

**Research Assessment Exercise 2020**  
**Impact Case Study**

**University:** The Hong Kong Polytechnic University (PolyU) |

**Unit of Assessment (UoA):** 16 – Civil Engineering and Building Technology |

**Title of case study:** Enhancing Construction Workers' Health and Safety in Hot Weather |

**(1) Summary of the impact** |

A team from UoA16 has pioneered a series of “Heat Stress” research projects since 2010 to help construction workers avoid the physiological and perceptual discomfort, illness and mortalities that may result if they fail to maintain thermoregulation. At least 75 construction workers suffered such injuries and deaths between 1998 and 2013 in Hong Kong. Among the outputs from the research is an anti-heat stress working uniform which offers a 28.8% reduction in heat storage and a 14.2% improvement in thermal comfort. Attention has been given to reducing the garments' retail price to improve their take up in several areas. The uniform was licensed to the Construction Industry Council in 2015 and was specified by the Government as standard work wear for all public works contracts in 2018. Over 116,000 anti-heat stress shirts and 36,000 pairs of trousers have been sold to over 100 organisations to date. The garments are being adopted for other work sectors including cleaning, gardening, and logistics in Hong Kong, Macao, Cambodia, and Saudi Arabia. |

**(2) Underpinning research** |

Four consecutive research projects with a common theme of “Heat Stress” have been pioneered and led by the PolyU team since 2010, funded by the Hong Kong RGC (PolyU510409, PolyU5107/11E, PolyU510513) and the Occupational Safety and Health Council (OSHC No. CM/4R/2011-01). These projects involved multidisciplinary professionals and experts from the Department of Building and Real Estate, Institute of Textile and Clothing of PolyU, Education University of Hong Kong, Shandong Sport University, Soochow University and the University of Manchester. The UoA's team of 14 academic researchers comprised: Prof Albert Chan, Prof Francis Wong, Prof Michael Yam, Prof Joanne Chung, Prof Yi Li, Prof Del Wong, Dr Yue-ping Guo, Dr Daniel Chan, Dr Edmond Lam, Dr Esther Cheung, Dr Wen Yi, Dr Yang Yang, Dr Wenfong Song, and Dr Yijie Zhao.

The research conducted over the past 10 years followed an integrated strategy to develop occupational interventions against heat stress and advanced with teams covering: (i) Clothing Design, (ii) Experimental Design and (iii) Coordination and Implementation. Their main practical output is an anti-heat stress clothing (AHSC) system which reduces heat strain in working hours and a personal cooling vest that accelerates recovery during rest periods. This work was based on the theory of clothing physiology and the AHSC study adopted DeJonge's 7-stage functional clothing design process [R1].

**Scientific work wear design:** The design of AHSC started with an empirical study with frontline workers to identify the required attributes of appropriate clothing in hot weather. Based on the identified criteria, thirty-nine types of fabrics (12 for polo shirts, 18 for trousers and 9 for reflective strips) were sourced, tested, and evaluated. Tests on air resistance, water vapour permeability, moisture management capacity, UV protection factor and abrasion were conducted to identify the physical properties of the selected fabrics. These characteristics were input into a purpose-developed Computer Aided Design (S-smart) system to identify the most appropriate fabrics with the best thermal-moisture performance. Ultimately, ‘Coolmax 100%’ was selected as the best fabric for the polo shirt. This was further enhanced by trimming the inside of the polo

shirt with nest mesh fabrics to foster better ventilation. The trousers were made from the ‘Dry-inside’ fabric, which incorporates a new moisture management technology developed by the research team. The fabric allows rapid one-way moisture transfer away from the skin to the surface of the garment. The unique features of ergonomic design include meshed warp knit fabric on the inside surfaces, porous reflective strips, loose-fit design to aid better ventilation, and different front and back designs to improve visibility.

**Advances in occupational intervention research:** Traditional research on clothing physiology relies heavily on the results of randomised controlled trials in laboratory settings. However, their results are questionable in terms of reliable and valid application to real-life settings. To bridge this gap, a novel occupational invention research methodology was adopted to evaluate the efficacy, effectiveness and acceptability of the AHSC [R2]. Participants were randomly assigned to wear AHSC and a traditional uniform (TRADE). Firstly, a laboratory experiment was conducted to evaluate the efficacy of AHSC in a climatic chamber maintained at 34.5 °C temperature and 75% relative humidity. The results showed that wearing AHSC lowered heat storage by 28.8% and improved thermal comfort by 14.2% as compared to TRADE. In particular, core temperature decreased significantly by 0.53 °C [R3] and the recovery rate in physiological strain rose by 9% when the AHSC system was used to aid recovery over a rest period [R4]. The lower core temperature and a greater relief of heat strain improves worker comfort and can accelerate recovery from fatigue. A field experiment was then undertaken to ascertain the effectiveness of the AHSC in alleviating perceptual strain among construction workers, showing a significant reduction of perceptual strain index by 7% when workers wore AHSC during work period [R5]. Finally, a field survey was run with 189 construction workers to evaluate their personal perceptions of the thermal, pressure, tactile comfort of the alternative AHSC and TRADE garments. The results indicated that AHSC offered great improvements in keeping the respondents cooler, drier and facilitating their body movements [R6]. An overwhelming majority (87%) of workers preferred to wear AHSC. The work has led to the team receiving seven local and international awards since 2015. |

### (3) References to the research

- R1. Chan, A.P.C., Guo, Y.P., Wong, F.K.W., Li, Y., Sun, S., Han, S. (2016). The development of anti-heat stress clothing for construction workers in hot and humid weather. *Ergonomics*. 59(4): 479-495. DOI: 10.1080/00140139.2015.1098733
- R2. Yang, Y., Chan, A.P.C. (2017). Heat stress intervention research in construction: gaps and recommendations. *Industrial Health*, 55(3): 201-209. DOI: 10.2486/indhealth.2016-0047
- R3. Yi, W., Chan, A.P., Wong, F.K., Wong, D.P. (2017). Effectiveness of a newly designed construction uniform for heat strain attenuation in a hot and humid environment. *Applied Ergonomics*. 58: 555-565. DOI: 10.1016/j.apergo.2016.04.011
- R4. Zhao, Y., Yi, W., Chan, A. P., Chan, D. W. (2017). Comparison of heat strain recovery in different anti-heat stress clothing ensembles after work to exhaustion. *Journal of Thermal Biology*, 69, 311-318. DOI: 10.1016/j.jtherbio.2017.09.004
- R5. Yang, Y., Chan, A.P. (2017). Role of work uniform in alleviating perceptual strain among construction workers. *Industrial Health*. 55(1): 76-86. DOI: 10.2486/indhealth.2016-0023
- R6. Chan, A.P.C., Yang, Y., Wong, F.K.W., Chan, D.W.M., Lam, E.W.M. (2015). Wearing comfort of summer work uniforms for construction workers. *Construction Innovation*. 15 (4): 473-492. DOI: 10.1108/CI-06-2015-0037 |

### (4) Details of the impact |

The pathways to impact for the new AHSC garments included (i) dissemination among the teams’ cross-disciplinary research communities, (ii) engagement of relevant stakeholders from early

stages, and (iii) participation in various promotion and exhibition activities. Over 180 construction workers were invited to take part in trialling the new wear and evaluate the acceptability and practicality of AHSC. Research findings were disseminated through seminars, exhibitions, a YouTube channel and newspapers, which captured widespread interest from workers, professionals, and the general public. The main indicators of the impact are summarised below:

### **i) Effective reduction of heat storage and improvement of thermal comfort of workers**

The practical impact of the AHSC system was demonstrated by monitoring in 2017 the outcomes after 1,500 sets of AHSC were distributed to outdoor Macao workers engaged in construction, gardening, logistics, and drainage services. A questionnaire survey investigated the experience of a sample of 203 front-line workers over one-year of wear. The results showed that 97% affirmed the effectiveness of anti-heat stress shirt in alleviating heat strain and 68% confirmed that the uniform was comfortable. Among 21 management staff, 90% deemed that the AHSC was an effective measure to counter heat stress [S1]. This led to over 2,700 pieces of uniforms being distributed in Macao [S2]. Construction workers of two large construction companies in Hong Kong also affirmed that *the newly designed uniforms not only provide a good image of uniformity and tidiness but also alleviate the risk of health hazards due to heat stress* [S3, 4].

### **ii) Changes in working practices**

A further impact of the research lies in the changes it has brought about in working practices and helping to develop new evidence-based industry standards. Wearing thin and light clothes with good permeability when working in hot weather has long been recommended by the government as a precautionary measure to protect workers from hot weather. However, these guidelines were loosely defined and had no precise specification. The UoA's work has led to a far more detailed, evidence-based, garment specification. The Development Bureau of the HK Government fabricated 1,000 sets of AHSC polo shirts for their Construction Safety Week in May 2015, while the Construction Industry Council (CIC) fabricated another 20,000 sets as a standard work wear for their trainees in September 2015. The AHSC was formally launched as the CIC's recommended uniform for construction workers in September 2016. CIC also introduced AHSC in their Reference Materials on 'Construction Site Welfare, Health and Safety Measures' [S5] stating: *"The site uniform, in the form of polo shirt (short-sleeve or long-sleeve to suit the weather conditions) and trousers, shall adopt the design of the anti-heat stress uniform of the Hong Kong Polytechnic University."*

The Development Bureau of the HK Government specified in their *Project Administration Handbook for Civil Engineering Works* that all contractors who intend to tender for public works contracts should provide a uniform to personnel working on public work sites to enhance the image of the construction industry. Previously, no standard designs of uniform for workers were specified in the Handbook and the HK Government introduced clauses to specifying the AHSC as standard for public work contracts in 2018. The HK Government also offers specific implementation guidelines to encourage contractors to provide the AHSC uniform to workers engaged in public works contracts [S6]. The widespread adoption of ASHC helps to improve health and safety policy, practice and processes across of the construction industry.

### **iii) Reduction of retail price**

Noting the possible effect of unit price on AHSC uniforms, the UoA team has collaborated with CIC to streamline procurement procedures and reduce administration and logistical costs. The AHSC is now available at a 20% lower retail price than the CIC's first generation construction uniform [S5].

### **iv) Technology transfer in Hong Kong and beyond**

In 2015, the AHSC technology was licensed to the HK CIC for a nominal value of HK\$1 as a service to the community [S5, 7]. Since then, AHSC has been available for sale via an on-line

platform managed by CIC (<http://www.cic.hk/eng/main/Antiheatuniforms/>). Between September 2016 and December 2018, a total of 116,000 pieces of anti-heat stress shirts and 36,000 pairs of trousers [S5] have been ordered by over 100 construction companies and HK Government Departments/public bodies/NGOs [S8]. The AHSC was further licensed to the Labour Affairs Bureau (LAB) of the Macao Government to benefit outdoor workers in sectors such as construction, gardening, logistics, and drainage on 21st November 2017 [S2, 7]. A total of 2,762 AHSC pieces had been distributed to outdoor workers in Macao by June 2019 [S2]. Cambodian workers have also tried the AHSC uniforms and reported improved comfort and heat tolerance compared to their usual clothes [S9]. More recently, Administration of King AbdulAziz University, Saudi Arabia purchased the AHSC uniforms for trial by their workers' [S10]. Their initial step opens the prospect of a potential untapped market that stretches well beyond Hong Kong.

**(5) Sources to corroborate the impact**

- S1. Brief results of the questionnaire survey collected from the Labour Affairs Bureau (in Chinese). Contact person: Mr. Calvin Chong, Senior Technician of LAB (Email: calvinho@dsal.gov.mo). 4 December 2018.
- S2. Labour Affairs Bureau (LAB), Macao SAR. Letter of Support - Application of anti-heat stress uniforms. Contact person: Mr. WONG Chi Hong, Director (Email: dsalinfo@dsal.gov.mo). 3 June 2019.
- S3. Hip Hing Construction Co., Ltd. Letter of Support-Impacts of anti-heat stress uniforms. Contact person: Ir K.H. Mok, Executive Director (Email: kh\_mo@hiphing.com.hk). 28 January 2019.
- S4. Yau Lee Construction Co., Ltd. Letter of Support - Anti-heat stress uniforms. Contact person: Ir Conrad T. C. Wong, Managing Director (Email: conradwong@yaulee.com). 4 March 2019.
- S5. Construction Industry Council (CIC), Hong Kong SAR, China. Letter of Support-Anti heat stress uniforms. Contact person: Ms. Sally Au-Yeung, Assistant Manager (Email: sallyauyeung@cic.hk). 14 October 2019.
- S6. Works Branch, Development Bureau, Hong Kong SAR. Letter of Support-Anti heat stress uniforms. Contact person: Mr. Frankie Tai (Email: frankielftai@devb.gov.hk). 26 June 2019.
- S7. PolyU Technology and Consultancy Company Limited. Letter of Support-License. Contact person: Mr. Edmond Lam, Assistant Director of Institute for Entrepreneurship (Email: edmond.lam@polyu.edu.hk). 11 February 2019.
- S8. Sales records of anti-heat stress clothing (Dec. 2017 - Dec. 2018) offered by the Construction Industry Council. Contact person: Ms. Sally Au-Yeung, Assistant Manager (Email: sallyauyeung@cic.hk). 18 January 2019.
- S9. Design and Manufacturing for Quality Workshop, Phnom Penh, Cambodia, Letter of Support Anti-heat stress uniform. Contact person: Mak Bannak, Operation Manager. 6 March 2019.
- S10. King Abdulaziz University. Purchase Requisition Email. Contact person: Eng. Tarek M. Abokhashabah, Deputy Director (Email: tabokhashabah@kau.edu.sa). 26 February 2019.