\mathrm{TS_i} - 1}{6} \quad (4.5)$$

where $\mathrm{RPE_i}$ and $\mathrm{TS_i}$ are the simultaneous perceived exertion and thermal sensation respectively, taken at any time during treadmill exercise. RPE adopts an 11-point scale from 0=nothing at all to 10=extremely hard (Borg, 1998); and TS refers to a 7-point scale from 1=very cool to 7=very hot.

In addition, the participant was asked to complete a self-administered questionnaire to describe the subjective sensations on the uniform during pre-exercise rest, physical activities on the treadmill (including exercise and active recovery), and passive recovery (Appendix 3). Each questionnaire included subjective assessments related to thermal and moisture sensations on the T-shirt and pants, respectively. Five items of subjective attributes were described as opposite adjectives on a seven-point scale. The meanings of scales 1 to 7 were denoted as from non-adhesive to sticky, from breathable to airtight, from dry to damp, from cool to hot, and from comfortable to uncomfortable. Nine valid sets of questionnaires on AHSU and ten valid sets on TRADE were obtained.

4.2.5 Statistical analysis

Data were reported as mean ± standard deviation. Prior to statistical analysis, the differences in anthropometric parameters, physiological and perceptual responses between males and females were examined by calculating effect size (d). Afterwards, all data were pooled for further statistical analysis. Objective parameters were transformed to one-minute averages for statistical analysis. T_{in}, $\overline{T_{sk}}$, $\overline{T_b}$, HR, and PhSI were analyzed separately during pre-exercise rest, exercise, active recovery and passive recovery by a two-way ANOVA with repeated measures [Condition (AHSU vs. TRADE) × Time (6, 12, 18, 24, 30 min during any activities expect active recovery; and 3, 6 min during active recovery)]. The Greenhouse-Geisser correction was designated as statistical significance when the Mauchly's Test of Sphericity was violated. A paired sample t-test was performed when a significant interaction effect was obtained from repeated measures. The differences in exercise duration, sweat rate, sweat efficiency, and $\dot{S}$ between AHSU and TRADE were examined by a paired sample t-test. The perceptual responses (RPE, TS, WS, CS, PeSI) were analyzed by the non-parametric Wilcoxon signed ranks method. The same procedure of a two-way ANOVA with repeated measures (Condition × Time) was conducted to detect the differences in skin temperatures ($T_{chest}, T_{forearm}, T_{thigh}, T_{calf}, T_{lateral\ chest}$), and microclimate humidity ($H_{micro-back}, H_{micro-thigh}$) between two T-shirts and between two pairs of pants, respectively. The results of the questionnaire survey were analyzed by the Wilcoxon signed ranks. The significance levels in all tests were $p<0.05$ (marked * on the graphs) and <0.01 (**). All these statistical analyses were conducted by the SPSS software.

As shown in Section 3.4.3 of Chapter 3, a sample size of 12 was determined as appropriate to provide a statistical power of 80% and to ensure the error of probability less than 5%. A 0.185 °C T_{in} difference with the standard deviation of 0.114 was detected after nine laboratory experiments were completed.

4.3 RESULTS

4.3.1 Differences between males and females

Moderate to large effect sizes were found for mean exercise time, $\overline{T_{sk}}$, sweat efficiency, $T_{chest}, T_{forearm}$, and T_{calf}, with decreased exercise time, increased skin temperatures, but higher sweat efficiency was recorded in females, regardless of wearing AHSU or TRADE. Sweat rate of females to a large extent was lower than that of males (d>0.8) in the AHSU condition, while $H_{micro-back}$ of females was lower than that of males (d>0.8) in the TRADE condition. The other variables between males and females exhibited small to moderate effect sizes, regardless of the types of uniform worn.

For males, small to moderate effect sizes were observed for all variables (except $T_{\text{lateral chest}}$), with minor differences between AHSU and TRADE. The responses of females might be sensitive to these two conditions, with decreased sweat rate and T_{forearm}, more pleasant thermal and comfort sensation, but increased $H_{\text{micro-back}}$ was recorded while wearing AHSU.

Table 4.2 Gender differences in anthropometric parameters and responses during the entire experiment

Variable/ Mean (SD)	Males (n=10)		Females (n=2)	
age (years)	21 (3.63)		20 (1.41)[b]	
height (cm)	174 (5.20)		162 (2.83)[c]	
weight (kg)	63 (6.83)		59 (3.41)[b]	
Condition	AHSU	TRADE	AHSU	TRADE
Exercise time (min)	24 (8)	23 (7)[d]	**17 (6)[c]**	**20 (5)[b,e]**
T_{in} (°C)	37.89 (0.49)	37.96 (0.55)[d]	37.97 (0.47)[a]	38.08 (0.51)[a,d]
$\overline{T_{sk}}$ (°C)	35.68 (0.62)	35.76 (0.63)[d]	**36.03 (0.47)[b]**	**36.28 (0.37)[c,e]**
$\overline{T_b}$ (°C)	37.16 (0.52)	37.20 (0.54)[d]	37.31 (0.44)[a]	37.48 (0.44)[b,d]
HR (bpm)	116 (36)	112 (36)[d]	120 (31)[a]	127 (28)[b,d]
Sweat rate (L/h)	0.50 (0.15)	0.52 (0.16)[d]	**0.32 (0.13)[c]**	0.56 (0.11)[a,f]
Sweat evaporative efficiency (%)	76 (14)	74 (9)[d]	**84 (10)[b]**	**84 (16)[b,d]**
T_{chest} (°C)	35.78 (0.89)	36.02 (0.74)[d]	**36.12 (0.69)[b]**	**36.44 (0.41)[b,e]**
T_{forearm} (°C)	35.77 (0.58)	35.80 (0.68)[d]	**36.04 (0.40)[b]**	**36.49 (0.30)[c,f]**
T_{thigh} (°C)	35.52 (0.67)	35.62 (0.74)[d]	35.73 (0.54)[a]	35.87 (0.80)[a,d]
T_{calf} (°C)	35.56 (0.75)	35.48 (0.81)[d]	**36.19 (0.73)[c]**	**36.12 (0.63)[c,d]**
$T_{\text{lateral chest}}$ (°C)	34.59 (0.74)	35.26 (0.90)[f]	35.10 (0.57)[b]	35.50 (0.58)[a,e]
$H_{\text{micro-back}}$ (%)	94 (5)	96 (3)[e]	95 (4)[a]	**88 (11)[c,f]**
$H_{\text{micro-thigh}}$ (%)	94 (7)	92 (8)[d]	93 (6)[a]	94 (9)[a,d]
RPE	2.85 (2.10)	2.63 (2.19)[d]	2.23 (1.88)[a]	2.45 (2.02)[a,d]
TS	4.65 (1.62)	5.10 (1.59)[d]	4.00 (0.69)[b]	5.23 (1.34)[a,f]
WS	4.90 (1.74)	5.37 (1.80)[d]	4.23 (1.60)[b]	5.32 (1.86)[a,e]
CS	4.36 (1.52)	4.97 (1.66)[d]	3.77 (1.19)[b]	5.09 (1.57)[a,f]

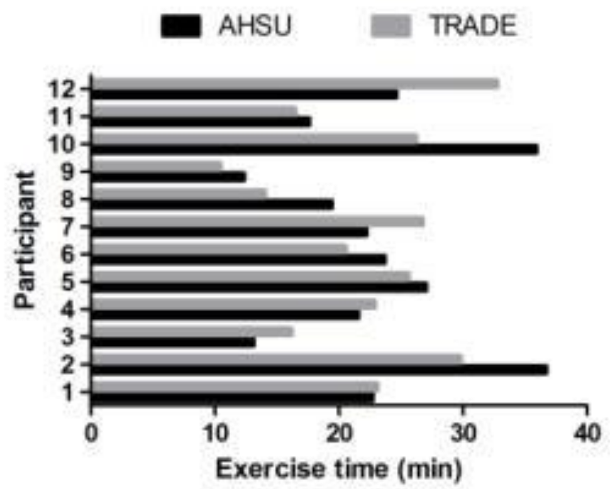
Note: Gender differences in anthropometric parameters and in physiological/perceptual responses for each wearing condition were presented as, [a]d <0.3 classified as small, [b]d=0.4–0.7 as medium, and [c]d>0.8 as large; differences in physiological/perceptual responses between AHSU and TRADE for each gender group were presented as, [d]d <0.3 classified as small, [e]d=0.4–0.7 as medium, and [f]d>0.8 as large (Christensen and Christensen, 1977).

4.3.2 The entire uniform

4.3.2.1 Exercise time and heart rate

Mean exercise time when wearing AHSU improved by 6% (~1 min) compared with that when wearing TRADE although no significant differences between these two conditions were observed (23.05±7.56 min for AHSU vs. 22.06±6.71 min for TRADE, $p>0.05$; Figure 4.4). The numbers of participants who terminated intermittent running by the criteria of T_{in}, HR, and participants' s volition were 6, 6, and 0 in AHSU; 6, 5, and 1 in TRADE, respectively. Heart rate of the participants did not vary between those wearing TRADE and those wearing AHSU during the entire test.

Figure 4.4 Exercise time of individual participants with AHSU and TRADE

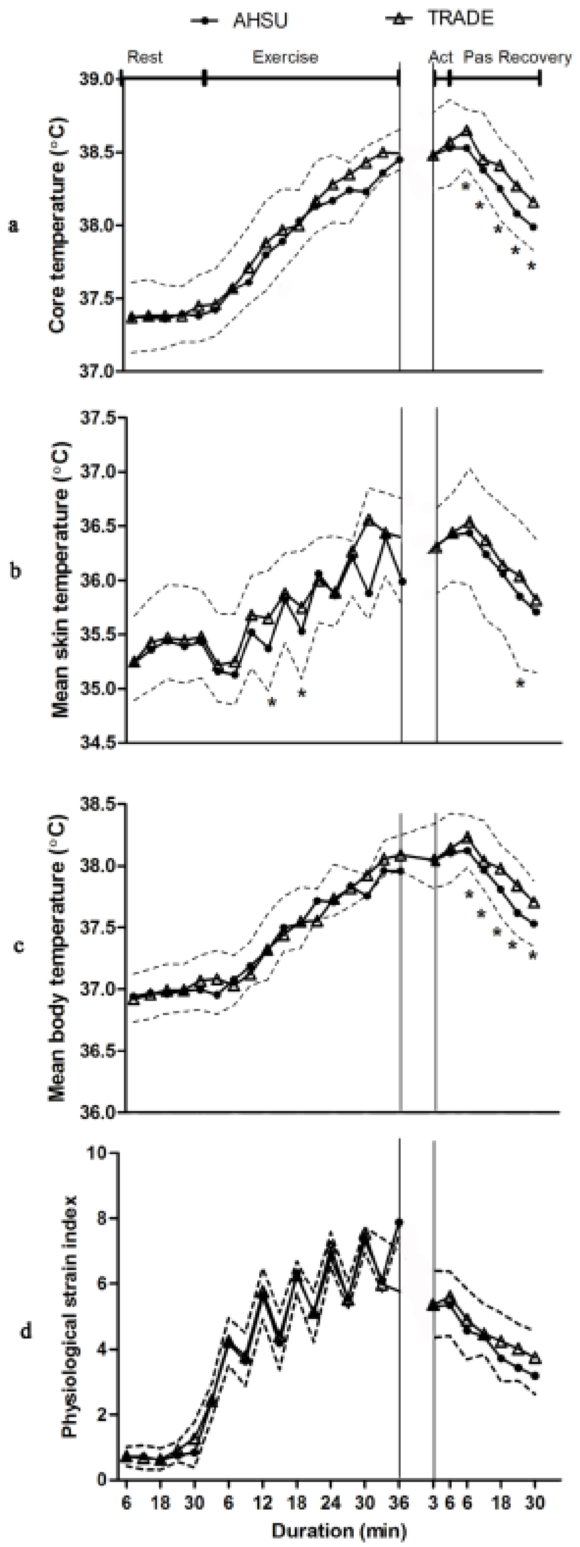


4.3.2.2 Thermo-physiological responses

No significant differences between body temperatures of participants wearing TRADE and those wearing AHSU were observed during pre-exercise rest and active recovery. Repeated measures ANOVA revealed a significant Condition ×

Time interaction for $\overline{T_{sk}}$ during exercise [$F_{7,21}$=2.91, p=0.027]. When the running speed reached a high value (8.5 km/h, 4% slope), $\overline{T_{sk}}$ of participants wearing AHSU was significantly lower than those wearing TRADE at the 12th and 18th min (p<0.05; Figure 4.5b). During passive recovery, body temperatures of participants wearing AHSU were significantly lower than those wearing TRADE [Main effect of Condition: $T_{in(AHSU)}$= 38.24±0.26 and $T_{in(TRADE)}$=38.39±0.27, $F_{1,\ 5}$=8.84, p=0.031; $\overline{T_{sk(AHSU)}}$ =36.06±0.61 and $\overline{T_{sk(TRADE)}}$ =36.19±0.55, $F_{1,\ 10}$=5.33, p=0.044; $\overline{T_{b(AHSU)}}$ =37.79±0.28 and $\overline{T_{b(TRADE)}}$ =37.92±0.28, $F_{1,\ 4}$=28.27, p=0.006; PSI_{AHSU}=4.29±1.09 and PSI_{TRADE}=4.61±1.07, $F_{1,\ 7}$=11.38, p=0.012; Figure 4.5]. Although no significant differences of $\dot{S}$ between the two conditions were found during pre-exercise, exercise, or post-exercise periods, $\dot{S}$ of participants wearing AHSU was significantly lower than those wearing TRADE across the rest-exercise-recovery cycle (52.39±16.15 for AHSU vs. 67.22±17.14 for TRADE, p=0.023; Figure 4.6). No significant difference in sweat rate (0.47±0.16 for AHSU vs. 0.53±0.16 for TRADE, p>0.05) or in sweat efficiency (77±11% for AHSU vs. 75±10% for TRADE, p>0.05) between the two conditions was detected (Figure 4.7).

Figure 4.5 Thermo-physiological responses of participants with AHSU and TRADE during the entire experiment (a: T_{in}, b: $\overline{T_{sk}}$, c: $\overline{T_b}$, d: PhSI)



Note: Dotted lines were presented as standard deviation

Figure 4.6 Rate of heat storage of participants with AHSU and TRADE during each activity

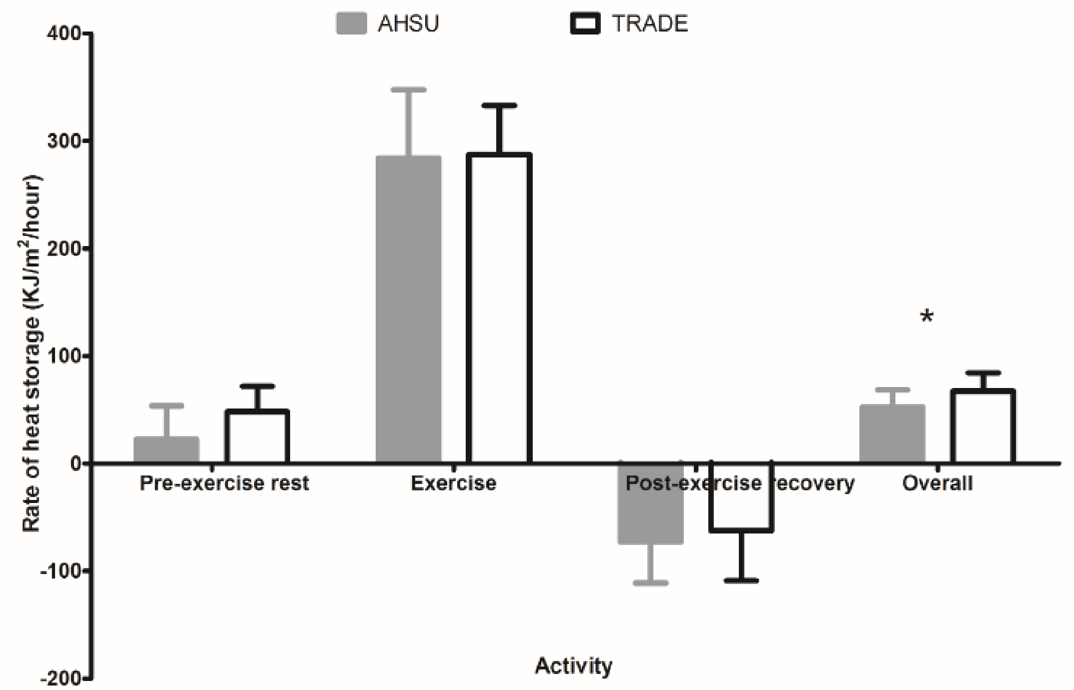
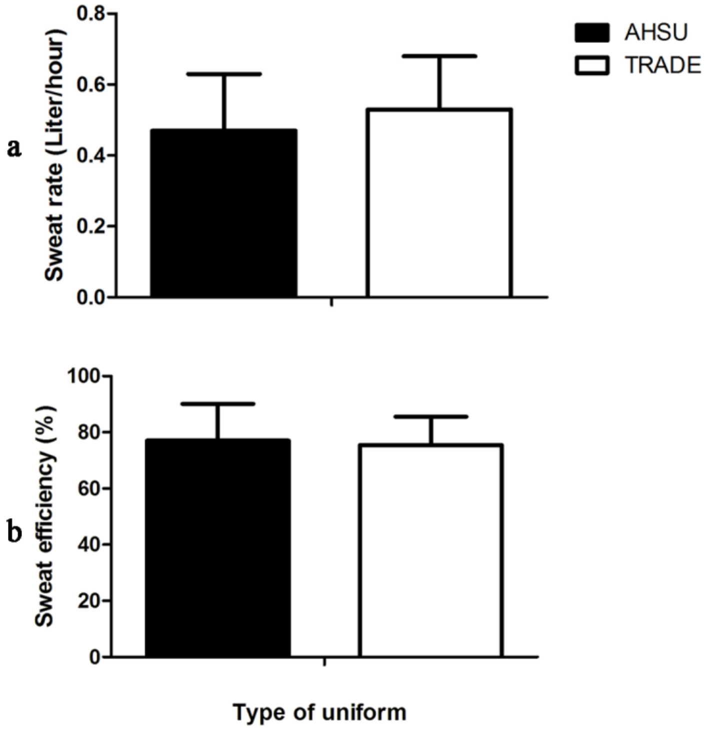


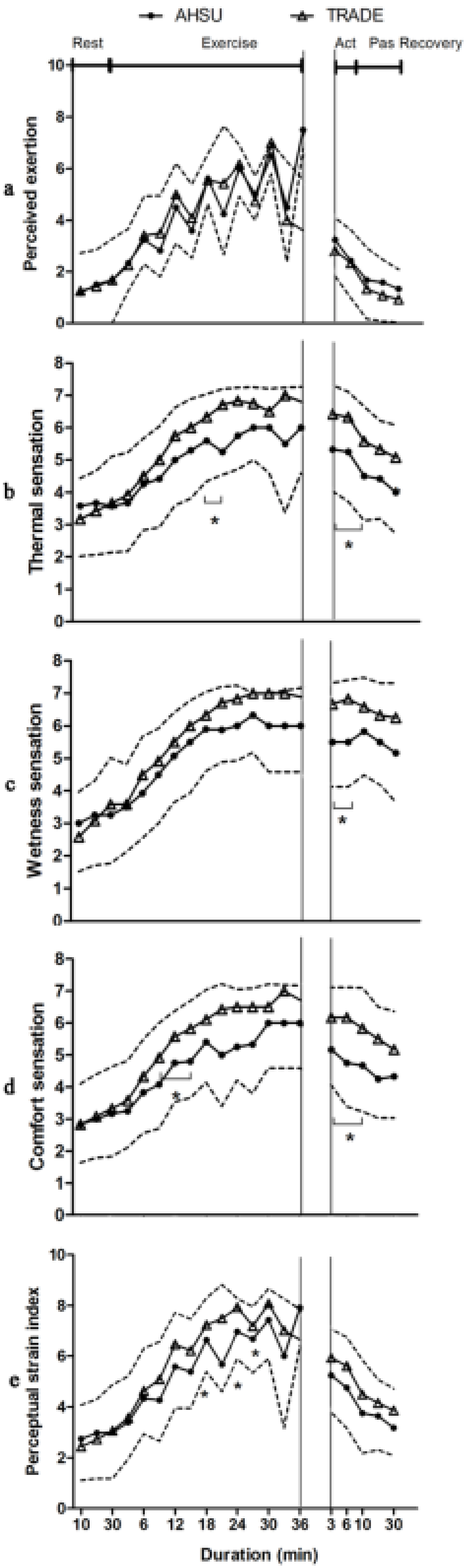
Figure 4.7 Sweat rate (a) and sweat efficiency (b) between the two conditions



4.3.2.4 Subjective sensations

No significant difference between RPE of participants wearing TRADE and those wearing AHSU was found during the entire experimental period (Figure 4.8a). The ratings of TS, CS, and the PeSI were significantly lower in participants wearing AHSU than those with TRADE at certain time of exercise and/or passive recovery ($p<0.05$, Figures 4.8b, 4.8d, 4.8e). Significant differences between TS, WS and CS of participants wearing TRADE and those wearing AHSU were observed during the entire active recovery ($p<0.05$; Figures 4.8b-d). Overall, the participants felt cooler, drier, and more comfortable when wearing AHSU during exercise and post-exercise recovery than those wearing TRADE.

Figure 4.8 Perceptual responses of participants with AHSU and TRADE during entire experiment (a: RPE, b: TS, c: WS, d: CS, e: PeSI)



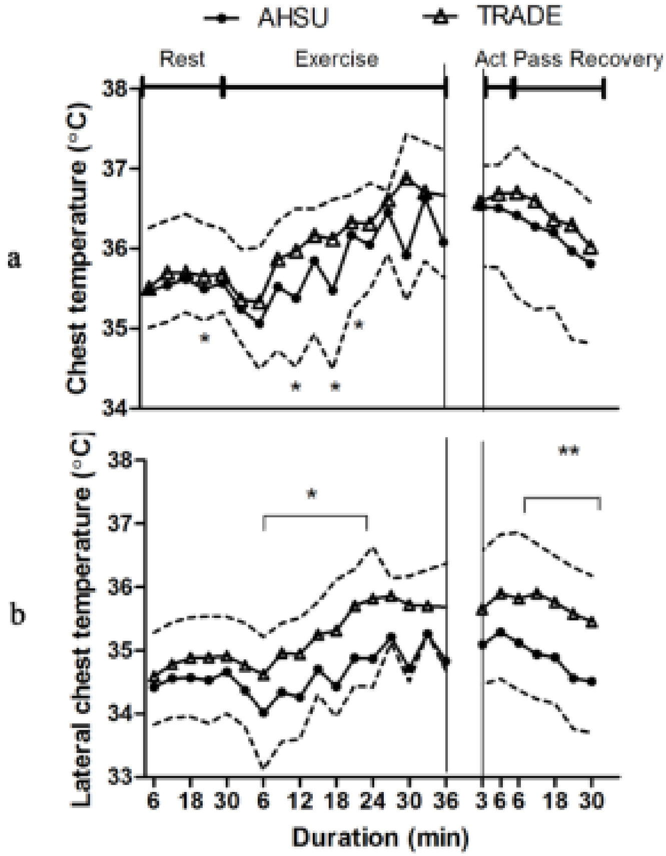
Note: Dotted lines were presented as standard deviation

4.3.3 T-shirts and pants

4.3.3.1 Objective measurements

The chest temperature of participants was significantly affected by Condition [$F_{1,3}$=18.13, p=0.024] and by Condition × Time interaction [$F_{7,21}$=6.76, p<0.001] during exercise, as shown in Figure 4.9a. Further, the chest temperature of participants wearing AHSU was significantly lower than those wearing TRADE when the participants ran at high exercise intensity (8 km/h, 4%) at the 12th, 18th, and 24th min (p<0.05). The interaction between condition and time was also observed in the lateral chest temperature of participants during exercise [$F_{3,9}$=2.11, p=0.033], while the main effect of condition in lateral chest temperature was found during passive recovery [$F_{1,11}$=18.13, p=0.005; Figure 4.9b]. The differences between forearm, thigh, and calf temperatures, $H_{micro\text{-}back}$ and $H_{micro\text{-}thigh}$ measured in the participants wearing AHSU and those wearing TRADE were not significantly different during the entire experiment.

Figure 4.9 Chest (a) and lateral chest temperatures (b) of participants wearing AHSU and TRADE shirts during the entire experiment.



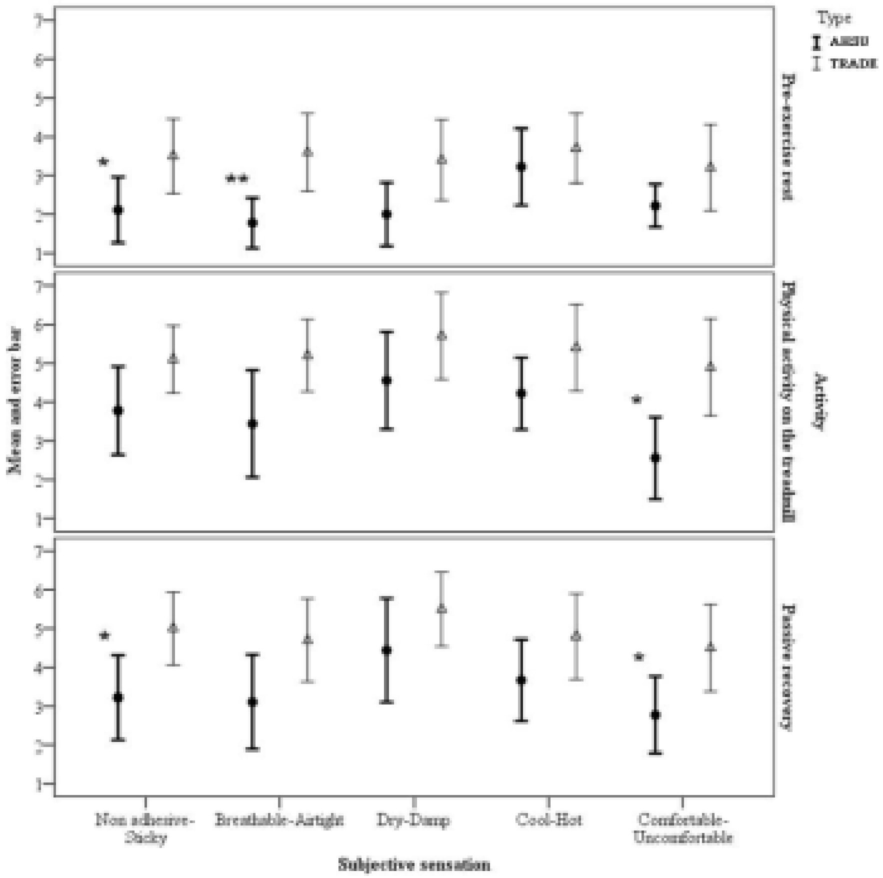
Note: Dotted lines were presented as standard deviation

4.3.3.2 Perceptual responses

Significant differences in the ratings of non-adhesive–sticky sensation and breathable–airtight sensation between the two shirts were found during pre-exercise rest (2.11±1.27 for AHSU vs. 3.50±1.51 for TRADE, $p<0.05$; 1.78±0.97 for AHSU vs. 3.60±1.58 for TRADE, $p<0.01$; Figure 4.10). Participants wearing AHSU shirt felt more comfortable when they performed physical activities on the treadmill (2.56±1.59 for AHSU vs. 4.90±1.97 for TRADE, $p<0.05$). During the passive recovery, they also reported that the AHSU shirt was less sticky and uncomfortable (3.22±1.64 for AHSU vs. 5.00±1.49 for TRADE; 2.78±1.48 for AHSU vs. 4.50±1.78 for TRADE; $p<0.05$). Perceived permeability during physical activities (4.89±1.36 for AHSU vs. 6.20±1.23 for TRADE; $p<0.05$) and comfort sensation during passive recovery (4.11±1.45 for

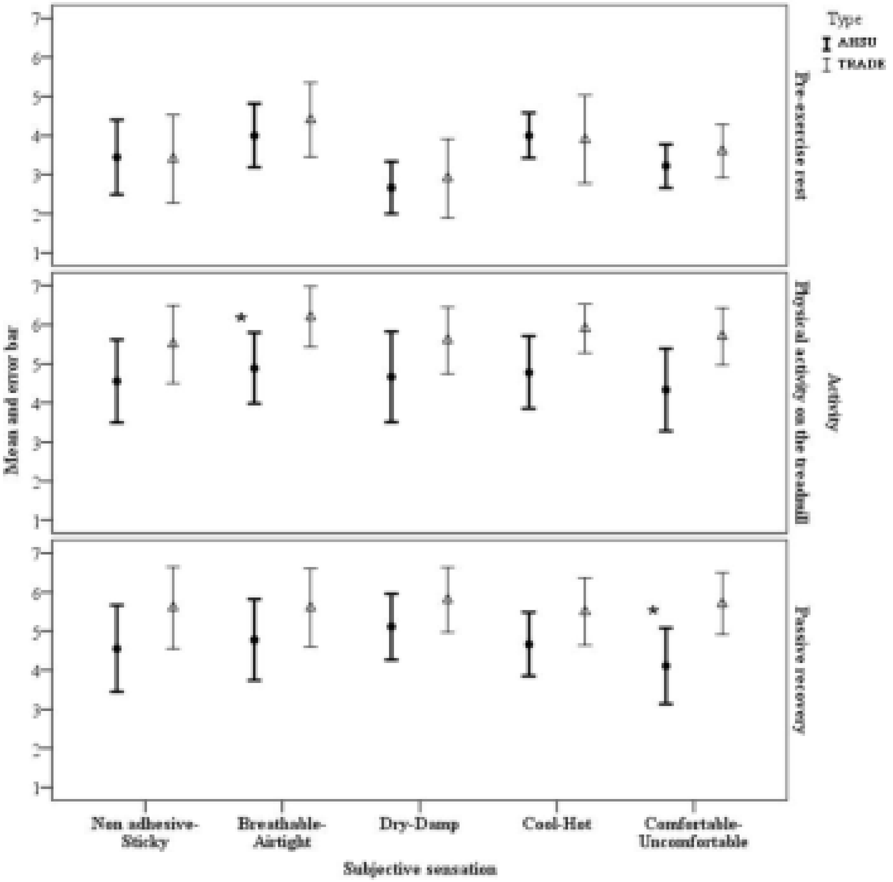
AHSU vs. 5.70±1.25 for TRADE; $p<0.05$, Figure 4.11) between AHSU and TRADE pants were significantly different. No significant differences in the ratings of thermal and wetness sensations between the two types of T-shirts, as well as between the two pairs of pants were observed during each activity period.

Figure 4.10 Subjective sensations on the two shirts during each activity period



Note: Values are shown as mean and standard error

Figure 4.11 Subjective sensations on the two pairs of pants during each activity period



Note: Values are shown as mean and standard error

4.4 DISCUSSION

This study aims to evaluate the efficacy of wearing a newly designed uniform (i.e., AHSU) in a hot and humid environment throughout a rest–exercise–recovery cycle. The key findings of this study indicate that AHSU significantly reduces thermo-physiological strain (e.g., body temperatures) and perceptual strain (e.g., sensations of thermal, wetness, and the perceptual strain index) at certain time of exercise and/or post-exercise recovery periods. Particularly, the benefit of AHSU in reducing rate of heat storage during the entire experiment is considerable because construction work consists of work-rest cycles (Yi and Chan, 2013a) rather than a sustained exercise.

The beneficial effects of the AHSU uniform in reducing skin temperatures are apparent at certain time of exercise because of the pumping effect[10] resulting from the advantages of its fabric properties, loose-fitting design, and the body movement. As evidenced by the consistently lower lateral chest temperature, meshed fabrics in the vertical side would not generate apparent barrier between the local skin and ambient environment, thereby improving air ventilation in the AHSU shirt. The loose-fitting design in the AHSU shirt also induces air ventilation with a wider air gap between the skin surface and clothing than the TRADE shirt. Body movement can also increase air ventilation in the loose-fitting garments than that in tight-fitting ones (McCullough et al., 1983). The pumping effect during body movements (Bouskill et al., 2002) causes the air trapped between the layer of clothing and the skin to circulate and force air ventilation around the body (Nielsen et al., 1985; Havenith et al., 1990; Ueda et al., 2006). Intense body movement, particularly during high running intensity (8.5 % km/h, 4% slope), brings additional airflow that is beneficial to evaporative heat loss directly from the skin surface by increasing water vapor pressure gradient (Gavin, 2003), as shown by the significant effect of the interaction of time and uniform type on lowering skin temperatures when wearing AHSU.

Despite the absence of body movement during passive recovery, significantly lowered thermo-physiological strain was found in those wearing AHSU, implying that post-exercise evaporation contributed to a significant cooling effect.

[10] The term “pumping effect” refers to a phenomenon that the air exchange between the microclimate and the external environment is enhanced when the dressed person performs physical activities (Havenith et al., 1990).

Fabrics with good water transfer property will help AHSU garments to spread out sweat quickly and take away heat through sweat evaporation and thus cool down the skin surface (Dai et al., 2008).

Rate of heat storage under the AHSU condition was significantly lower than that under the TRADE condition during the entire experiment, which indicates that evaporative heat dissipation with AHSU is more efficacious. This finding echoes to previous studies, which advocate that the physical characteristics of the clothing materials promoting heat transfer may decrease the body heat storage (McLellan and Cheung, 2000; Saunders et al., 2005). Whilst the rate of heat storage during pre-exercise rest tends to decline in AHSU, no differences between the two uniforms were observed during exercise. Possibly, the result might not be as a consequence of human thermoregulatory failure, but that of a reduced capacity of the stressful environment to absorb the heat generated by the vigorous exercise (Saunders et al., 2005), regardless of the type of uniform worn.

Gavin et al. (2001) and Gavin (2003) advocated that high sweat efficiency of fabric indicates high ability to release liquid and moisture from the garments, thereby helping to remove heat, promote sweat evaporation, and further provide enhanced body cooling. Sweat efficiency however will decrease when environmental humidity increases (Epstein et al., 1986). In the present study, no significant difference between sweat efficiency of participants wearing TRADE and those wearing AHSU was observed during the entire experiment because wet skin with high microclimate humidity and humid ambient environment might have impeded the water vapor pressure gradient, regardless of the type of uniform. Even though such insignificant differences were observed, the efficacy of wearing AHSU in alleviating body thermo-physiological strain was ascertained by the reduction of body temperatures. It is deduced that air ventilation serves an important role in promoting moisture evaporation and further lowering body temperatures.

The difference between heart rate of the participants wearing TRADE and those wearing AHSU was not significant under the given environmental conditions. Studies by Ha et al. (1999), Gavin et al. (2001), Brazaitis et al. (2010), and Kaplan and Okur (2012) confirmed that heart rate is primarily determined by the activity level in the experiment protocol. In relation to heart rate (Laing et al., 2008), the ratings of RPE reported by the participants showed no significant difference between the two types of uniform. Petruzzello et al. (2009) stated that wearing clothing with better heat dissipation ability might result in lower levels of perceptual strain than wearing clothing with the most encapsulation. Perceptual strain (sensations of thermal, wetness, comfort, and the PeSI) of participants wearing AHSU was significantly lower than those wearing TRADE at certain time of exercise and/or passive recovery, resulting in desirable subjective judgments. The superior overall moisture management capacity of the AHSU facilitates liquid sweat transfer from the inner side to the outer of fabric surface and thus, the skin surface is much drier and more comfortable. The results imply that wearing AHSU can buffer the detrimental effect of unpleasant subjective sensations and consequently encourage people not to take off these clothes in the heat (Heus and Kistemaker, 1998).

It is acknowledged that the single sample source of university students and the limited female participants are the limitations of the current study. Moderate to large effects have been observed for certain physiological and/or perceptual responses between males and females, regardless of the types of uniforms worn. It is envisaged that significant differences in thermal responses between males and females will be detected if more females are involved in the experiment.

Accordingly, a three-way ANOVA (clothing×time×gender) with repeated measures should be performed in future studies.

4.5 CHAPTER SUMMARY

Construction workers in subtropical climate are vulnerable to heat stress resulting from hot and humid weather. Properly selected fabrics and smartly designed uniform that enable workers to reduce heat strain are essential to protect construction workers from heat-related illness. The aim of this study is to evaluate the physiological and perceptual responses of wearing a newly designed uniform (AHSU) as compared to those of wearing a commonly used one in the industry (TRADE) throughout a rest–intermittent running–recovery cycle at an ambient of 34.5°C temperature and a relative humidity of 75%. The major findings manifested that the mean skin temperature ($\overline{T_{sk}}$) of participants with AHSU was significantly lower than that with TRADE when the running speed reached a high value (8.5 km/h, 4% slope) that is associated with marked pumping effects. During passive recovery, thermo-physiological strain (T_{in}, $\overline{T_{sk}}$, and mean body temperature $\overline{T_b}$, and the physiological strain index PhSI) of participants with AHSU was significantly lower than that with TRADE, as evidenced by the main effect of clothing type. Notably, the new shirt exhibits remarkable beneficial effects in reducing skin temperatures on the upper torso. The perceptual strain of participants with AHSU was significantly alleviated at certain time of exercise and/or post-exercise recovery as the participants felt cooler, drier and more comfortable than that with TRADE. The practical value of wearing AHSU pertains to the significant reduction in rate of heat storage throughout the rest-exercise-recovery cycle, which indicates that wearing AHSU enhances a more efficacious evaporative heat dissipation from the body to the environment.

CHAPTER 5 EFFECTIVENESS OF THE ANTI-HEAT STRESS UNIFORM[11]

5.1 INTRODUCTION

Construction workers are generally advised to wear appropriate summer clothing as a precautionary measure for working in hot weather (CIC, 2013; Labor Department, 2014). Although numerous laboratory tests have identified the efficacy of well-designed clothes in alleviating body heat strain, the role of summer work uniform in real-life settings has received little attention. In addition, the interaction effects among heat stressors are not well documented (Rowlinson et al., 2014). Interaction effects refer to the combined effects of the two or more causes on the consequences (Kupper and Hogan, 1978). Interaction effects may help elaborate on the complex correlations among various dimensions of heat stressors in relation to their influence on the responses to heat stress. Nevertheless, a scientific understanding of the responses to thermal stressors remains an intricate issue with few consensuses on the multiple heat stressors and their interactions. This chapter aims to examine the relationship between heat stressors and perceived heat strain and the effectiveness of a new work uniform in combating heat strain in real-work settings.

5.2 METHODS OF DATA COLLECTION

A field experiment with a randomized assignment of an intervention group to a newly designed uniform and a control group to a commercially available trade

[11] The detailed methodologies and research findings had been presented in a working paper: Yang, Y. and Chan, A.P.C. (2015). The role of work uniform in combating perceptual strain among construction workers.

uniform was conducted.

5.2.1 Participants

A total of 16 construction workers were randomly selected for the field experiment. The inclusive criteria included young male construction workers without known health problems. All the participants had acclimated to work in hot weather for approximately one month (from June to August in the summer season of Hong Kong). The demographic characteristics of these participants were as follows (mean and standard deviation): age 21.7 (1.9) years, height 173.7 (5.1) cm, body weight 65.0 (11.8) kg, and body mass index 21.5 (3.5) kg/m^2. Construction workers from different trades were involved to capture a wide spectrum of empirical data. The participants were drawn from four common work trades, namely, rebar, leveling, formwork, and painting and plumbing. The proportion of participants engaged in four trades was 37.5% for rebar work, 12.5% for leveling, 37.5% for formwork, and 12.5% for painting and plumbing works. The working areas of the participants (e.g., outdoors and semi-outdoor areas under a shade) were recorded. All the participants performed their usual work on the ground floor or at a platform. They participated in the field experiment on a voluntary basis and could withdraw at any time as they wished. After the provision of a clear briefing on the experimental purposes and testing procedures, they were asked to sign the consent forms prior to the experiment.

5.2.2 Experimental procedures

Sixteen field experiments were conducted for 16 working days from July to August 2014. Each experiment lasted from 8:00 am to 4:30 pm. On each experimental day, a newly designed work uniform (AHSU group) and a commercially available one (TRADE group) were randomly assigned to the participants in a counter-balanced order in the morning and afternoon, respectively. Prior to the experiment in the morning, the participants were asked to wear the assigned work uniform. Besides, a heart rate belt with monitor (Polar Wearlink®, the USA) was equipped. They were requested to provide basic personal information, including name, age, and trade. Body mass (including the uniform) was measured by using a digital scale with 0.1 kg precision (Tanita, Japan). Height was measured to the nearest centimeter with a wall-mounted ruler. Afterward, the participants were asked to rest for 30 minutes in an air-conditioned room with the temperature maintained at approximately 22 °C. Subsequently, they performed their usual daily work at the working sites for 135 minutes[12]. During this period, the participants were allowed to drink water, take breaks, and self-pace their workload as they desired. This procedure aimed to lower the risks of excessive heat strain induced by dehydration and inordinate work pace. Each participant might have different working durations depending on their work routines and consequently, the number of repeated measures for the targeted parameters may be unbalanced. After work, they recovered in the air-conditioned room for 30 minutes. Upon the completion of these testing procedures in the morning, the participates were advised to have lunch and rest in the air-conditioned room to ensure that they were fully cooled and dry before

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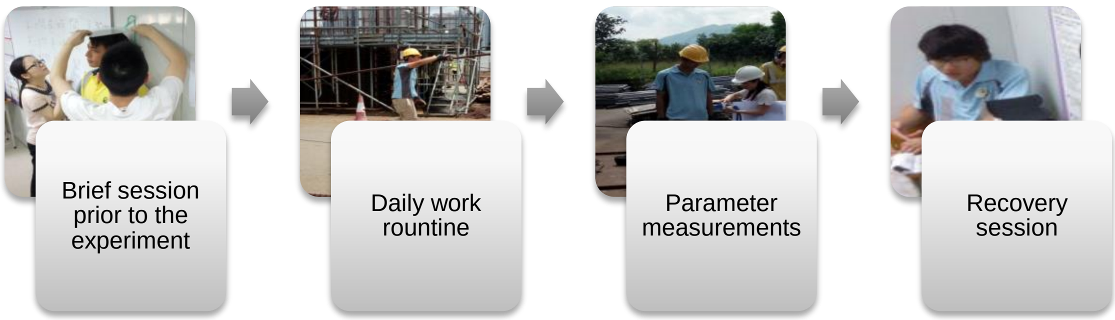
[12] The standardized exposure time for the field experiment was estimated by a heat stress model proposed by Yi and Chan (2014a), in which HTT = (RPE+5.43-0.11×WBGT- 0.1×API-0.06×AGE+ 0.07×PBF-2.28×ADH -0.5×SH -0.14×EC- 0.16×RE+ 0.01×RHR') /1.4×60, where HTT is heat tolerance time, RPE (rating of perceived exertion)=7 [voluntary exhaustion], WBGT (wet bulb globe temperature)=30 °C, API (air pollution index)=30, PBF (percentage of body fat) is assumed as 12.3 (%), AGE=21 years, ADH (alcohol drinking habit)=1 [no more than four drinks on any single AND 14 drinks per week], SH (smoking habit)=1 [one to four cigarettes per day], EC (energy consumption) =2 and RE (respiratory exchange)=2 refer to moderate workload, RHR' (resting heart rate)=78 bpm. According to this equation, the exposure time was estimated to be approximately 134 min. The use of a heat tolerance time here aimed to avoid excessive heat strain because of prolonged exposure in the heat.

participating in the afternoon test. Prior to the test in the afternoon, they were asked to change to another type of work uniform. The testing procedure in the afternoon was the same as that in the morning (Figure 5.1).

Figure 5.1 A typical run-down of the field experiment



5.2.3 Measurements and indices calculations

Empiric-based human and environmental monitoring was executed throughout the pre-work resting, working, and recovery periods. A heat stress monitor (QUESTemp°36, Australia) was located near to the participant to measure the wet bulb globe temperature (WBGT) at every minute. Heart rate (HR) was recorded at one-minute interval. HR and WBGT were transformed into five-minute averages for statistical analysis. The participants were asked to report the ratings of perceived exertion (RPE) and thermal sensation (TS) every 5 minutes. These environmental, physiological, and perceptual parameters were recorded synchronously. The real time of each measurement was recorded and further was calculated as the cumulative exposure time. Once the participant took a break, the measurement was suspended, and the cumulative exposure time was recounted when the participant resumed work.

The perceptual strain index (PeSI) developed by Tikuisis et al. (2002) is commonly used under uncompensable heat exposure (Yang and Chan, 2015). For extending its application to compensable heat stress, the reliability and validity of the modified Tikuisis's equation (Eq. (5.1)) has been proven in both laboratory and field settings (Yang and Chan, 2015; Chan and Yang, 2015), in which the modified PeSI can well reflect physiological strain.

$$\mathrm{PeSI} = 5 \times \frac{\mathrm{RPE_i}}{10} + 5 \times \frac{\mathrm{TS_i} - 1}{6} \tag{5.1}$$

where RPE_i and TS_i are the simultaneous perceived exertion and thermal sensation respectively during working period. RPE was recorded by the using an 11-point single-item scale with anchors ranging from 0 "resting" to 10 "maximal" (Borg, 1998). TS was measured by a seven-point scale modified based on Ballantyne et al. (1977)'s study, namely, 1=very cool, 2=cool, 3=slightly cool, 4=neutral, 5=slightly hot, 6=hot, and 7=very hot. These scales in Chinese languages were provided during the experiment. Modifications of the linguistic terms into non-English language were necessary (Lee et al., 2009) because the translation of English linguistic descriptors into Chinese may cause confusion. International standards for the measurements of subjective perceptions should consider the differences in linguistic descriptors across cultures and thus, comprehensive assessments on such a modification are still required in future studies (Lee et al., 2009).

The relative heart rate (RHR) (Eq. (5.2)) was used as an indicator to estimate physical workload associated with muscular activities (Shimaoka et al., 1997; Maiti, 2008).

$$\text{RHR} = \frac{\text{HR}_{\text{w}} - \text{HR}_{\text{r}}}{\text{HR}_{\text{max}} - \text{HR}_{\text{r}}} \times 100 \qquad (5.2)$$

where RHR refers to the heart rate increases compared to rest expressed as a percentage of the rest to maximal heart rate range, HR_w was HR measured during work, HR_r was the minimal HR during rest, and HR_{max}=220-Age (Rodahl, 1989).

A total of 568 sets of physical, physiological, perceptual, and microclimatological data were collected under wearing AHSU (N=291) and TRADE (N=277) conditions. A data collection sheet was used to record these data (Appendix 4).

5.2.4 Linear mixed-effects model

Given the nature of the experimental design and the complexity of the cause-effect relationship between the perceptual strain index and heat stressors, a linear mixed-effects model (LMM) with repeated measures was employed in the present study to ascertain the role of work uniforms in combating perceptual strain in real-life settings. This model was utilized to identify the determinants of a number of heat stressors on the perceptual strain index among the construction workers. In this study, work trade (coding: 1=rebar work, 2=leveling, 3=form work, 4=painting and plumbing), workplace (coding: 1=outdoor, 2=semi-outdoor), clothing type (coding: 1=AHSU, 2=TRADE), exposure time, WBGT, RHR, and their interactions were regarded as fixed effects, whereas the participants served as the random effects. In the whole-day experiment, repeated measurements for each participant were coded as sequential numbers, which might vary because of the differences in work routines. That is, the intervals between adjacent repeated measurements for each participant might not be the same.

A three-step process intended to generate the most appropriate LMM with the criterion of *most parsimonious with the best fit to the data* was adopted from Henderson et al. (2014) and Bertulat et al. (2013). A full factorial model was not included in the current study because of the collinearities and complex relations between or among the variables (Pearlmutter et al., 2014). The main effects included in the candidate model with the same random effects were determined first. The main-effects model was built in a manual backward stepwise manner by removing the parameters until all remaining parameters showed a significant effect ($p<0.05$). Meanwhile, Spearman's correlation for nominal variables and Pearson's correlation for continuous variables were tested for collinearity. If the magnitude of correlation between two independent variables was significantly higher than 0.7, then only the variable that resulted in a univariate model with the smaller p value was included in the main-effects model. In the second step, the interactions to be included in the candidate model set were determined. Based on the number of potential interactions among fixed effects, each potential two- or three-way interaction was added to the model that included the main effects derived from the first step. All possible two-way interactions, as well as all three-way interactions that included *clothing*, were included in the analysis. This procedure assisted in investigating how clothing type affects the perceptual strain. For the models that integrated three-way interactions, all their component two-way interactions were considered because interpreting linear models corrected by the lower-order interactions was necessary (Morrell et al., 1997; Henderson et al., 2014). The main effects-only model was compared with the more complex model using the corrected Akaike's information criterion (AICc) for small sample size (Hurvich and Tsai, 1989; Field, 2013). Only the interactions that resulted in AICc values that were smaller than those of the main effects-only model were included in the candidate model set. The final step comprised fitting all the candidate models with all possible combinations of the main effects and the interactions selected in the preceding steps and selecting the most appropriate model using AICc. A first-order autoregressive covariance structure was assumed for the covariance structure of the repeated measures in the sequential numbers (Henderson et al., 2014). Scale identity was assumed for the covariance structure of the random effects to consider the independence of the observations between participants (Poitras and Lajoie, 2014). Restricted maximum likelihood was used for parameter estimation. The analytical methods were all performed by SPSS 20.0, and statistical significance was set at a level of 5% for all statistical analyses.

5.3 RESULTS

Table 5.1 depicts the most appropriate linear mixed-effects model, based on the model selection procedure, included WBGT, RHR, exposure time, the interaction between clothing and trade/place, and the interaction between workplace and the WBGT. The statistical form of this model is given by Eq. (5.3). The parameter estimates of this model are shown in Table 5.2.

$$\mathrm{PeSI_{ij}} = \beta_0 + \beta_1 \times \mathrm{WBGT} + \beta_2 \times \mathrm{RHR} + \beta_3 \times \mathrm{T} + \beta_4 \times \mathrm{clo} \times \mathrm{trade} + \beta_5 \times \mathrm{clo} \times \mathrm{place} + \beta_6 \times \mathrm{place} \times \mathrm{WBGT} + \mu_i + \varepsilon_{ij} \quad (5.3)$$

where $\mathrm{PeSI_{ij}}$ is the perceptual strain level for the i^{th} participant in the j^{th} measure, β_n $(n = 1,2, \ldots 6)$ is the coefficients of fixed effects, WBGT is wet bulb globe temperature, RHR is relative heart rate, T is exposure time, clo is type of work uniform, place is the workplace, μ_i is the random effect for participant i, ε_{ij} is the random unexplained error.

Table 5.1 Results of linear mixed-effects model (LMM) selection: main-effects model and the top five factorial models selected using Hurvich and Tsai's Criterion (AICc)

Independent variable	**main-effects model**	**model 1**	**model 2**	**model 3**	**model 4**	**model 5**	**RI**
WBGT	√	√	√	√	√	√	1
RHR	√	√	√	√	√	√	1
T	√	√	√	√	√	√	1
Clo	√						0
Trade	√						0
Place	√						0
Clo×Trade		√	√	√	√	√	1
Clo×Place		√	√	√	√	√	1
Clo×WBGT×Trade						√	0.08
Trade×WBGT				√	√		0.34
Place×WBGT		√			√		0.51
AICc	1337.39	**1312.67**	1313.70	1313.91	1314.61	1315.71	-
ΔAICc	-	0	1.02	1.24	1.94	3.04	-
ω(AICc)	-	0.37	0.22	0.20	0.14	0.08	-

Abbreviation: WBGT – wet bulb globe temperature, RHR – relative heart rate, T – exposure time, clo – type of work uniform, place – workplace, ω – the Akaike weight, RI – relative importance of independent parameter.

Calculations: $\Delta AICc_i = AICc_i - minAICc$, $\omega(AIC_{ci}) = \frac{\exp(-\frac{1}{2}\times\Delta AICc_i)}{\sum\exp(-\frac{1}{2}\times\Delta AICc_i)}$, where i is the i^{th} model.

The final model produced statistically insignificant random effects, indicating the consistency of responses to perceptual strain across all participants. The effects of temperature, RHR, exposure time, clothing type, trade, and workplace on the perceptual strain were determined by a linear combination of the main and interaction effects. Temperature, RHR, and exposure time showed significantly positive effects on the perceptual strain index, which indicates that the perceptual strain increased along with temperature, workload, and exposure time. For instance, a temperature increase of 1 °C yielded a growth of 0.5 units in perceptual strain, and a workload increase of 10 W/m^2, while an extended exposure time of 10 min aggravated perceptual strain by 0.4 and 0.2 units, respectively. As regards to the highly significant interaction between clothing type and trade, wearing AHSU exhibited a significant benefit on alleviating perceptual strain. For example, perceptual strain was significantly reduced by 5.8, 6.3, 6.1, and 1.6 units when rebar, leveling, form, painting and plumbing workers wearing AHSU, respectively. This finding suggests the possible beneficial effect of AHSU in alleviating perceived heat strain for construction workers across the four trades.

Table 5.2 Coefficient and standard error of the linear mixed-effects model

Parameter		**standard error**	**P**
Fixed effects	**Coefficient**		
Intercept	-10.63	6.49	0.102
WBGT	0.51	0.21	**0.015**
RHR	0.04	0.01	**<0.001**
T	0.02	0.00	**<0.001**
AHSU × Rebar work	-5.76	1.11	**<0.001**
AHSU × Leveling work	-6.33	1.24	**<0.001**
AHSU × Form work	-6.11	1.11	**<0.001**
AHSU × Painting and plumbing work	-1.63	0.56	**0.004**
TRADE × Rebar work	6.92	6.56	0.293
TRADE × Leveling	8.42	6.60	0.203
TRADE × Form work	8.23	6.58	0.211
AHSU × Outdoor	13.40	7.01	0.056
WBGT× Outdoor	-0.33	0.21	0.126
Random effects	**variance**		
Participant	0.62	0.35	0.073
Residual	0.71	0.04	**<0.001**

5.4 DISCUSSION

Meteorological environment and physical activities are well-known factors that influence the human thermal state. Environmental stress in the workplace weakens the ability of the body to maintain thermoregulation (Inaba and Mirbod, 2007). Increasing ambient temperature and thermal radiation result in higher heat load on the body, and a humid environment without air ventilation impairs heat exchange through evaporation. Heat production arising from muscular activity is one of the main components of exercise-heat stress (Brotherhood, 2008). The metabolic heat load gained from both thermal environment and physical activity may prevent adequate heat loss from the body, further resulting in exaggerated fatigue (Hargreaves, 2008). Furthermore, prolonged exposure to hostile weather heightens the risk of heat-related illnesses when working in hot weather (Coris et al., 2004). The findings of the current study indicate that the increased ambient temperature, workload, and exposure time have significant effects on the aggravation of heat strain among construction workers. This observation echoes to the results of early studies (Yi and Chan, 2014a; Xiang et al., 2014).

The present study ascertains the role of the appropriate summer work uniform in helping construction workers combat heat strain by employing a holistic assessment on occupational heat stress. The practical value of the attenuation of perceptual strain lies in the fact that wearing AHSU may contribute to a higher tolerance level in the heat (Cheung, 2010) than wearing TRADE. The declined perceived thermal strain may allow individuals to increase their voluntary workload and to combat fatigue, and eventually to extend physical performance under heat exposures (Cheung, 2010). The participants from all four trades have experienced such benefits when wearing the new uniform. This finding provides a fresh perspective in ascertaining the role of summer work uniform in a field setting.

The current study presents two major contributions. First, the field experiment with randomized assignment was executed to evaluate the effectiveness of a new work uniform in helping construction workers combat heat strain in real-work settings. As an extension and expansion of a standard laboratory experiment, a randomized field experiment that accounts for the nature of a real-life setting (Chadwick et al., 1984) and produces unbiased estimates of intervention effects (Berk et al., 2010) can alternatively provide a clear picture of the functions of the work uniform. In light of the merits of the randomized experiments, the findings of the present study may be of practical value in the formulation of evidence-based guidelines that could safeguard construction workers exposed to hot weather. Second, the results generated from the mixed-effects model with repeated measures indicate the significant attenuation produced by wearing the new uniform in the perceptual strain level of construction workers from the four trades. In particular, the rebar, leveling, and form workers received more benefits from this uniform compared with the painting and plumbing workers.

5.5 CHAPTER SUMMARY

A total of 568 sets of physical, physiological, perceptual, and microclimatological data were obtained from 16 construction workers on sixteen working days between July and August of 2014 in Hong Kong in the field experiments. A linear mixed-effects model (LMM) was built to examine the cause-effect relationship between the perceptual strain index (PeSI) and multiple heat stressors, including wet bulb globe temperature (WBGT), relative heart rate (RHR), exposure time (T), trade, workplace, and clothing type. The results showed that the increase in the WBGT, RHR, and T significantly resulted in the rise of the perceptual strain. An interaction effect between clothing and trade revealed that the perceptual strain among workers was significantly alleviated when they wore the new uniform. The finding of this study provides a fresh and scientific approach to provide positivistic evidences on the effectiveness of a precautionary measure against heat stress at construction sites and thus contributes to the enhancement of research methodologies and practical problem solving.

CHAPTER 6 ACCEPTABILITY OF THE ANTI-HEAT STRESS UNIFORM[13]

6.1 INTRODUCTION

There is a pressing need to wear appropriate summer work clothes for improving wearing comfort in a harsh environment. However, the wearing comfort of construction work uniforms has not been extensively explored and documented. It is envisaged that wearing appropriate summer work clothes may keep workers comfortable without excessive heat stress or impeding their work performance. This study aimed to establish an analytical approach to evaluate the comfort performance of summer work uniforms. Human wear trials and the questionnaire surveys were administered to glean workers' perceptions on the two types of summer work uniforms. To deepen the understanding of how construction workers judge the wearing comfort of work uniforms, three prediction models, namely, multiple linear regression, artificial neural network, and fuzzy logic, would be employed for statistical analysis.

6.2 METHODS OF DATA COLLECTION

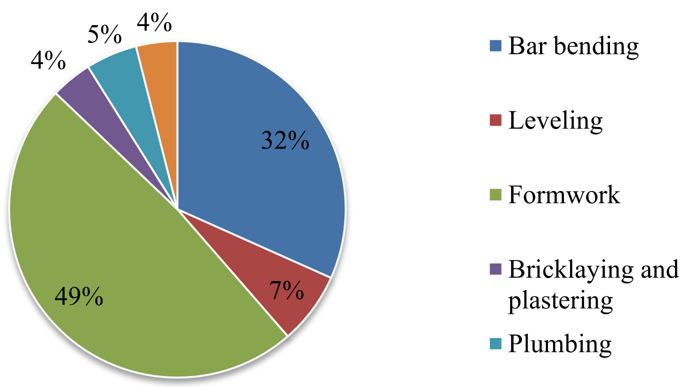
According to the sample size determined in Section 3.4.4 of Chapter 3, 189 male construction workers were invited to participate in the two-day wear trial (Figure 6.1). They were randomly divided into two groups; half of them wore AHSU and the other half wore TRADE on the first day. The uniform type was reversed on the

[13] Presented in a published paper: Chan, A.P.C., Yang, Y., Wong, F.K.W., Chan, D.W.M. and Lam, E.W.M. (2015). Wearing comfort of construction work uniforms. *Construction Innovation: Information, Process and Management*, 15(4), 473-492.

second day. Brief introduction of the purpose of the study and the test procedures were given to the participants prior to the wear trial. They then signed consent forms and provided their basic personal information including name, age, height, weight, trade of work, and work location. The demographic features (mean and standard deviation) of the participants were: age 33.1 (10.4) years, weight 69.2 (12.2) kg, and height 171.2 (6.8) cm. The distribution of their working trades is depicted in Figure 6.2. Bar benders, levelers, and formwork workers performed outdoor tasks, while the others worked in the semi-outdoors.

Figure 6.1 A typical run-down of the field survey

Figure 6.2 Distribution of trades of the participants



During the two-day trials, the participants were required to undertake similar work routines without disturbing their normal operations. The wet bulb globe temperature (WBGT) was measured by a heat stress monitor (QUESTemp°36™, Australia) throughout the wear trial. There were no considerable differences in WBGT between the two-day wear trials (Table 6.1).

Table 6.1 Wet bulb globe temperature (WBGT) collected during wear trials

No. of field study	**WBGT (°C) (mean and standard deviation)**	
	1^{st} day trial	2^{nd} day trial
1	33.05 (1.57)	31.94 (1.52)
2	31.50 (1.41)	31.33 (0.88)
3	33.71 (0.77)	31.26 (0.77)
4	34.72 (1.16)	33.33 (1.64)
5	31.72 (1.60)	30.43 (2.53)
6	31.76 (2.16)	33.44 (0.95)
7	30.92 (1.19)	30.86 (0.98)
8	33.70 (0.67)	31.07 (0.74)

Upon the completion of a whole day wear trial, the participants were required to complete a self-administered questionnaire on assessing the subjective perceptions on their work uniforms (Appendix 5). The subjective attributes were represented by the bipolar descriptors on a 7-point Likert scale (Table 6.2; Chan, et al., 2013b; Wong et al., 2004). A total of 189 pairs of questionnaires were obtained.

Table 6.2 Subjective assessments on the uniforms

Abbreviation/Score	1	2	3	4	5	6	7
A1	Hot						Cool
A2	Damp						Dry
A3	Clammy						Dry[14]
A4	Airtight						Breathable
A5	Thick and heavy						Thin and light
A6	Work performance interfered						Non-work performance interfered
A7	Uncomfortable						Comfortable

6.3 DATA ANALYSIS AND RESULTS

For all data sets, the differences in subjective attributes between the two uniforms were tested by the Wilcoxon signed ranks test via SPSS (19.0) software program. In addition, 151 pairs of data sets and 38 pairs were used to construct the prediction models and to test the prediction performance of the constructed models, respectively. These data sets were randomly selected for prediction and test purposes. The prediction models for gauging the wearing comfort of shirts and pants were developed separately.

6.3.1 Descriptive data

Mean values of the subjective assessments are shown in Table 6.3. In general, AHSU was rated significantly higher than TRADE on all sensory attributes. Meanwhile, the average ratings of AHSU on most of attributes were above four that indicates a satisfactory level based on the 7-point Likert scale. Therefore, AHSU is more acceptable than TRADE.

[14] Clammy-Dry describes the wetness of garments, while Damp-Dry means the skin wetness.

Table 6.3 Subjective ratings on AHSU and TRADE

Attribute/ mean and standard deviation	Shirt			Pants		
	AHSU	TRADE	**Sig.**	AHSU	TRADE	**Sig.**
A_1	3.87 (1.55)	2.33 (1.21)	p<0.001	4.20 (1.44)	2.42 (1.28)	p<0.001
A_2	3.71 (1.54)	2.17(1.26)	p<0.001	4.16 (1.62)	2.38 (1.35)	p<0.001
A_3	4.13 (1.42)	2.36 (1.30)	p<0.001	4.42 (1.53)	2.47 (1.42)	p<0.001
A_4	4.44 (1.56)	2.54 (1.24)	p<0.001	4.60 (1.48)	2.52 (1.41)	p<0.001
A_5	4.87 (1.44)	2.78 (1.30)	p<0.001	5.04 (1.38)	2.73 (1.38)	p<0.001
A_6	4.95 (1.51)	3.13 (1.40)	p<0.001	4.87 (1.53)	2.94 (1.43)	p<0.001
A_7	4.87 (1.57)	2.96 (1.36)	p<0.001	4.93 (1.53)	2.90 (1.43)	p<0.001

Abbreviation: A_1 is hot – cool, A_2 is damp – dry, A_3 is clammy – dry, A_4 is airtight – breathable, A_5 is thick and heavy – thin and light, A_6 is work performance interfered – non work performance interfered, A_7 is uncomfortable – comfortable.

6.3.2 Multiple linear regression analysis

The relationship between the wearing comfort as the dependent variable and the six sensory attributes (A_1–A_6) as the independent variables was examined by stepwise multiple linear regression analysis. Table 6.4 shows the results of stepwise regression. The sensory attributes A_2, A_4, A_5 and A_6 significantly explained 98% of the variance in the prediction model for the wearing comfort of shirts. Meanwhile, 98% of variance explained by A_6, A_4, and A_5 in the model predicting the wearing comfort of pants. In both prediction models, A_6 contributed most to determining the wearing comfort of work uniform.

Table 6.4 Results of stepwise regression

Model	Variable	Unstandardized coefficient (B)	Std. Error of B	Standardized coefficient (β)	R^2	Adjusted R^2	R^2 change	Sig. F change
Shirts (n=179)								
1	(constant)	0.211	0.076		0.946	0.945	0.946	0.000
	A_6	0.944	0.017	0.972				
2	(constant)	0.132	0.057					
	A_6	0.648	0.028	0.667	0.970	0.969	0.024	0.000
	A_5	0.331	0.028	0.342				
3	(constant)	0.109	0.052					
	A_6	0.630	0.026	0.649	0.975	0.974	0.005	0.000
	A_5	0.264	0.028	0.272				
	A_2	0.115	0.019	0.112				
4	(constant)	0.103	0.051					
	A_6	0.611	0.026	0.630				
	A_5	0.237	0.029	0.245	0.976	0.975	0.001	0.007
	A_2	0.092	0.021	0.090				
	A_4	0.071	0.026	0.072				
Pants (n=169)								
1	(constant)	0.112	0.064		0.959	0.959	0.959	0.00
	A_6	0.985	0.015	0.979				
2	(constant)	-0.007	0.044					
	A_6	0.655	0.024	0.652	0.982	0.981	0.022	0.000
	A_5	0.356	0.024	0.360				
3	(constant)	-0.003	0.041					
	A_6	0.628	0.023	0.624	0.984	0.984	0.002	0.000
	A_5	0.281	0.026	0.284				
	A_4	0.111	0.021	0.113				

Abbreviation: A_2 is damp – dry, A_4 is airtight – breathable, A_5 is thick and heavy – thin and light, A_6 is work performance interfered – non work performance interfered. Dependent variable is uncomfortable – comfortable.

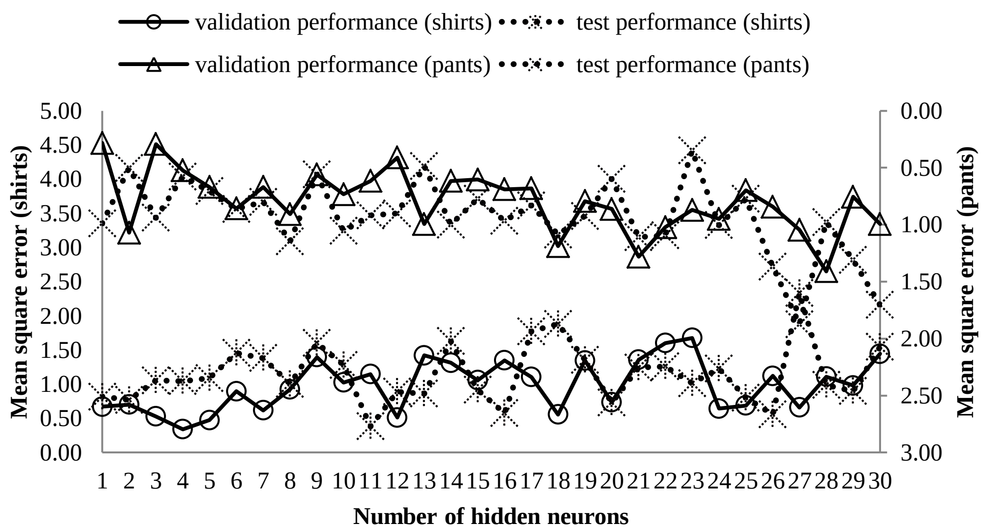
6.3.3 Artificial neural network

The artificial neural networks (ANN) that predict the wearing comfort of shirts and pants had similar structure, transfer function, and training method (Table 6.5). The feed-forward back-propagation network was developed to predict clothing comfort (Hui et al., 2004; Wong et al., 2003). The selected ANN structure consisted of a single hidden layer with log-sigmoid neurons and an output layer with the pure linear neuron (Wong et al., 2003). Levenberg-Marquardt algorithm was used in consideration of training speed and accuracy (Yam and Chow, 2001; Coulibaly et al., 2000). The data sets were randomly divided into 70%, 15%, and 15% by the networks for training, validation, and testing, respectively. Because limited theoretical evidences are available to determine the exact number of hidden neurons (Wasserman, 1993), a trial-and-error procedure was used to identify the optimal amount in a feed-forward network (Mirzaei et al., 2012). The range of hidden neurons between 1 and 30 for this was chosen because a small number of hidden neurons might avoid possible incorrect saturation (Lee et al., 1991). The initial setting of the number of hidden neurons was calculated with the equation $\mathrm{N_h} = 2 \times \mathrm{N_i} + 1$, where $\mathrm{N_h}$ is the number of hidden neurons, and $\mathrm{N_i}$ is the number of input neurons (Yang et al., 2005; Moon et al., 2013). The optimal range of hidden neurons was determined by the network validation performance with the lowest mean squared error (MSE), while the optimal amount of neurons within the optimal range was determined by the best test performance with the lowest MSE (Mirzaei et al., 2012). As shown in Figure 6.3, the optimal numbers of hidden neurons for the prediction model for the wearing comfort of shirts ranged from 1 to 8, and optimal amount of hidden neurons was *two* (Adjusted R^2=0.775). Meanwhile, the optimal numbers of hidden neurons for the prediction model for the wearing comfort of pants ranged from 3 to 12, and the best test performance was determined at *nine* hidden neurons (Adjusted R^2=0.816).

Table 6.5 Descriptions of initial neural network model

Structure	Input layer	Number of neurons: 6
		A_1 Hot – Cool
		A_2 Damp – Dry
		A_3 Clammy – Dry
		A_4 Airtight – Breathable
		A_5 Thick and heavy – Thin and Light
		A_6 Work Performance interfered – Non-work performance interfered
	Hidden layer	Number of neurons: 13
	Output layer	Number of neuron: 1
		i) Wearing comfort
Transfer functions	Hidden layer	Log sigmoid
	Output layer	Pure linear
Training method		Training goals: 0.01
		Epoch: 1000 times
		Algorithm: Levenberg-Marquardt back-propagation
		Number of matching sets: 278 for shirts and 290 for pants
		Percentage of training data: 70%
		Percentage of validation data: 15%
		Percentage of test data: 15%

Figure 6.3 Mean square error for varying amount of hidden neurons

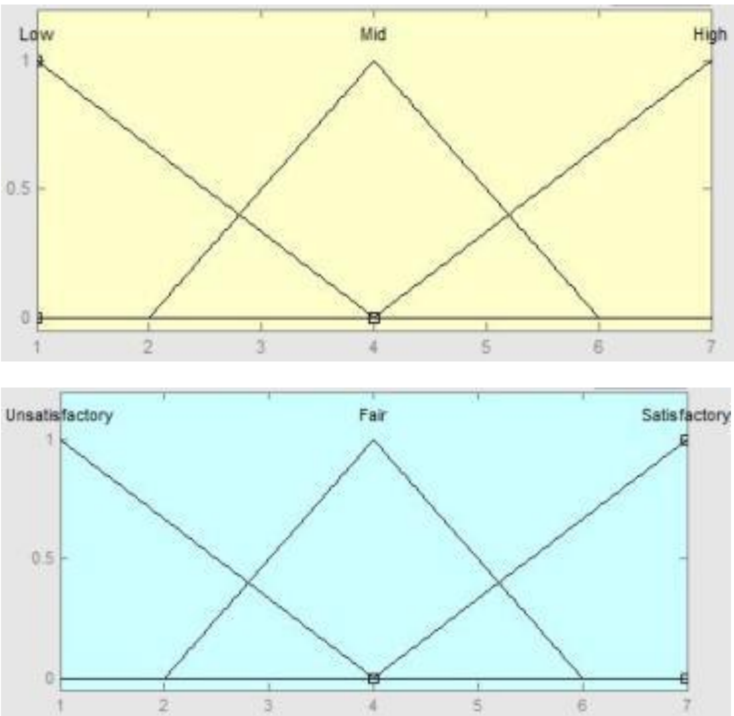


6.3.4 Fuzzy logic

6.3.4.1 Assumption of membership functions.

According to the 7-point Likert scale, the linguistic values of each sensory attribute can be assigned as {Low, Moderate, High}, while those of the classification result (i.e., wearing comfort) are described as {Unsatisfactory, Fair, Satisfactory}. Meanwhile, each variable was assigned as a triangular membership function (Figure 6.4).

Figure 6.4 Membership functions assumed in this study



Note: Upper: input attribute; Lower: output attribute

6.3.4.2 Induction of fuzzy rules from fuzzy decision tree.

The machine-learning process is one of approaches to obtain a set of fuzzy rules, which has the ability to acquire knowledge from sample cases (Chen et al., 2001). The development of fuzzy decision trees is a common machine-learning method, which comprises the fuzzy logic reasoning and the decision tree algorithm (Lien et al., 2011). Figure 6.5 depicts the process of inducing the fuzzy decision tree that is proposed by Yuan and Shaw (1995). In this method, fuzzy entropy is used to identify the most effective decision nodes (Chen et al., 2001). The detailed algorithms of developing the fuzzy decision tree are shown in Appendix 1. A total of 278 and 290 sets of valid data were employed as training data to develop the fuzzy decision tree for the shirts and that for the pants, respectively. Finally, 13 and 12 fuzzy rules for predicting the wearing comfort of shirts and that of pants, respectively, were derived from the fuzzy decision trees (Table 6.6).

Figure 6.5 Flow chart of inducing fuzzy decision tree based on Yuan and Shaw (1995)'s method

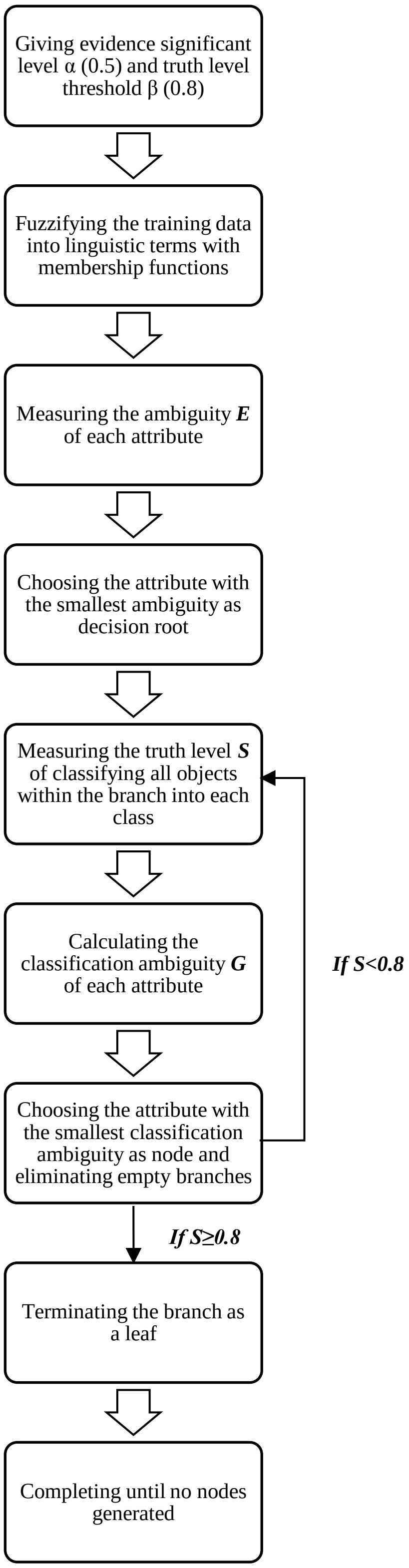


Table 6.6 Fuzzy rules derived from the fuzzy decision trees

T-shirt	Pants
R1: IF A6 is High, THEN C is Satisfactory	R1: IF R6 is High, THEN C is Satisfactory
R2: IF A6 is Low, THEN C is Unsatisfactory	R2: IF R6 is Low, THEN C is Unsatisfactory
R3: IF A6 is Middle, AND A5 is Middle, THEN C is Moderate	R3: IF R6 is Middle, AND A5 is Middle, THEN C is Moderate
R4: IF A6 is Middle, AND A5 is High, AND A4 is High, THEN C is Moderate	R4: IF R6 is Middle, AND A5 is High, AND A3 is High, THEN C is Satisfactory
R5: IF A6 is Middle, AND A5 is High, AND A4 is Low, THEN C is Unsatisfactory	R5: IF R6 is Middle, AND A5 is High, AND A3 is Middle, AND A4 is High, THEN C is Satisfactory
R6: IF A6 is Middle, AND A5 is High, AND A4 is Middle, AND A1 is High, THEN C is Satisfactory	R6: IF R6 is Middle, AND A5 is High, AND A3 is Middle, AND A4 is Low, THEN C is Moderate
R7: IF A6 is Middle, AND A5 is High, AND A4 is Middle, AND A1 is Middle, AND A2 is Low, THEN C is Moderate	R7: IF R6 is Middle, AND A5 is High, AND A3 is Middle, AND A4 is Middle, AND A1 is High, THEN C is Satisfactory
R8: IF A6 is Middle, AND A5 is High, AND A4 is Middle, AND A1 is Middle, AND A2 is High, AND A3 is High, THEN C is Satisfactory	R8: IF R6 is Middle, AND A5 is High, AND A3 is Low, AND A4 is High, THEN C is Satisfactory
R9: IF A6 is Middle, AND A5 is High, AND A4 is Middle, AND A1 is Low, AND A3 is High, THEN C is Satisfactory	R9: IF R6 is Middle, AND A5 is High, AND A3 is Middle, AND A4 is Low, THEN C is Unsatisfactory
R10: IF A6 is Middle, AND A5 is High, AND A4 is Middle, AND A1 is Low, AND A3 is Middle, AND A2 is High, THEN C is Satisfactory	R10: IF R6 is Middle, AND A5 is High, AND A3 is Middle, AND A4 is Middle, AND A1 is High, THEN C is Satisfactory
R11: IF A6 is Middle, AND A5 is Low, AND A4 is High, THEN C is Satisfactory	R11: IF R6 is Middle, AND A5 is Low, AND A2 is Middle, THEN C is Moderate
R12: IF A6 is Middle, AND A5 is Low, AND A4 is Middle, THEN C is Moderate	R12: IF R6 is Middle, AND A5 is Low, AND A2 is Low, THEN C is Unsatisfactory
R13: IF A6 is Middle, AND A5 is Low, AND A4 is Low, THEN C is Unsatisfactory	

Abbreviation: A_1 is hot – cool, A_2 is damp – dry, A_3 is clammy – dry, A_4 is airtight – breathable, A_5 is thick and heavy – thin and light, A_6 is work performance interfered – non work performance interfered, A_7 is uncomfortable – comfortable.

6.3.5 Prediction performance of the models

The modeling efficiency and prediction accuracy are important indicators for constructing a robust prediction model (Arakawa et al., 2011; Xu et al., 2012). The multiple linear regression analysis, artificial neural network, and fuzzy logic were employed to forecast the wearing comfort of construction work uniforms. The prediction performance of these three models was measured using the root mean square error (RMSE) and correlation coefficient (r-value) with the developing and simulation data sets (Table 6.7). The model precision was measured by the RMSE, while the strength and direction of the correlations between the predicting results and the actual outcomes were estimated by the r-value (Jeguirim et al., 2011; Hui and Ng, 2009; Wong et al., 2004). The results of this study indicated that fuzzy logic exhibited the strongest prediction performance, while multiple regression models had the poorest performance.

Table 6.7 Performance of three prediction models

Data set	Multiple linear regression	Artificial neural network	Fuzzy logic
	Developing data		
Shirts (n=278)			
RMSE	0.957	0.879	0.799
r-value	0.844	0.881	0.892
Pants (n=290)			
RMSE	0.800	0.777	0.765
r-value	0.900	0.904	0.910
	Simulation data		
Shirts (n=64)			
RMSE	1.168	1.049	0.905
r-value	0.712	0.748	0.800
Pants (n=63)			
RMSE	0.848	0.884	0.740
r-value	0.869	0.871	0.887

Note: $\mathrm{RMSE}=\sqrt{\frac{\sum_{t=1}^{n}(\widehat{y_t}-y_t)^2}{n}}$, $r=\frac{n\sum\widehat{y_t}\cdot y_t-(\sum\widehat{y_t})(\sum y_t)}{\sqrt{n(\sum y_t^2)-(\sum y_t)^2}\cdot\sqrt{n(\sum\widehat{y_t}^2)-(\sum\widehat{y_t})^2}}$, where $\widehat{y_t}$ is the predicted value of wearing comfort for the t^{th} data set, y_t is the actual rating of wearing comfort for the t^{th} data set, n is the number of data sets.

6.4 DISCUSSION

In the present study, multiple linear regression models had the poorest prediction performance, probably because they cannot deal with the non-linear relationships among subjective perceptions. Additionally, the results of the neural network might not be able to identify how construction workers judge wearing comfort because the correlations and interactions of the input variables were concealed (Wong et al., 2003). Fuzzy logic can well map the psychological process (Dubois and Prade, 1997; Wong, 2003; Wong and Li, 2003) by handling uncertainties of subjective judgments (Nguyen, 1985). It is advantage has been well documented in this study. Through translating the numerical ratings to linguistic languages, the results of fuzzy rules are easy to be interpreted. For example, workers would feel uncomfortable when wearing the uniform impeded their work performance, regardless of the judgments on the other sensory attributes. Therefore, fuzzy logic offers a practical tool to address workers' needs for work uniforms.

It is recognized that thermal comfort plays a fundamental role in determining the wearing comfort of summer clothes (Li, 2001). Nevertheless, a surprising finding of the present study is that construction workers perceived that pressure attributes affected the wearing comfort of work clothes most preferentially, followed by thermal-wet attributes. Working people may desire to dress comfortably without considerable restraints on the body dynamic movements (Li, 2001). Unsatisfied pressure comfort can increase the metabolic production of workers and further impede their work performance (Teitlebaum and Goldman, 1972; Laing and Sleivert, 2002). These findings provide a fresh perspective that pressure comfort predominantly influences the wearing comfort of summer work clothes. Table 6.3 indicated that construction workers preferred to wear AHSU because of its overwhelming benefits of pressure comfort. This finding stressed the important role of pressure comfort in the design of work uniform to improving wearing comfort for construction workers.

6.5 CHAPTER SUMMARY

The objective of this study was to evaluate the acceptability of the newly designed work uniform by assessing its wearing comfort judged by construction workers. A series of wear trials and questionnaire surveys were administered, in which seven subjective attributes were rated by 189 construction workers. Three analytical techniques, namely, multiple regression, artificial neural network, and fuzzy logic were further used to predict the wearing comfort affected by the six subjective attributes. Fuzzy logic was found as a robust and practical tool in terms of its prediction performance and interpretable results. Pressure attributes were found to preferentially affect wearing comfort, followed by thermal-wet attributes. Overall, the new uniform had profound benefits in improving the wearing comfort because it kept workers cooler, drier, and more comfortable without impeding work performance than the trade uniform.

CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS

7.1 INTRODUCTION

A summary of the research findings and accentuates the significance, contributions, and limitations of this study is presented in this chapter. It also provides suggestions and directions for future research.

7.2 SUMMARY OF THE MAJOR FINDINGS

The present study aims to develop heat stress intervention development research in construction. The specific objectives are as follows: to set the research framework for heat stress intervention development research; to assess the efficacy, effectiveness, and acceptability of the anti-heat stress work uniform; to formulate recommendations for formulating precautions for working in hot weather.

7.2.1 The research framework of intervention studies

One of the objectives of this study is to furnish theoretical and methodological bases for future intervention research on developing precautionary measures against heat stress. Heat stress intervention study in development research phase in the construction field has received scare attention. The failure of this field to advance may be attributed to the lack of a comprehensive research methodology. The proposed research framework can provide a full description and definite guidelines for conducting intervention development studies. An integrated 5-D model with an *efficacy–effectiveness–diffusion* process as detailed in Chapter 3 is established based on the multi-disciplinary perspectives of occupational safety and health and clinical medicine, which may provide a fresh idea in the conduct of a comprehensive intervention development research. Five key tasks, namely, to **d**etermine research problems, to **d**evelop partnerships and collaborations, to **d**esign study approaches, to **d**o assessments and analysis, and to **d**isseminate research findings, are indispensable to the optimization of the quality and significance of intervention research. Moreover, the sequential process of *efficacy–effectiveness–diffusion* throughout all the tasks is highlighted by the overwhelming need of a holistic assessment on developing an intervention strategy. This research framework was verified through a case study of evaluating the effects of wearing a newly designed anti-heat stress uniform.

7.2.2 Efficacy the anti-heat stress uniform

The superior thermal and moisture performance and smart clothing design of AHSU are contributory to the efficacy in alleviating the body thermo-physiological and perceptual strain under tightly controlled conditions (e.g., 34.5°C and 75% relative humidity). The major findings showed that the mean skin temperature ($\overline{T_{sk}}$) of participants with wearing AHSU was significantly lower than that with TRADE toward a high running speed (e.g., 8.5 km/h, 4% slope), which may be associated with a remarkable pumping effect for enhancing air ventilation. During passive recovery, thermo-physiological strain (T_{in}, $\overline{T_{sk}}$, and mean body temperature $\overline{T_b}$, the physiological strain index PhSI) of participants with wearing AHSU was significantly lower than those with wearing TRADE, as evidenced by the main effect of clothing type. The perceptual strain of participants with wearing AHSU was significantly alleviated at certain time of exercise and/or post-exercise recovery as the participants felt cooler, drier and more comfortable than those wearing TRADE. Because construction work consists of work-rest cycles (Yi and Chan, 2013a) rather than a sustained exercise, it is considerably beneficial to reduce rate of heat storage with wearing AHSU during the rest-exercise-recovery cycle, which indicates that wearing AHSU enhances efficacious evaporative heat dissipation from the body to the environment.

7.2.3 Effectiveness of the anti-heat stress uniform

A linear mixed-effects model (LMM) was developed to examine the cause-effect relationship between the perceptual strain index (PeSI) and multiple heat stressors, including wet bulb globe temperature (WBGT), estimated workload (RHR), exposure time, trade (rebar work, leveling, formwork, painting and plumbing works), workplace (outdoor; semi-outdoor), and clothing type (AHSU; TRADE). The results demonstrate that the increase in the WBGT, workload, and exposure time significantly result in the rise of the perceptual strain. An interaction effect between clothing and trade revealed that perceptual strain of construction workers was significantly alleviated by 1.6 – 6.3 units when they wore AHSU. Insignificant random effects implied that the responses to perceptual strain were consistent across all the participants. The finding of this study provides a fresh and scientific approach to provide positivist evidence on the effectiveness of a precautionary measure against heat stress in real-work settings, which contributes to the enhancement of the research methodologies and practical problem solving.

7.2.4 Acceptability of the anti-heat stress uniform

Three models of predicting wearing comfort, namely, linear regression, artificial neural network, and fuzzy logic, were developed based on the six subjective perceptions of construction workers. Fuzzy logic has been found as a robust tool to predict wearing comfort. Moreover, it is a practical technique to cope with the non-linear relationships between wearing comfort and subjective attributes and to identify the psychological process of judging wearing comfort.

Pressure attributes were found to be the predominant factors that affect wearing comfort, followed by thermal-wet attributes. This phenomenon may be attributed to the nature of construction workers and their working conditions. Based on the understanding of how construction workers judge the wearing comfort of their work clothes, AHSU was found to be more comfortable in terms of more pleasant thermal and pressure sensations than TARDE. The results provided robust evidence that wearing newly designed AHSU enables workers to remain cooler, drier, and more comfortable without impeding work performance.

7.2.5 Recommendations on formulating precautionary measures

A 5-D model with an *efficacy–effectiveness–diffusion* process was used as a holistic assessment tool to develop a useful and feasible heat stress intervention in construction settings. This research framework was verified through a case study of evaluating the benefits of wearing a newly designed anti-heat stress uniform. The results led to the recommendation that formulating the heat stress precautionary measures should take account for scientific rigor and practical problem solving to address the regional specifics.

A broad theoretical research on the intervention characteristics should be conducted to support the reasoning behind the possible effects of intervention. This study facilitates the refinement and improvement of existing research methods from a multi-disciplinary perspective that is determined by the nature of the intervention. A comprehensive research context drives the understanding of how the functions of an intervention can be validated. Developing collaboration is strongly recommended because it not only involves the practitioners as intervention participants, but also enables researchers to deliver their findings to large populations. Stakeholder involvement in the research process will serve as a reminder that the developed intervention relies on the balance between scientific rigor and practical considerations. Proper research methods and approaches should be employed prudently in conducting intervention development research. Through this step-by-step procedure, the efficacious, effective, and diffusible precautionary measures against heat stress can be formulated based on both scientific rigor and practical problem solving to improve the health and safety of working people.

7.3 SIGNIFICANCE AND CONTRIBUTIONS

7.3.1 Advancing a research method for developing an industry standard

There is lacking of an industry standard on summer work uniform, probably because the capability of such work clothes to reduce human heat strain has not been defined properly. Based on a scientific approach with robust research methodologies, this study demonstrates that a newly designed anti-heat stress work uniform not only exhibits excellent performance in alleviating body heat strain under both laboratory and real-work settings, but also satisfies construction workers. Extensive theoretical research on the body-clothing-environment system supports the reasoning behind the possible effects of the newly designed anti-heat stress clothing on human physiological and perceptual responses. This study also drives how the performance of the anti-heat stress uniform can be proven. Developing collaboration in the research process will illustrate that engineering the anti-heat stress clothing relies on the balance between scientific rigor and practical considerations. Overall, the efficacy, effectiveness, and acceptability of the newly designed anti-heat stress uniform are ascertained. This result proves that the new uniform can be applicable in industrial settings, and eventually applied to larger populations and locations. The convincing research findings can enable both the academia and practitioners to improve work practices in the construction industry through developing an industry standard.

Along with the development of textile science, the production of innovative fibers and fabrics with superior thermal and moisture performance and reasonable costs is anticipated. The fabric properties of the anti-heat stress uniform can be used as an industry standard or a benchmark to determine appropriate summer work uniform in comparison with existing garments.

7.3.2 Facilitating heat stress intervention research in construction

At present, limited attention on intervention research on the development of heat stress precautionary measures in the construction industry has been shown. Conducting heat stress intervention development studies, particularly those involving a large-scale research agenda in terms of various intervention types, populations, rigorous methodologies, and practical issues, is necessary to provide scientific and positivist evidence in addressing the threat of heat stress on construction workers toward the formulation of solid guidelines. In view of this, the present study heightens the importance and value of intervention research in heat stress prevention strategies.

A comprehensive research framework that considers scientific knowledge and implemental issues to guide heat stress intervention research is lacking. To bridge this gap, this study follows the well-established process of occupational intervention development research and adopts a fresh perspective derived from medical intervention studies. Subsequently, a case study is conducted to demonstrate the applicability of the methodology in ascertaining the efficacy, effectiveness, and diffusion of wearing the newly designed anti-heat stress clothing that combats body heat strain. This procedure proves that this intervention strategy is practical and can be applied extensively. The present study provides a fresh perspective on heat stress intervention development research. Meanwhile, it offers a direction for researchers, practitioners, and policymakers in formulating solid guidelines to solve theoretical, methodological, and practical issues. The assistance and support from stakeholders will be pivotal to the success of the intervention development research in construction.

Conducting intervention research in construction is challenging given the safety and scheduling concerns and the limited sample size. An easily understood and considerate study plan may be conducive to communicating with the intervention participants, which could improve successful access to study populations and increase participation rates (LaMontagne and Needleman, 1996). Although the limited sample size is one of the major concerns in intervention research, researchers can clarify the statistical power or address this limitation by drawing prudent conclusions. The case study, which comprises elaborate research procedures and recognized practical issues, demonstrates the applicability and feasibility of conducting heat stress intervention research in the construction industry. This study provides fresh insights that are useful to such initiatives as expanding research areas, exploring new trends, and solving practical problems in heat stress prevention strategies. The research framework is a feasible and reliable approach in the conduct of heat stress intervention development research, which can facilitate the creation and discovery of scientific knowledge. Therefore, the framework can lead to the improvement and development of practical problem solving methods. Despite the challenges, intervention research can provide a platform to facilitate communication and collaboration among researchers and practitioners, which will help stimulate and nurture the growth of the promising heat stress intervention research area. Although the applicability of this study is specific to the Hong Kong construction industry, the application of the present research methodology may be expanded to other occupational settings and other regions toward the facilitation of a comprehensive evaluation of heat stress intervention strategies in future studies.

7.4 LIMITATIONS OF THE STUDY

In the present study, the sampling plan of the laboratory and field experiments has several limitations. First, the single sample source composed of university students and young construction workers in the laboratory experiment and field experiment, respectively, was inclusive. The differences in physique statues between university students and construction workers are recognized. In this regard, the results of the laboratory experiments should be validated and replicated to examine the impacts of the new uniform on construction workers. Regarding only young workers tested in the field experiment, further studies with wider age groups should be launched to verify the current findings. Second, the imbalance of male and female participants in the laboratory experiment potentially produces biased results because of the discrepancy in the physique between males and females. This is evidenced by the differences in physiological and perceptual responses between males and females in terms of moderate to large effect sizes. Thus, justifying the differences between male and female should be accomplished in future studies by recruiting balanced male and female participants.

To perform a field experiment and a field survey pose great challenges. First, the unavoidable placebo effect yielded by non-blind test in the field experiment and field survey is an inherent limitation. The placebo effect should be treated prudently, particularly given that the measurement instruments in the field experiment and field survey are subjective measurements. Such a self-healing property (Kienle and Kiene, 1998) may influence participants' beliefs and expectations that possibly result in a positive outcome toward a treatment (Clark et al., 2000). It is a reporting bias (e.g., the wish to please the investigator) (Wechsler et al., 2011) that affects the reliability of participants' subjective responses. Moreover, the research outcomes may be also influenced by the experimenters' bias in which the experimenter has an expectation on outcomes and may further consciously or subconsciously influence the responses of the participants (Sackett, 1979). Therefore, blinding is important to reduce information bias from persons involved in the experiment (Kristensen, 2005). Further intervention study should be performed in a double-blind setting to avoid potential placebo effect, in which the intervention and control groups are not informed to the participants and the conductors who seeing the participants. Second, another limitation held in the field experiment is the potential confounding effect of the morning test session on the afternoon session, even though effort has been exerted to minimize such an effect (i.e., resting in an air-conditioning room between the two sessions). The optimal strategy to conduct a field experiment is to perform each test session with a complete work shift. Furthermore, it is a challenge to conduct the field survey in two days regarding the two preconditions: (1) the participants should perform similar work routines, and (2) the environmental conditions should not be considerably different. The analysis of covariance (ANCOVA) can be performed to assess human subjective sensations in conjunction with the covariance factors (e.g., workload and environmental condition) when these preconditions are violated.

Additionally, it is recognized that many boundary conditions, such as health condition, medicine, nutrition (US Army, 2003), aerobic fitness (Pandolf, 1978), alcohol and smoking habits (Grassi et al., 1992), sleep quality (Dawson and Reid, 1997), motivation (Adams et al., 1994), thermal preferences and other inter-individual variables (Cheung, 2010), etc, were not scrutinized in the current study. A short questionnaire survey or careful measurements on these facets can be performed in future studies.

7.5 FUTURE RESEARCH DIRECTIONS

This study has formulated a research framework for heat stress intervention research in the construction industry. The applicability and feasibility of this framework has been demonstrated through a case study. This framework can allow researchers and practitioners to replicate the research procedures and generate convincing results directly at the other heat stress intervention strategies, such as shields, shades, portable fans, and personal cooling equipment. The solid guidelines for working in hot weather can be convincingly formulated based upon the obtainment of positivist evidences on the efficacy, effectiveness, and acceptability of these measures.

Furthermore, upon the completion of the intervention development research phase, the subsequent steps turn to the intervention implementation and impact research phases (Goldenhar et al., 2001). The core issue regarding the intervention implementation research is the investigation of the implementation quality of a proposed intervention at the company, industrial, national, and international levels with wider populations. Subsequently, longitudinal study could be carried out to examine the impacts of the proposed intervention strategy on safety climate, prevention of heat-related illness, and social and economic consequences (Goldenhar et al., 2001). Cost-benefit/effectiveness/utility analysis is an alternative technique to support the decision-making process (Ikpe et al., 2012) in investing in heat stress interventions at the company, industrial, or national levels. Intervention development, implementation, and impact studies that are conducted in sequence will foster continuing improvement and success of the intervention strategy in occupational settings (Goldenhar et al., 2001).

7.6 CHAPTER SUMMARY

This chapter has summarized the major findings, illuminated the significance and contributions, acknowledged the limitations, and proposed research directions for future studies. The information documented herein has clarified how an industry standard of summer work uniform can be developed. This study also has shown a fresh insight to heat stress intervention research that can formulate solid guidelines in consideration of scientific rigor and practical problem solving to address the regional specifics.

APPENDICES

Appendix 1: Development of a fuzzy decision tree (Yuan and Shaw, 1995)[15]

In the current study, the aim of inducing fuzzy decision tree is to derive fuzzy rules which can be written in the form: IF (A_1 is R_j) AND … (A_6 is R_j) THEN (C is C_n), where A={A_1,…A_6} is the collection of attributes, $R(A_i)_j$ ={R_1, R_2, R_3} refers to a set of discrete linguistic terms, C={C_1, C_2, C_3} is the set of outcome. For instance,

A = {hot – cool, is damp – dry, clammy – dry, airtight – breathable, is thick and heavy – thin and light, work performance interfered – non work performance interfered}

For example, hot – cool = {Low, Moderate, High}

C = {Unsatisfactory, Fair, Satisfactory}

A fuzzy set A in a universe of discourse U is characterized by a membership function (Figure 3.3) μ_A which takes values in the interval [0,1]. For instance,

Low/Unsatisfactory={1,0.67,0.33} when R_1=1, R_2=2, R_3=3

Moderate/Fair={0.5,1,0.5} when R_1=3, R_2=4, R_3=5

High/Satisfactory={0.33,0.67,1} when R_1=5, R_2=6, R_3=7

The membership functions of input/output variables are assumed by the following

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[15] Presented in a published paper: Chan, A.P.C., Yang, Y., Wong, F.K.W., Chan, D.W.M. and Lam, E.W.M. (2015). Wearing comfort of construction work uniforms. *Construction Innovation: Information, Process and Management*, 15(4), 473-492.

equations.

$$u_{A(Low)} = \begin{cases} 0, & \text{if } x \geq 4 \\ \frac{x-1}{4-1}, & \text{if } 1 < x < 4 \\ 1, & \text{if } x = 1 \end{cases}$$

$$u_{A(Moderate)} = \begin{cases} 0, & \text{if } x \leq 2 \\ 0, & \text{if } x \geq 6 \\ \frac{x-2}{4-2}, & \text{if } 2 < x < 4 \\ \frac{x-4}{6-4}, & \text{if } 4 < x < 6 \\ 1, & \text{if } x = 4 \end{cases}$$

$$u_{A(High)} = \begin{cases} 0, & \text{if } x \leq 4 \\ \frac{x-4}{7-4}, & \text{if } 4 < x < 7 \\ 1, & \text{if } x = 7 \end{cases}$$

where $u_{(A)}$ is the membership function of each attribute, the integer x refers to the numerical value of each attribute and it ranges from 1 to 7.

The ambiguity of attribute A is $E_a(A) = \frac{1}{m}\sum_{i=1}^{m} E_a\,(A(u_i))$, where the ambiguity of the attribute A for object u_i is measure by $E_a\big(A(u_i)\big) = g(\pi_R(u_i))$, the possibilistic measure of ambiguity is measured by $g(\pi) = \sum_{i=1}^{n}(\pi_i^* - \pi_{i+1}^*)\ln(i)$, the permutation of the possibility distribution $\pi^* = \{\pi_1^*, \pi_2^*, \ldots, \pi_n^*\}$ which is sorted by descending order, the possibility distribution is normalized as $\pi_{R_s}(u_i) = \mu_{R_s}/\max_{1\leq j\leq s}\{\mu_{R_j}(u_i)\}$, the membership function is described as $\{\mu_{R_1}(u_i),\ \mu_{R_2}(u_i),\ \mu_{R_2}(u_i)\}$.

The fuzzy subsethood $S(A, B) = \frac{\sum_{u\in U}\min(\mu_A(u), \mu_B(u))}{\sum_{u\in U}\mu_A(u)}$ is described as the degree of a condition fuzzy set A belonging to conclusion fuzzy set C.

Given fuzzy evidence E with membership $\mu_E(u)$, it is assumed that E_α is the fuzzy evidence at significant level α=0.5, then the membership function of a set of fuzzy evidence $\{E_1,..E_k\}$ represents as $\mu_{E_\alpha}(u_i) = \begin{cases} \mu_E(u) & \text{if } \mu_E(u) \geq 0.5 \\ 0 & \text{if } \mu_E(u) < 0.5 \end{cases}$.

The possibility of classifying an object to class C_i given fuzzy evidence E is defined as $\pi(C_i|E) = \frac{S(E,C_i)}{\max_j S(E,C_j)}$, where $S(E, C_i)$ is the degree of truth for the classification rule, $\pi(C_i|E)$ is the normalized possibility distribution on the non-fuzzy label space $C=\{C_1,\ldots C_m\}$.

The weighted average of classification ambiguity with each subset of the partition is calculated as $G(P|F) = \sum_{i=1}^{k} w(E_i|F) G(E_i \cap F)$, where $G(P|F)$ denotes the fuzzy partitioning $P=\{E_1,\ldots E_k\}$ on fuzzy evidence F, $G(E_i \cap F)$ is the classification ambiguity with fuzzy evidence $E_i \cap F$, $w(E_i|F) = \frac{\sum_{i=1}^{k} \sum \min(\mu(E_i),\mu(F))}{\sum_{j=1}^{k} \min(\mu(E_j),\mu(F))}$ is the weight of the relative size of subset $E_i \cap F$ in F.

Appendix 2: Data collection sheet used in the laboratory experiment

Project Title: Anti-heat stress clothing for construction workers in hot and humid weather – laboratory experiment

Experiment Data Collection Sheet																		
Date	Name	Age:	95 % HRmax:						Height (cm):					Test No:		Time:		
										Condition: AHSU ( ); TRADE ( )								
Event	Time	Treadmill		Physiological parameters							Sweating				Subjective perception			
1: Start running; 2: Stop running; 3: Start rest; 4: Stop rest; 5: Cool down; 6: Drinking; 7: Change clothes; 8: Measure weight; 9: Cool down; 10. Remark	Real time	Time	Speed	T_c	T_{sk}					HR	Pre-exercise body weight	Post-exercise body weight	Fluid intake	Weight of clothes and towel	RPE	TS	WS	CS
	hr:min: second				chest	arm	thigh	calf	lateral chest		kg	kg	ml	kg				
Resting measurement (30min)																		

Warm up (9 min)																		
		3 min	6 km/h,4%															
		3 min	8 km/h, 1%															
		3 min	6 km/h, 4%															
Interim running																		
		3 min	8.5 km/h,4%															
		3 min	5 km/h, 1%															
		3 min	8.5 km/h, 4%															
		3 min	5 km/h, 1%															
		3 min	8.5 km/h, 4%															
		3 min	5 km/h, 1%															
		3 min	8.5 km/h, 4%															
		3 min	5 km/h, 1%															
Active recovery (6 min)																		
		3 min	3.5 km/h, 0%															

		3 min	2 km/h, 0%															
Recovery (30 min)																		

Appendix 3: Questionnaire used in the laboratory experiment

The Hong Kong Polytechnic University
Construction Health and Safety Research Team

Project title

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

A1. Please tick the subjective scale that is most appropriate to you (Before exercise)

Type of T-shirt (   )

Subjective scale	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
1. Clammy	☐	☐	☐	☐	☐	☐	☐	Dry
2. Airtight	☐	☐	☐	☐	☐	☐	☐	Breathable
3. Damp	☐	☐	☐	☐	☐	☐	☐	Dry
4. Heavy	☐	☐	☐	☐	☐	☐	☐	Light
5. Hot	☐	☐	☐	☐	☐	☐	☐	Cool
6. Scratch	☐	☐	☐	☐	☐	☐	☐	Non-scratch
7. Stiff	☐	☐	☐	☐	☐	☐	☐	Pliable
8. Inelastic	☐	☐	☐	☐	☐	☐	☐	Elastic
9. Unfitting	☐	☐	☐	☐	☐	☐	☐	Well-fitting
10. Uncomfortable	☐	☐	☐	☐	☐	☐	☐	Comfortable
11. Dislike	☐	☐	☐	☐	☐	☐	☐	Like

A2. Please tick the subjective scale that is most appropriate to you (Before exercise)

<u>Type of Pants (   )</u>

Subjective scale	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
1. Clammy	☐	☐	☐	☐	☐	☐	☐	Dry
2. Airtight	☐	☐	☐	☐	☐	☐	☐	Breathable
3. Damp	☐	☐	☐	☐	☐	☐	☐	Dry
4. Heavy	☐	☐	☐	☐	☐	☐	☐	Light
5. Hot	☐	☐	☐	☐	☐	☐	☐	Cool
6. Scratch	☐	☐	☐	☐	☐	☐	☐	Non-scratch
7. Stiff	☐	☐	☐	☐	☐	☐	☐	Pliable
8. Inelastic	☐	☐	☐	☐	☐	☐	☐	Elastic
9. Unfitting	☐	☐	☐	☐	☐	☐	☐	Well-fitting
10. Uncomfortable	☐	☐	☐	☐	☐	☐	☐	Comfortable
11. Dislike	☐	☐	☐	☐	☐	☐	☐	Like

B1. Please tick the subjective scale that is most appropriate to you (After exercise)

<u>Type of T-shirt (   )</u>

Subjective scale	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
1. Clammy	☐	☐	☐	☐	☐	☐	☐	Dry
2. Airtight	☐	☐	☐	☐	☐	☐	☐	Breathable
3. Damp	☐	☐	☐	☐	☐	☐	☐	Dry
4. Heavy	☐	☐	☐	☐	☐	☐	☐	Light
5. Hot	☐	☐	☐	☐	☐	☐	☐	Cool
6. Scratch	☐	☐	☐	☐	☐	☐	☐	Non-scratch
7. Stiff	☐	☐	☐	☐	☐	☐	☐	Pliable
8. Inelastic	☐	☐	☐	☐	☐	☐	☐	Elastic
9. Unfitting	☐	☐	☐	☐	☐	☐	☐	Well-fitting
10. Uncomfortable	☐	☐	☐	☐	☐	☐	☐	Comfortable
11. Dislike	☐	☐	☐	☐	☐	☐	☐	Like

B2. Please tick the subjective scale that is most appropriate to you (After exercise)

<u>Type of Pants (   )</u>

Subjective scale	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
1. Clammy	☐	☐	☐	☐	☐	☐	☐	Dry
2. Airtight	☐	☐	☐	☐	☐	☐	☐	Breathable
3. Damp	☐	☐	☐	☐	☐	☐	☐	Dry
4. Heavy	☐	☐	☐	☐	☐	☐	☐	Light
5. Hot	☐	☐	☐	☐	☐	☐	☐	Cool
6. Scratch	☐	☐	☐	☐	☐	☐	☐	Non-scratch
7. Stiff	☐	☐	☐	☐	☐	☐	☐	Pliable
8. Inelastic	☐	☐	☐	☐	☐	☐	☐	Elastic
9. Unfitting	☐	☐	☐	☐	☐	☐	☐	Well-fitting
10. Uncomfortable	☐	☐	☐	☐	☐	☐	☐	Comfortable
11. Dislike	☐	☐	☐	☐	☐	☐	☐	Like

C1. Please tick the subjective scale that is most appropriate to you (After recovery)

Type of T-shirt (   )

Subjective scale	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
1. Clammy	☐	☐	☐	☐	☐	☐	☐	Dry
2. Airtight	☐	☐	☐	☐	☐	☐	☐	Breathable
3. Damp	☐	☐	☐	☐	☐	☐	☐	Dry
4. Heavy	☐	☐	☐	☐	☐	☐	☐	Light
5. Hot	☐	☐	☐	☐	☐	☐	☐	Cool
6. Scratch	☐	☐	☐	☐	☐	☐	☐	Non-scratch
7. Stiff	☐	☐	☐	☐	☐	☐	☐	Pliable
8. Inelastic	☐	☐	☐	☐	☐	☐	☐	Elastic
9. Unfitting	☐	☐	☐	☐	☐	☐	☐	Well-fitting
10. Uncomfortable	☐	☐	☐	☐	☐	☐	☐	Comfortable
11. Dislike	☐	☐	☐	☐	☐	☐	☐	Like

C2. Please tick the subjective scale that is most appropriate to you (After recovery)

Type of Pants (   )

Subjective scale	1	2	3	4	5	6	7	
1. Clammy	☐	☐	☐	☐	☐	☐	☐	Dry
2. Airtight	☐	☐	☐	☐	☐	☐	☐	Breathable
3. Damp	☐	☐	☐	☐	☐	☐	☐	Dry
4. Heavy	☐	☐	☐	☐	☐	☐	☐	Light
5. Hot	☐	☐	☐	☐	☐	☐	☐	Cool
6. Scratch	☐	☐	☐	☐	☐	☐	☐	Non-scratch
7. Stiff	☐	☐	☐	☐	☐	☐	☐	Pliable
8. Inelastic	☐	☐	☐	☐	☐	☐	☐	Elastic
9. Unfitting	☐	☐	☐	☐	☐	☐	☐	Well-fitting
10. Uncomfortable	☐	☐	☐	☐	☐	☐	☐	Comfortable
11. Dislike	☐	☐	☐	☐	☐	☐	☐	Like

D. The Purpose of Collecting Personal Information

Your personal information is collected by the Construction Safety Research Team of The Hong Kong Polytechnic University for the project *of Anti-heat stress clothing for construction workers in hot and humid weather.* The aim is studying on the subjective comfort, practicability, and acceptability of the newly designed anti-heat stress clothing. We will not disclose your personal information which will only be used for the project reports and be destroyed after the project is completed. If you have any questions, please contact the project director Prof Albert Chan (Tel: 2766 5814).

This is the end of the questionnaire, thank you!

研究項目標題

酷熱天氣下建築工人抗熱抗濕工作服的研究

上衣類型（由研究人員填寫）:

A1. 請選出主觀感覺（Before exercise）

主觀感覺刻度:		**1**	**2**	**3**	**4**	**5**	**6**	**7**	
1	粘貼	☐	☐	☐	☐	☐	☐	☐	不粘貼
2	悶焗	☐	☐	☐	☐	☐	☐	☐	透氣
3	濕	☐	☐	☐	☐	☐	☐	☐	乾
4	重	☐	☐	☐	☐	☐	☐	☐	輕
5	熱	☐	☐	☐	☐	☐	☐	☐	冷
6	僵硬	☐	☐	☐	☐	☐	☐	☐	柔軟
7	無彈性	☐	☐	☐	☐	☐	☐	☐	有彈性
8	不合身	☐	☐	☐	☐	☐	☐	☐	合身
9	阻礙活動	☐	☐	☐	☐	☐	☐	☐	不阻礙活動
10	不舒服	☐	☐	☐	☐	☐	☐	☐	舒服
11	不喜歡	☐	☐	☐	☐	☐	☐	☐	喜歡

長褲類型（由研究人員填寫）:

A2. 請選出主觀感覺（Before exercise）

主觀感覺刻度:	1	2	3	4	5	6	7	
1. 粘貼	☐	☐	☐	☐	☐	☐	☐	不粘貼
2. 悶焗	☐	☐	☐	☐	☐	☐	☐	透氣
3. 濕	☐	☐	☐	☐	☐	☐	☐	乾
4. 重	☐	☐	☐	☐	☐	☐	☐	輕
5. 熱	☐	☐	☐	☐	☐	☐	☐	冷
6. 僵硬	☐	☐	☐	☐	☐	☐	☐	柔軟
7. 無彈性	☐	☐	☐	☐	☐	☐	☐	有彈性
8. 不合身	☐	☐	☐	☐	☐	☐	☐	合身
9. 阻礙活動	☐	☐	☐	☐	☐	☐	☐	不阻礙活動
10. 不舒服	☐	☐	☐	☐	☐	☐	☐	舒服
11. 不喜歡	☐	☐	☐	☐	☐	☐	☐	喜歡

上衣類型（由研究人員填寫）:

B1. 請選出主觀感覺（After exercise）

主觀感覺刻度:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
1. 粘貼	☐	☐	☐	☐	☐	☐	☐	不粘貼
2. 悶焗	☐	☐	☐	☐	☐	☐	☐	透氣
3. 濕	☐	☐	☐	☐	☐	☐	☐	乾
4. 重	☐	☐	☐	☐	☐	☐	☐	輕
5. 熱	☐	☐	☐	☐	☐	☐	☐	冷
6. 僵硬	☐	☐	☐	☐	☐	☐	☐	柔軟
7. 無彈性	☐	☐	☐	☐	☐	☐	☐	有彈性
8. 不合身	☐	☐	☐	☐	☐	☐	☐	合身
9. 阻礙活動	☐	☐	☐	☐	☐	☐	☐	易於活動
10. 不舒服	☐	☐	☐	☐	☐	☐	☐	舒服
11. 不喜歡	☐	☐	☐	☐	☐	☐	☐	喜歡

長褲類型（由研究人員填寫）:

B2. 請選出主觀感覺（After exercise）

主觀感覺刻度:	1	2	3	4	5	6	7	
1. 粘貼	☐	☐	☐	☐	☐	☐	☐	不粘貼
2. 悶焗	☐	☐	☐	☐	☐	☐	☐	透氣
3. 濕	☐	☐	☐	☐	☐	☐	☐	乾
4. 重	☐	☐	☐	☐	☐	☐	☐	輕
5. 熱	☐	☐	☐	☐	☐	☐	☐	冷
6. 僵硬	☐	☐	☐	☐	☐	☐	☐	柔軟
7. 無彈性	☐	☐	☐	☐	☐	☐	☐	有彈性
8. 不合身	☐	☐	☐	☐	☐	☐	☐	合身
9. 阻礙活動	☐	☐	☐	☐	☐	☐	☐	易於活動
10. 不舒服	☐	☐	☐	☐	☐	☐	☐	舒服
11. 不喜歡	☐	☐	☐	☐	☐	☐	☐	喜歡

上衣類型（由研究人員填寫）

C1. 請選出主觀感覺（After recovery）

主觀感覺刻度:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
1. 粘貼	☐	☐	☐	☐	☐	☐	☐	不粘貼
2. 悶焗	☐	☐	☐	☐	☐	☐	☐	透氣
3. 濕	☐	☐	☐	☐	☐	☐	☐	乾
4. 重	☐	☐	☐	☐	☐	☐	☐	輕
5. 熱	☐	☐	☐	☐	☐	☐	☐	冷
6. 刮擦	☐	☐	☐	☐	☐	☐	☐	不刮擦
7. 僵硬	☐	☐	☐	☐	☐	☐	☐	柔軟
8. 無彈性	☐	☐	☐	☐	☐	☐	☐	有彈性
9. 不合身	☐	☐	☐	☐	☐	☐	☐	合身
10. 不舒服	☐	☐	☐	☐	☐	☐	☐	舒服
11. 不喜歡	☐	☐	☐	☐	☐	☐	☐	喜歡

長褲類型（由研究人員填寫）:

C2. 請選出主觀感覺（After recovery）

主觀感覺刻度:	1	2	3	4	5	6	7	
1. 粘貼	☐	☐	☐	☐	☐	☐	☐	不粘貼
2. 悶焗	☐	☐	☐	☐	☐	☐	☐	透氣
3. 濕	☐	☐	☐	☐	☐	☐	☐	乾
4. 重	☐	☐	☐	☐	☐	☐	☐	輕
5. 熱	☐	☐	☐	☐	☐	☐	☐	冷
6. 刮擦	☐	☐	☐	☐	☐	☐	☐	不刮擦
7. 僵硬	☐	☐	☐	☐	☐	☐	☐	柔軟
8. 無彈性	☐	☐	☐	☐	☐	☐	☐	有彈性
9. 不合身	☐	☐	☐	☐	☐	☐	☐	合身
10. 不舒服	☐	☐	☐	☐	☐	☐	☐	舒服
11. 不喜歡	☐	☐	☐	☐	☐	☐	☐	喜歡

D. 收集資料目的

你所提供的個人資料將由香港理工大學建築及房地產學系建築健康及安全研究小組收集，目的旨在研究 2 款制服在主观感觉上的舒适性，我們將會小心處理你所提

供的資料，加以保密，數據將會在此研究結束後作撰寫研究報告之用，並在研究完成後銷毀。如對這份問卷有任何查詢，請聯絡香港理工大學建築及房地產學系研究項目“ **建築防護服抗高溫高濕性能的研究**”首席調查員陳炳泉教授 (電話: 2766 5814)。

§问卷结束，感谢您的参与§

Appendix 4: Data collection sheet used in the field experiment

Project Title: Anti-heat stress clothing for construction workers in hot and humid weather – field experiment

Condition	Activity	Time	Duration	HR	RPE	TS
	Pre-work rest		5			
			10			
			15			
			20			
			25			
			30			
	Work		5			
			10			
			15			
			20			
			25			
			30			
			35			
			40			
			45			
			50			
			55			
			60			
			65			
			70			
			75			
			80			
			85			
			90			
			95			
			100			
			105			
			110			

			115			
			120			
			125			
			130			
			135			
	Post-work rest		5			
			10			
			15			
			20			
			25			
			30			

Appendix 5: Questionnaire used in the field survey

The Hong Kong Polytechnic University
Construction Health and Safety Research Team

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

The objective of this study is to evaluate the **anti-heat stress clothing** for comfort, suitability, practicality, and acceptability, and rating of perceived exertion scale on the basis of human psychological responds. In order to achieve this objective, please give us your valuable advises by ticking the enclosed questionnaire on the scales. Thank you very much for your cooperation.

A. Personal information

1. Name：

2. Gender：

3. Age：

4. Trade：

5. Height (cm)：

6. Weight (kg)：

Questionnaire (After work)

Type of T-shirt	Blue （ ）	Yellow （ ）
Size of T-shirt		

B1. Subjective assessments — T-shirt

Subjective rating	1	2	3	4	5	6	7	
1. Hot								Cool
2. Damp								Dry
3. Clammy								Dry
4. Airtight								Breathable
5. Heavy sweating								Light sweating
6. Thick and heavy								Thin and light
7. Work performance interfered								No work performance interfered
	*If work performance interfered, please indicate the reason(s) (multiple choices)： a. Shoulder（ ）； b. Arm （ ）； c. Chest （ ）；d. Back （ ）； e. Others_________________							
8. Uncomfortable								Comfortable
	*If uncomfortable, please indicate the reason(s)(multiple choices): a. Hot and/or damp（ ）； b. Misfit（ ）； c. Stiff （ ）； d. Rough （ ）； e. Itchy and scratchy（ ）； f. Others_________________							
9. Dislike								Like
10. Upon the completion of two-day wear trial, please indicate your preference	A. Blue one（ ） B. Yellow one（ ） C. Both T-shirts（ ） D. Neither of them（ ）							

Type of pants	Dark blue （ ）	Khaki（ ）
Size of pants		

B2. Subjective assessment —pants

Subjective rating	1	2	3	4	5	6	7	
1. Hot								Cool
2. Damp								Dry
3. Clammy								Dry
4. Airtight								Breathable
5. Heavy sweating								Light sweating
6. Thick and heavy								Thin and light
7. Work performance interfered								No work performance interfered
	*If work performance interfered, please indicate the reason(s) (multiple choices)： a. Hip（ ）; b. Thigh（ ）; c. Calf（ ）; d. Others________________________							
8. Uncomfortable								Comfortable
	*If uncomfortable, please indicate the reason(s)(multiple choices): a. Hot and/or damp（ ）; b. Misfit（ ）; c. Stiff（ ）; d. Rough（ ）; e. Itchy and scratchy（ ）; f. Others__________________							
9. Dislike								Like
10. Upon the completion of two-day wear trial, please indicate your preference	A. Khaki one（ ） B. Dark blue one（ ） C. Both pairs of pants（ ） D. Neither of them（ ）							

C. The Purpose of Collecting Personal Information

Your personal information is collected by the Construction Health and Safety Research Team of The Hong Kong Polytechnic University for the project *of Anti-heat stress clothing for construction workers in hot and humid weather*. The aim is studying on the subjective comfort, practicability, and acceptability of the newly designed anti-heat stress clothing. We will not disclose your personal information which will only be used for the project reports and be destroyed after the project is completed. If you have any questions, please contact the project director Prof Albert Chan (Tel: 2766 5814).

香港理工大學

建築及房地產學系建築安全研究隊伍

酷熱天氣下建築工人抗熱抗濕工作服的研究

本問卷基於人類心理反應原理設計，目的為評估 2 款制服在主觀感覺上的舒適性能，並給予工作辛苦程度評級。為了達成目的，請在以下環節內，根據您的個人感覺給予寶貴意見，并請在合適的盒子或括號裡打勾 （√）以示分數。非常感謝您的合作！香港理工大學建築及房地產學系建築安全研究隊伍受香港職業安全健康局委託進行本項研究。

A．個人資料

1. 姓名：____________ **2.** 性別：______________

3. 年齡：_____________ **4.** 工種：______________

5. 身高 (公分)： ________ **6.** 體重 (公斤)：__________

問卷調查 **(工作結束後)**

T 恤衫类别（請√）	藍色 （ ）	黄色（ ）

T 恤衫尺寸:		

B1. 請選出主觀感覺和工作辛苦程度— T 恤衫

<table>
<tr><th>主觀感覺刻度
（程度）</th><th>1
（非常）</th><th>2
（比較）</th><th>3
（稍微）</th><th>4
（中等）</th><th>5
（稍微）</th><th>6
（比較）</th><th>7
（非常）</th><th></th></tr>
<tr><td>1. 熱
（指人體對衣服的感覺）</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>冷</td></tr>
<tr><td>2. 濕
（指人體對衣服的感覺）</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>乾</td></tr>
<tr><td>3. 黏
（指皮肤和衣服之间）</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>乾爽</td></tr>
<tr><td>4. 不透氣</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>透氣</td></tr>
<tr><td>5. 強烈出汗
（指人體）</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>不出汗</td></tr>
<tr><td>6. 厚重</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>輕薄</td></tr>
<tr><td rowspan="2">7. 阻礙活動
（衣服穿著后使人活動受限）</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td rowspan="2">易於活動</td></tr>
<tr><td colspan="7">*如有阻礙，請指出具體部位 （多選）：
a. 肩部（ ）；b. 前臂（ ）； c. 胸部（ ）；
d. 其它______________________</td></tr>
<tr><td rowspan="2">8. 不舒服</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td rowspan="2">舒服</td></tr>
<tr><td colspan="7">*如有不舒服，請指出其中引起不適的原因（多選）：
a. 上衣較热或較湿（ ）；b. 上衣不合身（ ）；c. 衣料不柔軟 （ ）；d. 衣料粗糙 （ ）； e. 衣料對皮膚有刮擦、刺癢等感覺（ ）； f. 其它________________</td></tr>
<tr><td>9. 不喜歡</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>喜歡</td></tr>
<tr><td>10. 在完成两日穿著实验后，你将会选择哪件 T 恤：</td><td colspan="7">A. 蓝色 （ ） B. 黄色 （ ）
C. 两者都可選（ ） D. 两者都不選（ ）</td><td></td></tr>
</table>

褲子衫类别（請√）	藍色 （ ）	黃色（ ）
褲子衫尺寸:		

B2. 請選出主觀感覺和工作辛苦程度—褲子

<table>
<tr><th>主觀感覺刻度
（程度）</th><th>1
（非常）</th><th>2
（比較）</th><th>3
（稍微）</th><th>4
（中等）</th><th>5
（稍微）</th><th>6
（比較）</th><th>7
（非常）</th><th></th></tr>
<tr><td>1. 熱
（指人體對衣服的感覺）</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>冷</td></tr>
<tr><td>2. 濕
(指人體對衣服的感覺)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>乾</td></tr>
<tr><td>3. 黏
（指皮肤和衣服之间）</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>乾爽</td></tr>
<tr><td>4. 不透氣</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>透氣</td></tr>
<tr><td>5. 強烈出汗
（指人體）</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>不出汗</td></tr>
<tr><td>6. 厚重</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>輕薄</td></tr>
<tr><td rowspan="2">7. 阻礙活動
（衣服穿著后使人活動受限）</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td rowspan="2">易於活動</td></tr>
<tr><td colspan="7">*如有阻礙，請指出具體部位 （多選）：

a.臀部（ ）；b. 大腿（ ）； c. 小腿（ ）；

d. 其它______________________</td></tr>
<tr><td rowspan="2">8. 不舒服</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td rowspan="2">舒服</td></tr>
<tr><td colspan="7">*如有不舒服，請指出其中引起不適的原因（多選）：

a. 裤子较热或较湿（ ）；b. 褲子不合身（ ）；c. 褲料不柔軟（ ）；d. 褲料粗糙 （ ）； e. 褲料對皮膚有刮擦、刺癢等感覺（ ）； f. 其它________________</td></tr>
<tr><td>9. 不喜歡</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>喜歡</td></tr>
<tr><td>10. 在完成两日穿著实验后，你将会选择哪件褲子：</td><td colspan="7">A. 卡其色 （ ） B. 深藍色 （ ）
C. 两者都可選（ ） D. 两者都不選（ ）</td><td></td></tr>
</table>

C. 收集資料目的

你所提供的個人資料將由香港理工大學建築及房地產學系建築健康及安全研究小組收集，目的旨在研究 2 款制服在主观感觉上的舒适性，我們將會小心處理你所提供的資料，加以保密，數據將會在此研究結束後作撰寫研究報告之用，並在研究完成後銷毀。如對這份問卷有任何查詢，請聯絡香港理工大學建築及房地產學系研究项目“ **建築防護服抗高溫高濕性能的研究**”首席調查員陳炳泉教授 (電話: 2766 5814)。

§问卷结束，感谢您的参与§

Appendix 6: Consent form used in the study

Consent To Participate In Research

Project Title

<u>Anti-heat stress clothing for construction workers in hot and humid weather</u>

I hereby ________________ consent to participate voluntarily in the study conducted by <u>Building and Real Estate of The Hong Kong Polytechnic University</u>.

I understand that the collected data may be used for the research and publication. But the privacy of my personal information is properly protected and not released.

The researchers have clearly explained the field study protocol to me and I understand the related benefit and risk. I participate in the study voluntarily.

I can choose whether to be in this study or not. If I volunteer to be in this study, I may withdraw at any time without consequences of any kind. I may withdraw my consent at any time and discontinue participation without penalty.

Signature of participants ____________________________

Date ____

參與研究同意書

研究項目標題

酷熱天氣下建築工人抗熱抗濕工作服的研究

本人________________同意參與由 香港理工大學 建築與房地產學系開展的上述研究。

本人知悉此研究所得的資料可能被用作日後的研究及發表， 但本人的私隱權利將得以保留，即本人的個人資料不會被公開。

研究人員已向本人清楚解釋列在所附資料卡上的研究程序，本人明瞭當中涉及的利益及風險；本人自願參與研究項目。

本人知悉本人有權就程序任何部分提出疑問，並有權隨時退出而不受任何懲處。

參與者簽署________________________________

日期________________________________

Appendix 7: Equipment for collecting data

Equipment	Profile	Parameters/ functions
Climatic chamber (LabTester, Smart-Computer Series, KSON, Taiwan)		The environmental condition inside the climatic chamber was maintained at 34.5 °C temperature and 75% relative humidity.
Motorized treadmill (h/p/cosmos pulsar, Germany)		Exercise intense (km/h), and exercise time (min)
Heat stress monitor (QUESTemp°36, Australia)		Wet bulb globe temperature (°C)
CorTemp data logger and capsule (HQI, America)		Intestinal temperature (°C)

Temperature probe and data logger (Lutron, Taiwan)		Temperature (°C)
Thermistor sensor and data logger (LT8A, Gram Co., Japan)		Skin temperature (°C)
Microclimate humidity sensor and data logger (Especmic, Japan)	 	Microclimate humidity (%)
Heart rate belt (Polar T34 Transmitter, Finland)		Heart rate (bpm)
Heart rate belt and data logger (Polar Wearlink, America)		Heart rate (bpm)

Weight scale (HD-382, Tanita, Japan)		Body mass (kg)
Scale (E-SNO-PSL-150KPC, Sam Hing Scales Fty. Ltd., Hong Kong)		Body mass (kg)
Scale (GF-2000, A & D Company Ltd., Japan)		Mass of garments and towels (g)
Bum bag with a tiny digital camera (Designed by Mr I.K. Chan, Senior technician, Building and Real Estate Department, The Hong Kong Polytechnic University)		The CorTemp data logger and a small digital camera were inside the bag that was attached to the waist of the participant. This procedure aimed to collect the core temperature stably.

Multiple videos on one screen (Designed by Mr I.K. Chan, Senior technician, Building and Real Estate Department, The Hong Kong Polytechnic University)		This digital technology aimed to observe and record core temperature, heart rate, wet bulb globe temperature, and human activities synchronously by the investigators outside the climatic chamber.

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