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Distributed network for measuring climatic parameters in heterogeneous environments: Application in a greenhouse

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ABSTRACT

In Mediterranean countries of Southern Europe, the climatic conditions are usually favourable to cultivate greenhouse vegetables but not always for workers. The aim of this study was to design a network of weather stations capable of gathering data of environmental parameters related to the wellbeing of workers in greenhouses in south-eastern Spain. The unevenness of the thermal environment was studied both vertically as well as horizontally following guideline ISO 7726. The results indicate that the greenhouse should be considered a heterogeneous environment, implying that, for an evaluation of the environmental conditions related to thermal stress of the workers inside the greenhouse, measurements should be taken at different points within the greenhouse at three heights (ankle, abdomen, and head).

1. Introduction

Labourers interact directly with their working environment, which, depending on different production sectors (Fig. 1), can vary and should be monitored for dangers and risks to worker health and safety (ILO, 1985).

Monitoring of the working environment is meant to combine all the disciplines related to safety (health, accidents, psychosocial factors, ergonomics, hygiene, illnesses, etc.). In agriculture (primary sector), three factors are distinguished in the discipline of environmental ergonomics: physical factors, organismic factors, and adaptive factors (Rohles, 1985). These factors have greater or lesser implications for the workers according to the tasks undertaken.

Agriculture around the planet is the second source of world employment. It involves contact with plants, animals, machinery, fertilizers, biocides, pests, etc. both in enclosed areas as well as in the open air (ILO, 2010). South-eastern Spain (Almería) has the greatest surface area of greenhouses in Europe, with 30,230 ha directly employing 55,813 workers (per year) of different nationalities (Cabrera-Sánchez et al., 2016).

These greenhouses, lightly built metal structures covered with transparent plastic, have wall and ceiling ventilation with interior diffuse solar radiation. These conditions are favourable for cultivating vegetables (Pérez-Alonso et al., 2011), but are not always suitable for the wellbeing of the greenhouse workers (Callejón-Ferre et al., 2011a). For purely agricultural control, greenhouses are equipped with sensors such as psychrometers, thermometers, pyrometers, conductivimetres, or pH metres (Castilla, 2005).

The vegetables cultivated in the province of Almería are tomatoes, peppers, cucumbers, green beans, eggplant, squash, melons, and watermelons. Workers tend all the tasks over the growing cycle of the vegetables, such as transplanting, pruning, biocide application, or harvesting. These tasks last for a complete crop cycle (growing season), i.e. from the end of July to the beginning of June of the following year. Also, maintenance work is carried out when the greenhouse contains no crop (Callejón-Ferre et al., 2009, 2011b).

The greenhouses of south-eastern Spain rarely need heating systems. Nevertheless, the temperature range varies sharply over the four seasons, from 40 °C in the summer to hardly more than 2–3 °C in winter (at night) (Castilla, 2005; Cecchini et al., 2010). Under these conditions, the study of heat stress in humans requires an analysis of the physical magnitudes associated with the environment (temperature, humidity, air velocity, etc.), with the individual, and with the type of work (metabolic rate, acclimation, physical activity, clothes, etc.) (ISO 7933, 2004).

Related to the heat stress in greenhouse climatic conditions, Callejón-Ferre et al. (2011a) studying the thermal conditions of workers in Almería-type greenhouses stated that, during the warmer months, the conditions under which heat stress risk could appear were common. Cecchini et al. (2010) showed that, in greenhouses of central Italy, the risk for workers during manual harvesting should not be underestimated, pointing to the possibility of the risk of heat stroke during

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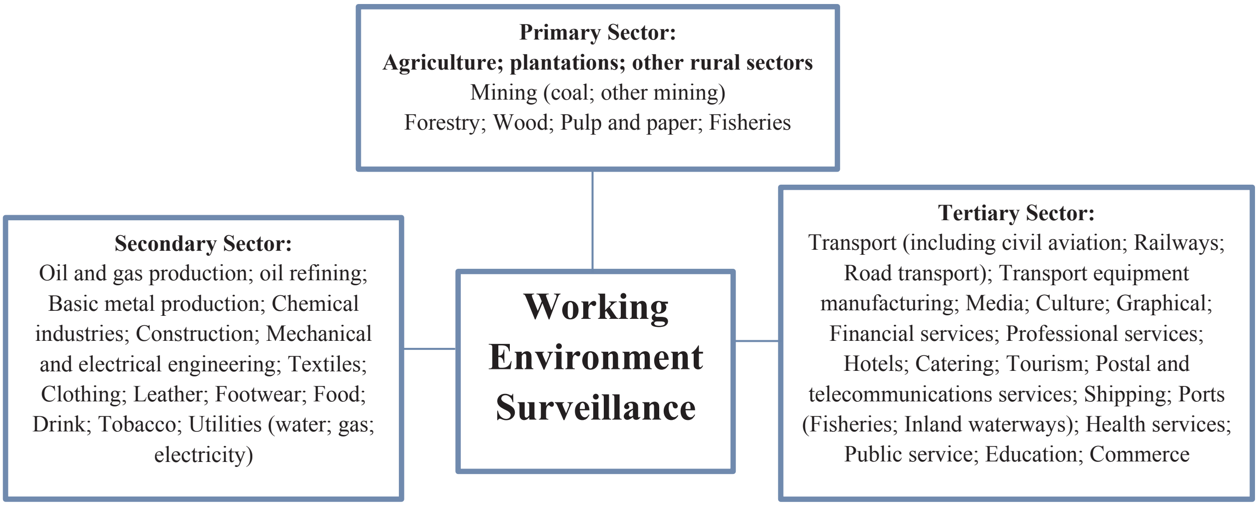

Fig. 1. Surveillance of the working environment of different economic sectors.

the hottest hours of the day in spring and summer. Also in central Italy, Marucci et al. (2012) studied the heat stress suffered by workers in vegetable grafting greenhouses, concluding that workers were subject to the risk of heat stress mainly between April and October. Similar results have been found for greenhouses of Calabria (southern Italy) (Diano et al., 2016) and Japan (Okushima et al., 2001), where the summertime proved dangerous, especially in the midday. While the risk of heat stress during the hottest months has been pointed, risk of cold stress has also been reported (Callejón-Ferre et al., 2011a). Other studies have examined the heat stress of workers during the greenhouse construction (Pérez-Alonso et al., 2011). This latter scenario differs from the previous ones in that most of the work is done outdoors. The results of above tasks are based on the evaluation of comfort and heat-stress indices.

The thermal-environment assessment is regulated by several rules (Parsons, 2013). The International Standard Organization (ISO) classifies the environment in two categories: moderate and extreme. Each category is evaluated through an appropriate index and the corresponding ISO Standard. Moderate environments should be evaluated through the Predicted Mean Vote index (PMV) according to ISO 7730 Standard (ISO 7730, 2005). Hot extreme environments should be initially treated by means of the Wet Bulb Globe Temperature index (WBGT) as stated at ISO 7243 Standard (ISO 7243, 1989); if limits of the WBGT index are surpassed, a more detailed analysis based on the energy balance equation (subject-environment heat transfer) is required. This analysis must be made according to the ISO 7933 Standard (ISO 7933, 2004), where the Predicted Heat Strain index (PHS) is suggested. Besides ISO standards, other comfort and stress indices have been proposed in the literature for the thermal environment (Epstein and Moran, 2006; D'Ambrosio-Alfano et al., 2011).

The WBGT index, according to ISO 7243 (1989), should be calculated according to one of the next two scenarios: (i) inside buildings and outside buildings without a solar load, and (ii) outside buildings with a solar load. Since the cover of the greenhouses consists of plastic film (with several additives), workers inside the greenhouse are exposed to diffuse radiation (Nijskens et al., 1985). Thus, conditions inside greenhouses do not exactly match any of the scenarios where WBGT index equation is defined (Callejón-Ferre et al., 2011a). Since the WBGT index might not be adequate for greenhouses, and due to the limitations of this index when the relative humidity is high and the wind speed is low (Budd, 2008; Callejón-Ferre et al. (2011a) used the Humidex Index (HI) (Masterton and Richardson, 1979) instead of WBGT index.

The calculation of the previous indices requires the measurement of several climatic parameters (air temperature, black globe temperature, air velocity, humidity, etc.) and, for PMV and PHS indices, also the metabolic rate related to the worker's physical activity, based in ISO 8996 (2004), and the clothing insulation and sweat rate (ISO 9920, 2007). Measurement of climatic parameters should be conducted in accordance with the ISO 7726 Standard (ISO 7726, 1998). This Standard, establishes the minimum characteristics of instruments for measuring the physical quantities that define a thermal environment. Also, ISO 7726 (1998) refers to the measuring methods, which should take into account that the values of physical quantities may vary in space and time. In case of heterogeneous environments, physical quantities need to be measured at different locations throughout the work place, in a horizontal direction and also in a vertical one. Previous studies address the distribution of air temperature inside greenhouses (López et al., 2012a, 2012b; López et al., 2013; Molina-Aiz et al., 2004; Granados et al., 2016). Experimental works took place in multispan greenhouses showed maximum differences of air temperature in a horizontal plane, at 1.75 m height from the ground, between 2 °C and 6 °C depending on the ventilation conditions and other factors (López et al., 2012a, 2012b; López et al., 2013). Molina-Aiz et al. (2004) studied the vertical profile of air velocity and air temperature in an Almería-type greenhouse, where a maximum temperature difference of 14.5 °C was measured when low wind speed. Granados et al. (2016) measured the soil and air temperature profiles for different solarisation strategies, with a maximum difference of 9.1 °C, between 0.2 m and 2.0 m height, of the mean air temperature at 2p.m. during January to March. In view of these results, it seems logical to think that a typical greenhouse could presents conditions of heterogeneity according to ISO 7726 (1998). Since previous works focus on the climatic conditions involved in crop growth, further specific studies are needed to evaluate the spatial variation of the climatic parameters concerning the assessment of the heat stress.

To meet this need, the implementation of a multi-point measurement system inside a greenhouse would provide relevant information on the temporal and spatial variation of the climatic parameters related