The following publication Chan, A.P.C., Wong, F.K.W. and Yang, Y. (2016), "From innovation to application of personal cooling vest", Smart and Sustainable Built Environment, Vol. 5 No. 2, pp. 111-124 is published by Emerald and is available at https://doi.org/10.1108/SASBE-11-2015-0041.

From innovation to application of personal cooling vest

Abstract

Purpose The Hong Kong government agencies launched a "Cooling Vest Promotion Pilot Scheme" across four industries, namely, construction, horticulture and cleaning, airport apron services, and kitchen and catering industries in 2013. A follow-up questionnaire survey regarding this innovative heat stress controlling measure was administered to evaluate its applicability to these industries.

Design/methodology/approach The questionnaire surveys were separately administered to frontline workers and management staff. A total of 232 workers from the four industries participated in the full-scale Questionnaire Survey (A), which aimed to evaluate the perceived effectiveness of cooling vests, worker satisfaction, and willingness to wear cooling vests. The survey was also geared toward eliciting the comments of the workers regarding logistics-related issues. A total of 100 members of the management staff across the four industries participated in the Questionnaire Survey (B), which aimed to solicit their feedback about the Pilot Scheme and the logistic arrangements for using cooling vests.

Findings On the basis of the survey results, a systems model was established. The model revealed that the applicability of cooling vests mainly depends on the perceived benefits (i.e., worker satisfaction) and logistic costs. The results implied that the existing personal cooling vest failed to satisfy the workers' needs and incurred potential logistic costs, which likely limited the broad application of cooling vests.

Originality/value The current study employed a systematics thinking approach and provided practical recommendations that could benefit industrial practitioners in the extensive application of an innovative heat stress precautionary measure.

Keywords

systems thinking; frontline worker; management staff; questionnaire survey; perceived benefit; four industries

Introduction

Extreme environment conditions are commonly encountered in many industries, such as iron, steel and nonferrous foundries, glass and calcium carbide manufacturing, mining operations, farming operations, airport apron service sectors, and other outdoor operations (Da Costa *et al.*, 2012). In conjunction with hot conditions, occupational settings that involve strenuous physical workloads and prolonged work duration potentially pose excessive heat load for working people (Pérez-Alonso *et al.*, 2011). 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 may result in potential lethality (Inaba and Mirbod, 2007).

The alarming reported heat-related incidents in the Hong Kong occupational settings

(Chan *et al.*, 2013) have compelled the government agencies, the industries, and the academia to develop and implement appropriate precautionary measures that can protect workers against heat stress. A series of heat stress precautionary measures incorporating environmental engineering controls, administrative controls, and personal protective controls have been addressed in these guidelines and practice notes (e.g., Labour Department of the HKSAR, 2014). Environmental engineering controls are often utilized to mitigate or eliminate hazardous exposure to the physical environment. For instance, the provisions of natural or mechanical ventilation, shields or insulation, portable blowers, and air conditioners may help workers avoid exposure to direct sunlight or remove excessive heat from an occupied space. However, these environmental engineering controls 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). Administrative controls are the assigned or rescheduled work practices and policies implemented by the employer, including the reduction of magnitude, duration, and/or frequency of worker exposure to risk factors (Federal Register, 2001); however, their effectiveness 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 heat stress to acceptable levels (The Real Estate Developers Association of Hong Kong and The Hong Kong Construction Association of the HKSAR, 2005). Among personal protective controls, personal cooling garments that can facilitate a cool and comfortable microclimate have been well documented in many occupational settings (Furtado *et al.*, 2007; Choi *et al.*, 2008). It is envisaged that Hong Kong occupational workers may possibly benefit from using personal cooling garments because these apparels may improve the sustainable working environment in hot weather. Nevertheless, personal cooling garments are not widely used in Hong Kong industries.

The current study intends to provide practical recommendations for promoting personal cooling vests as an innovative technology in industrial settings. For this purpose, this study first reviewed the factors affecting innovation adoption and described the employed research methods, including the questionnaire survey, data analysis, and systems modeling. This study was concluded by the contributions of systems thinking approach to the adoption of innovative technologies in occupational settings.

Literature review

Innovations in safety and health systems refer to “new medicines, diagnostics, health technologies, new ideas, practices, objects or institutional arrangements perceived as novel by an individual or a unit of adoption" (Atun, 2012). Inventions from the fields of industrial arts, engineering, applied sciences, and/or pure sciences embody technological innovation (Garcia and Calantone, 2002). Adopting advanced technologies can alleviate the problems related to health and safety in the workplace (Harrisson and Legendre, 2003) and can thus improve the well-being of occupational workers. Technological innovation encompasses both product and process types of innovations (Cleand and Bidanda, 1990). Product innovation refers to the organizational capacity to adapt new products (Jiang *et al.*, 2012), whereas process innovation is the implementation of a new technology in an organization (Toole, 1998). It is important to evaluate how the innovation can be diffused to users after the launch of new innovations (Liao and Cheung, 2002). The difficulty in promoting successful innovations to improve health and safety in organizations is attributed to the complex interaction among union leaders, management, and employees (Karasek, 1992; Lipsey and Cordray, 2000). The innovation process involves individuals with their motivations, perceptions, attitudes, beliefs, ambitions, personalities, abilities, and prior knowledge and experience that determine the potential success of an innovation (Goldhar *et al.*, 1976). Many marketing studies focused on consumers' perception of new technologies (Moore and Benbasat, 1991), whereas some sociological studies in this subject analyzed how societal characteristics affect technology adoption by potential users (Selwyn, 2003; Slowlkowski and Jarratt, 2007). These studies underpinned that it is more critical to understand the users than the product itself (Brown and Duguid, 1991; Haggman, 2009). Therefore, the key components of the adoption and application of the technological innovation, including *people, product, and process*, were adopted in the current study.

Client satisfaction

Studies on technological innovation emphasized the positive influence of consumers or clients on the success of innovations (Hislop, 2002). Clients are classified into two parties: first, the term "client" represents an individual or group that affects the decision of a firm to adopt innovations in its safety and health system; second, "clients" are the end users who reflect their demand and satisfaction after directly using an innovative product (Lim and Ofori, 2007). However, client satisfaction of innovative safety measures has received little attention.

Understanding the factors that influence user satisfaction of technological innovation is of interest to both researchers and manufacturers of technology. Client satisfaction is a crucial factor in adopting innovations in organizations (Gallivan, 2003) and in determining participation in innovative health treatments (Lebow, 1983). Generally, user satisfaction is a measurement of the felicity when using an innovation (Doll and Torkzadeh, 1988). A broad understanding of the situation, needs, and demands of customers is important in the successful development of new products (Kärkäinen *et al.*, 2001). Many new product development projects likely fail because the products do not meet the expectations of customers (Matzler and Hinterhuber, 1998). Customers who are dissatisfied with a new technology, they may later become non-users (Kingsley and Anderson, 1998; MacVaugh and Schiavone, 2010). Thus, evaluating client satisfaction of innovative safety measures will help understand the motivation and willingness of consumers to use technological innovations.

Perceived benefits and costs

Gardiner and Rothwell (1985) suggested that clients should be full partners in the innovation process. The perception of clients on the benefits and costs of innovation primarily influences their decisions regarding their involvement the innovation process because the funding of innovations is largely based on the financial capacity of a firm (Ivory, 2005). First, innovations in the occupational safety and health (OSH) system may provide potentially tangible and intangible returns, such as the prevention of accidents, improvement in productivity, enhancement of quality of working life, and establishment of company reputation. Clients may become concerned about reductions in tangible and intangible benefits as a result of financial constraints, which further can restrict the capacity of clients to invest in an innovation (Kaine *et al.*, 2007). Unexpected and unforeseen costs may emerge when additional expenses related to the maintenance of an innovative product are incurred. Firms may face strong pressures to increase expenses for innovations in terms of personnel, equipment, regulations, and testing costs (Shields and Young, 1994; Corcoran, 1992). As a result, firms take on the risks and costs of developing and applying an innovation (Ivory, 2005).

Reliability of innovation

Aside from the perceived value of an innovative product and related costs, the perceived risks associated with the supposed reliability of an innovation also influences client satisfaction (French and O'Cass, 2001) and innovation adoption (Ma *et al.*, 2012; Katila *et al.*; 2002). The unreliability of innovation success affects client participation in an innovation (Ivory, 2005). Thus, the quality, pricing, convenience, applicability, aesthetics, and reliability of an innovation (Ma *et al.*, 2012) should be analyzed to determine the attributes of an innovation (Rankin and Luther, 2006).

Many studies showed that the adoption and application of new technology depend on other contextual factors, such as organizational culture, management style, and OSH policy (Damanpour, 1987; Harrisson and Legendre, 2003; Atun, 2012). Dodgson *et al.* (2008) advocated that technological innovation often requires changes and management in an organization, as well supplementing strategies. Particularly, the innovation process involves managerial and organizational integrations and decisions (Dodgson *et al.*, 2008). Bossink (2004) and Lim and Ofori (2007) identified and classified environmental pressure, research capability, knowledge exchange, and boundary spanning as drivers of innovation. Although the effectiveness of innovative strategies depends on the knowledge about these implicit components (Binder, 2007), these components are attributed to contextual factors, which are beyond the scope of this study.

Method

Cooling vest

The Labour Department, in conjunction with the Occupational Safety and Health Council, took initiatives to launch a "Cooling Vest Promotion Pilot Scheme" in Hong Kong in 2013. The purpose of this scheme was to test the feasibility of using cooling vests in four selected industries, namely, construction, outdoor cleaning and horticulture, kitchen work and work involved manual handling at the airport (Labour Department of the HKSAR, 2013). Under the "Cooling Vest Promotion Pilot Scheme" initiated by the Labour Department of the HKSAR Government, about 1,500 sets of cooling vests have been given to 195 participating organizations in four industries, including, construction, catering and kitchen, airport apron services, horticulture and outdoor cleaning (Labour Department of the HKSAR, 2013). The cooling vest (ICEBANK®, Korea) utilizes both active and passive cooling systems. Two detachable electronic fans (with a diameter of approximate 10 cm) are embedded in the lower back of the vest. Three frozen gel packs, each with a covering area of 160 cm^2 and mass of 150 g, are stored inside three pockets on the belly and back of the vest. The function of the cooling vest is to enhance air ventilation by promoting convective heat loss and sweating evaporation via ventilation fans (i.e., the active cooling system), as well as to absorb heat from the body when the frozen gel packs transform phases from solid to liquid (i.e., the passive cooling system). The total weight of cooling vest, including all auxiliary devices (i.e., batteries), is approximately 1.0 kg.

Questionnaire survey

Prior to the questionnaire survey, a total of 232 frontline workers[1] were invited to undertake a series of wear trails voluntarily and indicated their sensory perceptions after putting on the cooling vest. Workers were given a set of cooling vest in proper sizes to try on during summer time (July to August) in 2013. The workers were encouraged to wear the cooling vest when the air temperature was above 30 °C. The questionnaire survey was administered between September and October 2013 after they had gained a hands-on experience of the cooling vest[2]. The study was approved by the Human Subjects Ethics Sub-committee of the authors' host organization.

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[1] Sample size is determined by the equation $\mathrm{n} = \frac{\frac{\mathrm{P}[1-\mathrm{P}]}{\frac{\mathrm{A}^2}{\mathrm{Z}^2}+\frac{\mathrm{P}[1-\mathrm{P}]}{\mathrm{N}}}}{\mathrm{R}^2}$, where n is the required sample size, N=1475 is the number of cooling vests distributed, P=0.5 is the estimated variance in population, A=7% is the precision desired, Z=1.96 for confidence level at 95%, R=0.90 is the estimated response rate. Thus, n=214.

[2] The detailed methodologies of the questionnaire survey among frontline workers were elaborated in a previous working paper titled "Evaluating the usability of a hybrid cooling vest: A structural equation models" by Chan, A.P.C., Yang, Y., and Song, W.F. 2014 (unpublished). Only a part of data was used in the current paper.

To understand the potential application of the existing cooling vest in the four industries, the variables and measurements that may affect innovation adoption are summerized in Table 1. Two rounds of questionnaire surveys were administrated to collect these variables: Questionnaire A sought to evaluate the effectiveness, suitability, and maintainability of cooling vests among frontline workers; and Questionnaire B sought to assess the practicability of the supporting logistic arrangements among the management staff (Chan, 2013).

[Please insert Table 1 here]

For the Questionnaire A, the participants were asked to rate 3 items of subjective attributes described as opposite adjectives based on a five-point Likert scale (Table 1). The interpretation of scales 1 to 5 are represented by the following: from ineffective to effective on protection from heat stroke, from unsatisfied to satisfied, and from neither during work or rest to during whole work and rest. Comments on logistic arrangements of cooling vest (e.g., cleaning, storage and maintenance of the cooling vest) from frontline workers were captured. For the Questionnaire B, the members of management staff who were in charge of the Pilot Scheme in their participating organizations were invited to complete the questionnaire. A total of 100 participants[3] took part in this survey. Management staff was requested to provide comments on the Pilot Scheme and the logistic arrangements for using the cooling vests.

Sample profile

A total of 232 valid replies were obtained for the Questionnaire A. The sample comprised 202 male workers and 30 female workers. The demographic information of the participants is shown in Table 2. Trade distributions in each industry are illustrated in Figure 1. Participants with a wide spectrum of age (ranging from 19 to 65 years old), working experience (ranging from 0 to 43 years), and various trades in each industry contributed in this study to ensure a representative sample of frontline workers. A total of 100 valid replies were collected for the Questionnaires B from 67 groups. Figure 2 shows the distribution of management staff positions in the four industries. Management staff members from different positions were involved to capture a wide spectrum of qualitative data.

[Please insert Table 2 here]
[Please insert Figure 1 here]
[Please insert Figure 2 here]

Data analysis

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[3] Sample size is determined by the equation $n = \frac{\frac{P[1-P]}{\frac{A^2}{Z^2}+\frac{P[1-P]}{N}}}{R^2}$, where n is the required sample size, N=195 is the number of the organizations participating in the Scheme, P=0.5 is the estimated variance in population, A=9% is the precision desired, Z=1.96 for confidence level at 95%, R=0.90 is the estimated response rate. Thus, n=91.

Spearman correlation analysis was used to investigate the relationships among "satisfaction", "perceived effectiveness", and "degree of willingness to wear". Content analysis was performed to extract the most frequently mentioned key words from the participants' comments. Multiple-correspondence analysis was employed to examine whether the characteristics of the individuals (i.e., industry, gender, age, and working experience) could be associated with subjective sensations (Callejón-Ferre et al., 2015). This approach could identify the correlations between variable categories as well as within variables of the same category (Callejón-Ferre *et al.*, 2015). The category of each variable is coded in Table 3. All statistical analyses were performed by the SPSS (Version 20).

[Please insert Table 3 here]

Results

The results of the questionnaire survey showed that "perceived effectiveness" and "worker satisfaction" were rated as neutral with a rating score of 3, while the workers expressed limited willingness to wear the cooling vest with a rating score below 3 (Table 4). The direction and significance of the relationships among the target variables are presented in Table 4. Worker satisfaction was positively related to perceived effectiveness, as well as willingness to wear.

[Please insert Table 4 here]

The results of multiple-correspondence analysis are shown in Table 5. The first dimension explained 39.8% of the variance with a Cronbach α coefficient of 0.748 and an eigenvalue of 2.788, and the second explained 31.6% of the variance with the α coefficient of 0.639 and an eigenvalue of 2.211. The full model explained 35.7% of the total variance with a mean α coefficient of 0.700 and an eigenvalue of 2.499. The first dimension showed high discrimination values in subjective sensations of "perceived effectiveness" (0.616) and "worker satisfaction" (0.724). The second dimension showed middle discrimination value for "willingness to wear" (0.465). The discrimination values for industry, gender, age, and working experience were low in both dimensions. Hence, a trivial level of discrimination existed between the categories of these variables.

[Please insert Table 5 here]

Comments on the logistic arrangements of the cooling vest (e.g., cleaning, storage and maintenance of the cooling vest) were solicited from frontlines workers. The top 5 concerns on the logistic arrangements identified were found to be (in descending order): (1) require additional accessories (i.e., frozen gel packs, batteries) and cooling vest for change; (2) inconvenient/lack of guidance to clean; (3) inconvenient to recharge/replace batteries/frozen gel packs during working time; (4) long time to freeze ice pack; and (5) no space for storage. Many workers complained that,

> "*As a result from the short effective time of the frozen gel packs and batteries, I would like to replace the accessories. Unfortunately, no extra accessories were available for replacement when the frozen gel packs melt and the batteries run down". Moreover, "it will be troublesome to frequently replace these accessories during work period because my worksite is far from the site office where those accessories are stored*".

Comments on the logistic arrangements of cooling vest were solicited from management staff. The top 3 concerns identified were found to be (in descending order): (1) inconvenient to recharge/replace batteries/frozen gel packs during working time; (2) require cleaning service for the cooling vests; and (3) require maintenance service for the cooling vests. Consistent with workers' feedback, the management staff concerned about workers' convenience in the use of cooling vest and the firms' capability of logistic support.

The top 4 concerns on the Pilot Scheme identified were (in descending order): (1) lack of industry-specific design (e.g., reflective strips); (2) costly cooling vest; (3) require further improvement in cooling vest prior to wide application; and (4) workers dissatisfaction. Some members of management staff pointed out that the cooling vest should be tailor-made in terms of the safety requirement of the firm (i.e., incorporated reflective strips) and image (i.e., color of uniform and company logo). They suggested that,

> "*There should be some space to improve the re-designing and re-engineering of the cooling vest in terms of cooling effect, user-friendliness, and reasonable expenses, although this scheme is good and creative*".

Systems thinking approach

Systems thinking is helpful in introducing new measures into safety systems to improve safety, or in analyzing the reasons for rapid or poor acceptance of safety interventions with proven benefits and costs (Atun, 2012). Understanding how people adopt innovations through established feedback loops enables researchers and practitioners to ascertain the key facets affecting the implementation of innovations.

On the basis of the literature review, and the results of Spearman Correlation and content analyses, a systems model of innovation adoption was developed, as delineated in Figure 3. Positive relationships among "effectiveness", "satisfaction", and "degree of willingness" were determined on the basis of the empirical analysis of the feedback from the construction workers. A reinforcing loop R was structured by the three positive links. That is, the increased effectiveness of cooling vests would improve worker satisfaction and further elevate workers' willingness to wear cooling vests. The logistic burden of using cooling vests was identified from the comments of frontline workers. A balancing loop B1 was structured. This balancing loop indicated that the increasing logistic burden associated with the rising willingness to wear cooling vests would reduce workers satisfaction. Worker satisfaction was one of the concerns of the management staff in adopting cooling vests. However, logistic burden also increased with the adoption of cooling vests. Thus, a balancing loop B2 was established. Finally, the capacity of organizations to provide logistic support in terms of cleaning, maintenance, and storage services would help promote the use of cooling vests. However, this capacity would be restricted by the increasing logistic burden. Hence, a balancing loop B3 was delineated. According to this established systems model, the application of cooling vests mainly depends on perceived benefits (i.e., worker satisfaction) and costs (i.e., logistic burden) from the perspective of frontline worker and management staff. This model provides a direction in evaluating an innovative protection measure with consideration of the costs and benefits to companies and end users.

[Please insert Figure 3 here]

Differences in opinions and perceptions of reality between the workforce and its management may elicit latent or concealed problems in the workplace (Øystein *et al.*, 2003). Thus, a thorough understanding of the perception of frontline workers and management staff toward cooling vests is crucial to comprehensively evaluate the feasibility of this protective apparel in the four industries. Nevertheless, similar opinions were observed from frontline workers and management staff. The results suggest that user satisfaction and logistics-related issues are two major facets that affect the implementation of cooling vests.

Several limitations were recognized in this study. The contextual factors across the four industries may differ because of work nature, workers' characteristics, and OSH policies. Thus, the lack of a specific industry-by-industry study was a main limitation in this study. Moreover, the benefits and costs were not exactly quantified. Future studies that quantify the benefits and costs of using cooling vest should be conducted to comprehensively assess the applicability of such protective clothing.

Conclusion

Personal cooling vest, which represent an innovative heat stress control measure, is not widely used in Hong Kong industries. Under the "Cooling Vest Promotion Pilot Scheme" introduced to the four industries, a series of questionnaire surveys among frontline workers and management staff were administered to evaluate the applicability of personal cooling vests in occupational settings. The results of the questionnaire surveys indicated that the cooling vest failed to satisfy the workers' needs and produced potential logistic costs. On the basis of these findings, a systems model was established to ascertain the underlying factors affecting the adoption of an innovative heat stress precaution. The established systems model revealed that worker satisfaction and logistic burden were the two key factors affecting the willingness of workers or management staff to use cooling vests. It is highlighted the importance of continuously improving cooling vests in terms of minimizing logistic costs and providing substantial benefits to expand their application. To obtain a holistic assessment of innovation adoption, future studies should quantify the benefits and costs of using cooling vests.

Acknowledgement

The authors declare that they have no conflict of interest. This project is jointly funded by the Occupational Safety and Health Council (OSHC Research Grant No. CM/4R/2011-01) and Research Grants Council of the Hong Kong Special Administrative Region, China (RGC Project No. PolyU5107/11E and PolyU5105/13E respectively). The authors wish to acknowledge the contributions of Dr YP Guo and Dr W Yi. In particular, the participation of volunteers in this study is gratefully acknowledged.

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